Swimming Fastest

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This book is dedicated to my wife, Cheryl.
She was the love of my life,
and was taken too soon.
Cheryl provided the love and support
that inspired the writing of this book
and all other achievements in my life.

Contents

Preface

When the first edition of this book, *Swimming Faster,* was published in 1982, I was both overjoyed and humbled by its acceptance in the swimming community. I experienced the same emotions when the second edition, *Swimming Even Faster,* came out in 1993 and was selected as the best competitive-swimming manual by members of U.S. Swimming (now known as USA Swimming). Today, research continues at a fast and furious pace, and there is enough new information to warrant another edition.

Although the information has been revised and updated, the goal has remained the same: to apply scientific information to the training process so that coaches can train swimmers more effectively and serious swimmers can improve their performances. I have strived to convey not only the *how* but also the *why* of training. My hope is that coaches and athletes will use *Swimming Fastest* to educate themselves in the areas of hydrodynamics and exercise physiology so that they can evaluate present and future concepts of training and stroke mechanics. My goal is to provide a reference for all elements of competitive swimming. This book is not meant to be read from cover to cover. Instead, it is to serve as a source that coaches and athletes can pull from the shelves to research a topic that concerns them at the moment.

Swimming Fastest, like the previous editions, is divided into three parts. Part I deals with the techniques of competitive swimming and part II deals with training. Part III is concerned with topics that pertain specifically to competition and racing.

I consider part I the most important segment of this new edition because it contains a great deal of new information. There have been a number of advances since the previous edition was published in 1993. The most important of these is the reexamination of the role of lift forces in swimming propulsion. Recent research suggests that swimmers are not using the limbs as airfoils or propeller blades to apply propulsive force but instead may be using them like paddles to push water backward in a diagonal path. These research results caused me to reevaluate my own beliefs on both the physical basis of swimming propulsion and the techniques swimmers use to apply propulsive force. I now believe that some of the information I presented on stroke mechanics in previous editions was incorrect. My primary purpose with this edition is to correct that information.

To help illustrate proper technique, part I includes a large number of sequential photos of the competitive strokes, starts, and turns. In most cases, the photos are new to this edition and feature world-class swimmers. New drawings have also been included in this edition to illustrate important components of these skills. As in previous editions, however, each competitive stroke chapter, as well as the chapter on starts and turns, contains sections on common stroke faults and drills for correcting them.

Part II covers the training process in detail. Unlike stroke mechanics, theories on training have not changed much since the previous edition of this book. The anaerobic threshold remains the pivotal concept around which training is planned. Some aspects of that concept need to be revised, however. For example, the anaerobic threshold does not represent the most effective training speed for improving aerobic endurance. It is only one of many different speeds that must be used. There are compelling reasons that swimmers must train frequently at speeds both slower and faster than anaerobic threshold speeds. New to this edition is an explanation of the effects that various training speeds have on fast-twitch and slow-twitch muscle fibers.

Another aspect that requires further elaboration is the relationship between endurance and sprint training. These two types of training produce antagonistic effects, in that endurance training tends to reduce speed and sprint training tends to reduce endurance. The effects must be balanced carefully so that swimmers use the optimal combination of both to achieve the best possible race performance. The possibility of an antagonistic relationship between endurance and sprint training was discussed in the previous edition of this book, but research about this issue was scarce at that time. Important new studies now define this relationship more precisely. An important feature of this edition will be to present these studies and suggest their implications for training. Part II also contains many new graphics and figures that illustrate and summarize the most important information.

As with previous editions, I have studiously avoided presenting training information in a "cookbook" format. There are still too many areas where questions, rather than answers, prevail. Instead, I have tried to indicate the questions and present both sides of the issue so that readers can draw their own conclusions and develop their own innovative programs.

The topics presented in part III concern competition and racing. Information on pacing, strategy, stroke rates, and warm-up have not changed, but they have been updated from the previous edition.

I hope this book will be received as well as previous editions have been. I also hope that the information presented will help swimmers continue to improve far into the future.

part I

Technique

Competitive swimming is a unique sport. Athletes compete while suspended in a fluid medium and they must propel their bodies by pushing against liquid rather than solid substances. This creates two major disadvantages compared to land sports. The first is that water offers less resistance to swimmers' propulsive efforts than, for example, the ground that runners push against. Another is that water, because of its greater density, offers considerably more resistance to the forward progress of swimmers than air offers to the progress of land athletes. For these and other reasons, the usual applications of the laws of motion do not always apply to swimming in the same way they apply to land sports. This has made it difficult to identify the physical laws swimmers must apply to propel their bodies through the water more efficiently.

As a result, several different theories of swimming propulsion have been put forth. An examination of these theories is the topic of chapter 1. Although our understanding of swimming propulsion is far from complete, I believe that the information presented in chapter 1 of this edition brings us closer than ever to understanding the mechanisms of human swimming propulsion while, at the same time, correcting some of my earlier interpretations of those mechanisms.

Chapter 2 is devoted to water resistance and its negative effect on forward motion. The types of water resistance swimmers must deal with are described in this chapter along with techniques they can use to reduce them.

In chapter 3, I have tried to apply information from the previous two chapters to describe stroke techniques common to all of the competitive styles. The information presented in the first two chapters has been used to develop guidelines for efficient stroking in all swimming styles.

Techniques of competitive swimming strokes are described in the next four chapters. The front crawl, commonly referred to as the *freestyle*, is the topic of chapter 4, followed by a description of the butterfly in chapter 5, the back crawl in chapter 6, and the breaststroke in chapter 7. Starts, turns, and finishes are described in chapter 8, the final chapter of part I.

Much of the research reviewed in chapters 1, 2, and 3 involves the concept of relative motion. An explanation of that concept may make it easier to understand the implications of that research.

Relative Motion

It is difficult to measure the forces swimmers exert against water when they move through it. Therefore, much of the research that bears on human swimming propulsion has been conducted by suspending plaster models of swimmers' hands and arms in wind tunnels and water channels. The models are held in place while air or water is pushed past using some motorized device. There are several reasons why this method is valid:

Air and water are both classified as fluids. Consequently, the physical laws that apply to one also apply to the other, even though water is considerably more dense than air. In addition, because the difference in speed between the objects and the water is the same whether the objects are moving through the fluid or the fluid is moving past the objects, the forces exerted by moving fluids on stationary objects will be the same as the forces that objects moving at the same speed would exert against stationary fluids. Thus, they are relative to one another.

Scientists have made many important breakthroughs by studying scale models of objects in wind tunnels or water channels. In fact, this was the method the Wright brothers used to study the potential of wing shapes for flight.

Stroke and Velocity Patterns

I will be using a multitude of graphics to illustrate various aspects of swimming propulsion. The two that I use most frequently are stroke patterns and body velocity patterns.

Stroke patterns have traditionally been constructed by plotting the movement of the middle fingers during underwater stroking motions. These patterns can be shown from two points of view. The first is relative to a fixed point in the swimming pool. This method depicts the actual directions and relative distances the hands move as they perform the stroke. The illustration in figure I.1 shows the side and front views of the front crawl stroke patterns.

The directions are complex, three-dimensional circular patterns. Unfortunately, these patterns can only be illustrated in two dimensions on the printed page. Therefore, a stroke pattern must be shown from at least two different views so that all three directional components can be viewed. In figure I.1, for example, the vertical (upward/downward) and horizontal (forward/backward) components of motion can be discerned from the side view stroke pattern, while the lateral (inward/outward) component can be discerned from the front view pattern. You need only put these two views together in your mind to visualize the actual three-dimensional nature of hand movements during the various phases of the underwater stroke.

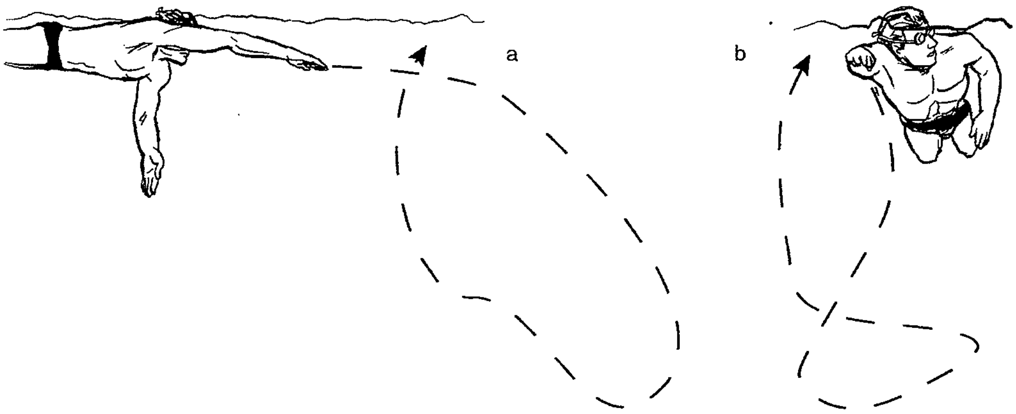


Figure I.1 *(a)* Side and *(b)* front view stroke patterns for the front crawl stroke drawn relative to a fixed point in the pool.

The second method of depicting stroke patterns is according to the movements of the hand and arm in relation to the body. Illustrations of this type depict the movements of the arms as though they were moving past a stationary body. In reality, of course, the body is also moving forward, past the hand, when the hand and arm are moving diagonally backward past the body. The value of depicting a stroke pattern relative to the body lies in its use as a teaching aid. The best way for swimmers to learn the correct hand and arm movements is by moving them from point to point relative to the body during the various phases of each underwater stroke (i.e., bring the hand in under the chest, push it out and up to the thigh, etc.).

The forward velocity patterns shown in the following chapters depict the changing forward velocity of swimmers' centers of mass during one complete stroke cycle. Graphs of this type illustrate the propulsive nature of each phase of the cycle, specifically, whether swimmers are accelerating or decelerating and by how much. This graphic is one-dimensional, in that it portrays only forward velocity. The body will also be moving up and down and from side to side during each stroke cycle, but these velocities are not displayed. An example of hand and body velocity graphs for swimmers of the front crawl stroke is shown in figure I.2.

Also included with the velocity graphs are hand velocity patterns, which are graphed according to the velocity of the middle finger during the underwater stroke. The graphs illustrate the changes in hand speed and their relationship to forward velocity during the underwater stroke. Unlike body velocity patterns, hand velocity patterns are three-dimensional in nature. They do not portray speed in any particular direction, i.e., forward or backward. Instead, these velocities are the algebraic summation of hand movements, in all directions, during a particular phase of the stroke. For example, hand velocity value during the latter phase of the insweep is a combination of hand speeds in inward, upward, and backward directions.

I hope this information will make the contents of the chapters in part I more meaningful. With that, I want to move on to chapter 1 and discuss the various theories of swimming propulsion.

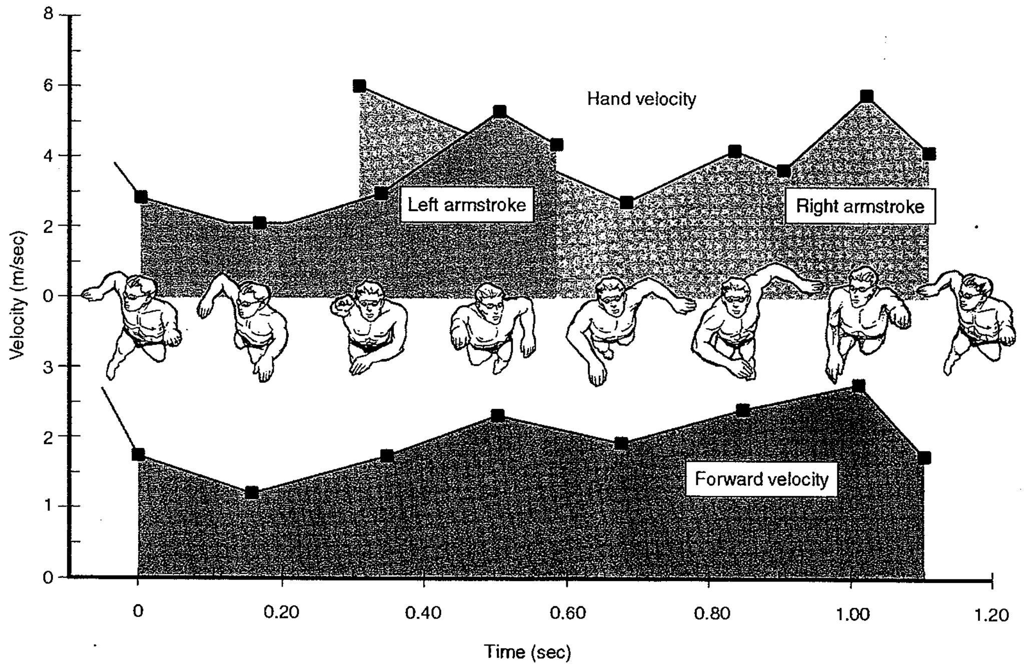
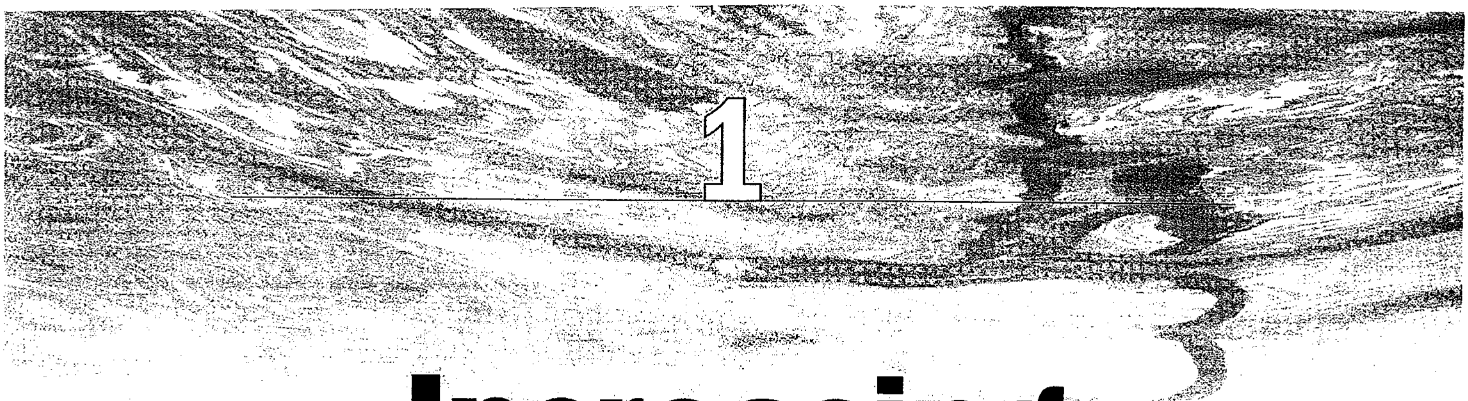


Figure I.2 Hand and body velocity patterns for the front crawl stroke.



1

Increasing Propulsion

New in this edition:

- A reevaluation of the principles of human swimming propulsion
- Increased emphasis concerning the propulsive role of the arm
- Answers to common questions about propulsion theory

When the first edition of this book, *Swimming Faster,* was published in the early 1980s, I believed that the Bernoulli effect, which I will explain later, produced the lift forces primarily responsible for swimming propulsion. In that edition, I suggested mechanics for the four competitive strokes that involved three-dimensional sculling movements in which swimmers used the limbs like hydrofoils to maximize the production of those lift forces.

I was still of the opinion that lift forces were an important propulsive mechanism when the second edition of this book, *Swimming Even Faster,* was published in the early 1990s. By that time, however, I had come to doubt that the Bernoulli effect was responsible for those lift forces. I suggested instead that Newton's third law of motion, the action-reaction principle, was the principal physical law responsible for swimming propulsion. I had come to believe, unequivocally, that swimmers had to push water backward in order to move forward. Nevertheless, I continued to believe that swimmers were sculling the limbs through the water like hydrofoils to propel the body forward. The difference was that I believed those sculling motions were displacing water backward rather than utilizing the Bernoulli mechanism to create lift forces.

Today I am more convinced than ever that Newton's third law of motion is the principal propulsive mechanism in human swimming propulsion. I no longer believe that swimmers scull the limbs through the water like hydrofoils to produce that propulsion, however. Now I believe that they use the limbs as paddles to push large amounts of water backward for short distances. I still believe that swimming propulsion is produced by a combination of lift and drag forces, but I am now suggesting that swimmers produce those forces by using the limbs like paddles instead of hydrofoils.

Understanding Lift and Drag

Although the terms *lift* and *drag* are common to swimmers, their full implications may not be understood by some readers. Therefore, I want to define them before moving on.

Drag

Drag is the term used to identify the resistance of water to swimmers' movements through it. Water has density because it is composed of billions of hydrogen and oxygen molecules. Therefore, like air, it is classified as a semisolid. Water, however, because it is 1,000 times denser than air, supplies considerably more resistance to swimmers' movements through it. That resistance is caused by a difference in pressure between the water in front of and behind swimmers. Objects tend to be pushed from areas of high pressure toward areas of low pressure. Consequently, if the pressure of the water in front of swimmers is greater than the pressure behind, their forward speed will be slowed unless they can overcome the added pressure by stroking with greater force. The reduction in speed will be in direct proportion to the magnitude of the difference in water pressure in front of and behind the body.

Drag force is always exerted in a direction opposite the direction of movement. In other words, it is a force that opposes the movement of an object. We usually think of drag as negative, a force that impedes forward progress. It is certainly true that drag forces can reduce swimming speed when the resistance of the water impedes swimmers' forward progress through it. Drag can also be propulsive, however. Swimmers can accelerate the body forward by pushing the limbs backward against the resistance of the water, just as runners propel their bodies forward by pushing backward against the ground. The major difference, of course, is that water, being a fluid, gives way when limbs push against it while ground does not. Consequently, swimming propulsion is not nearly so efficient as land propulsion. The body will not accelerate forward as fast or as far when swimmers push back against the water as will the body of a runner.

For ease of communication, I will separate the single concept of drag force into two types. Drag forces that hold swimmers back will be referred to as *resistive drag* and drag forces that accelerate swimmers forward will be termed *propulsive drag*.

Lift

Lift force is exerted perpendicular to the direction of drag force. Drag force must be present before a lift force can be produced. Lift, like drag, is caused by differences in the pressure on two sides of an object. Rather than resist the motion of an object, however, lift force pushes objects in the direction it is being exerted. Figure 1.1a illustrates one way that an increase in pressure below a foil can produce lift. In this illustration, a foil-shaped object is moving through the water from right to left in the direction of the arrow enclosed by the foil. The difference in pressure between the front of the foil, where the pressure is greater, and behind the foil, where the pressure is lower, creates a drag force opposite the direction the foil is moving. The direction of the drag force is indicated by the drag vectors.

The foil splits the stream of water molecules as it moves into them. Some molecules are pushed down underneath the foil and others are pushed up over the top of the foil. (Streams of water molecules are also displaced to either side of the foil, although that is not evident in this two-dimensional illustration.) Because the rate of the fluid flowing under the foil is slowed somewhat, the water molecules become tightly packed and the pressure underneath the foil increases. At the same time, the rate of flow is increased over the foil. The water molecules become less tightly packed, causing a reduction in pressure above the top of the foil. As a result of this pressure differential, the foil is pushed up from underneath where the pressure is greater (+) to above where the pressure is lower (–). *Lift* is the term used to designate that pushing force.

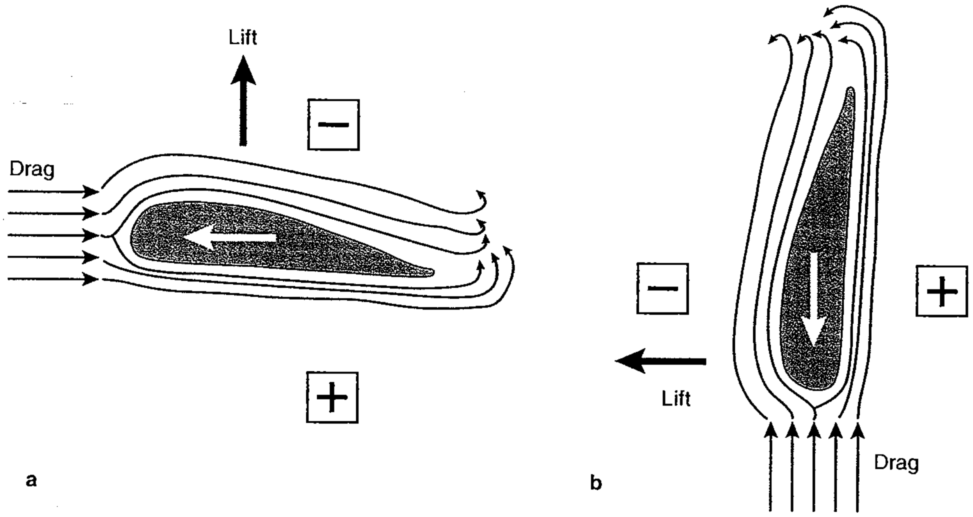


Figure 1.1 Lift force: *(a)* in an upward direction and *(b)* in a forward direction.

It is unfortunate that the term *lift* has been used to identify this pushing force because lift forces do not, in all cases, act in an upward direction. *Lift forces can act in any direction that is perpendicular to drag forces.* The illustration in figure 1.1b shows how forward lift could be produced if the same foil were traveling down instead of forward. I will have more to say about this topic later in this chapter.

Theories of Swimming Propulsion

No one has yet identified with certainty the way swimmers propel the body through the water. All we have are theories, and they have varied considerably through the years. I will provide a brief review of the various theories of swimming propulsion that have been proposed over the years before describing the theory I have adopted.

In the early 1900s, attempts to describe human swimming propulsion compared the movements of swimmers' arms to those of oars and paddle wheels. It was thought that the arms, held in a completely extended position, moved in a semicircular pattern that resembled the sweep of an oar or a paddle wheel, a form of paddle-wheel propulsion illustrated in figure 1.2. This description was based on neither the application of any physical laws nor underwater observations of swimmers' actual stroking movements;

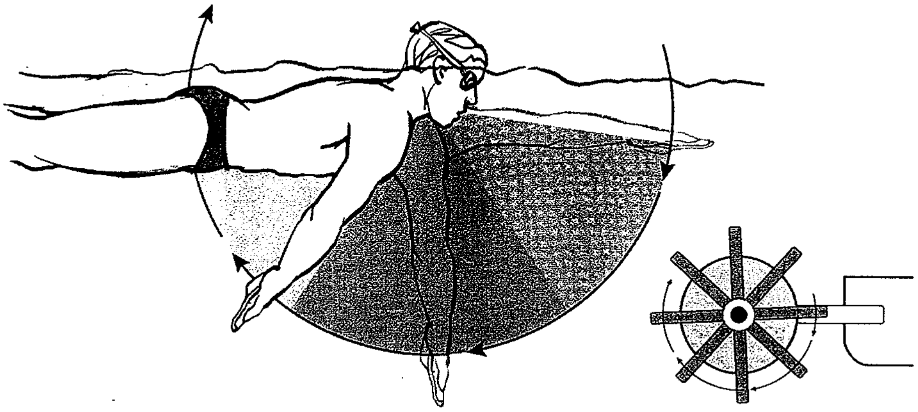


Figure 1.2 The paddle-wheel theory of propulsion.

it was simply based on the forms of aquatic propulsion that were evident at the time. This theory survived for several decades without any serious examination.

Propulsive Drag Theories

Some scientists and swimming coaches began attempting to define the physical laws governing human swimming propulsion by the late 1960s. Of the swimming coaches, the most notable were Dr. James E. Counsilman of Indiana University and Charles Silvia of Springfield College. As a result of underwater observations, both men reported that swimmers were not stroking in a paddle-wheel fashion with straight arms but were instead alternately bending and extending their arms during the underwater phases of the various competitive strokes. In separate publications, both men suggested that swimmers were stroking in this way to utilize Newton's third law of motion as a propulsive mechanism (Counsilman 1968; Silvia 1970).

Newton's third law of motion states that every action (*force*) of an object will produce a reaction (*counterforce*) of equal magnitude in the opposite direction. When applied to swimming propulsion, this law means that when swimmers use muscular force to push water back, that action creates a counterforce of equal magnitude that propels them forward. Thus, they believed that swimmers accelerated the body forward by pushing water backward. Further, they believed that the resulting amount of forward propulsion was directly related to both the amount of water they pushed backward and the distance it was pushed backward.

The Horizontal Backward Push

As a result of this reasoning, swimmers of the day were advised to use the hands and arms like paddles to pull, then push, the water horizontally backward over the longest possible distance. They were also advised, where possible, to keep the hands directly under the midline of the body as long as possible. They were taught to do this by flexing the arms at the elbows in the first half of the underwater stroke and then extending the arms in the second half. An example of how the horizontal backward push was utilized in the front crawl stroke is illustrated in figure 1.3.

The S Pattern

During the early days of paddle propulsion theory, experts advised that pushing water in any direction but backward would cause the body to veer away from its forward path, which would increase the resistance it encountered and reduce forward speed. Many experts, including Counsilman and Silvia, revised this opinion when underwater movies of world-class competitive swimmers revealed that their hands did not travel

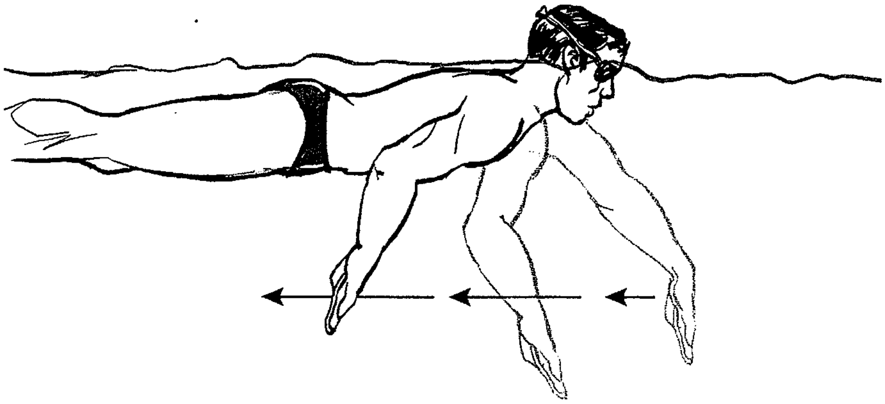


Figure 1.3 An example of the propulsive drag theory: using a horizontal backward push to create forward propulsion.

straight backward under the midlines of their bodies during the propulsive phases of their underwater strokes. Instead, in the front crawl and butterfly strokes, their hands moved in three-dimensional S-shaped paths, coming down and in under their bodies during the first half of their underwater strokes and then traveling out and up beside their bodies during the second half. Figure 1.4 shows an underneath view of this S-shaped path for the front crawl stroke. Their hands also traced an S pattern during the backstroke, but in this case moved down, up, and back to their sides. During the breaststroke, their hands traced the first half of the S pattern but then recovered forward before completing the remainder of the S-shaped movement Their hands moved in a double S pattern during the butterfly.

Figure 1.4 A freestyle swimmer shown from an underneath view moving her hand in an S-like propulsive pattern during the propulsive phase of her underwater armstroke.

Counsilman reasoned that swimmers moved the hands in S-shaped patterns because pushing several handfuls of water in directions that were mostly backward for short distances would produce more propulsion than pushing one handful of water directly backward for a long distance. This was because water gains momentum once it is moving. Therefore, the only way swimmers could continue to accelerate water backward, and accelerate the body forward, would be to increase the backward speed of the limbs beyond that of the backward-moving water. They would have to push the arms backward at increasingly faster rates from the beginning to the end of an underwater stroke if they wanted to continue accelerating the body forward. Obviously, this would require considerable effort and predispose swimmers to early fatigue.

On the other hand, those large increases of limb velocity would not be required in order to accelerate the body forward if swimmers changed the direction of the hands periodically during their underwater strokes. Changing hand direction would allow them to get the hands out of water that was previously accelerated backward and into quiet or slowly moving water that they could accelerate in a mostly backward direction with less muscular effort. Thus, they could gain more propulsion with less muscular force by using an S-shaped underwater stroke.

Critics of this theory argued that the sideward, downward, and upward components of these S patterns would increase drag and, therefore, reduce propulsion. Proponents of the theory countered by stating that the net propulsive force would be greater during each stroke despite the lateral and vertical arm motions. This notion that more propulsive force can be produced by movements that contain some lateral and vertical components than by movements that are made directly backward is an important one. You will learn later that swimmers cannot and should not stroke directly backward even when applying Newton's action-reaction law to propel the body forward.

Lift Theories of Propulsion

The stroke patterns depicted in figures 1.2, 1.3, and 1.4 are hypothetical plots of swimmers' underwater hand motions and, as such, are flawed because they show the hands moving back relative to the body. As mentioned in the introduction to part I of this book, the fallacy in presenting stroke patterns this way is that swimmers appear to stay in one place while the arms move back past the body. In reality, of course, the body is always moving forward when they swim, so the arms are traveling back considerably less than is indicated by these figures.

Brown and Counsilman (1971) were the first to show the actual directions of swimmers' hands during underwater armstrokes. In their landmark study, they filmed swimmers in a darkened pool with a light attached to their fingertips. When the film was exposed, the stroke patterns revealed by these motion pictures were quite different from any seen before. They showed swimmers making diagonal stroking motions with their hands moving more in lateral and vertical directions than in a backward direction. Their results were later verified by several studies that showed swimmers using circular stroke patterns with vertical and lateral components of motion that exceeded the backward movements of their hands (Plagenhoff 1971; Barthels and Adrian 1974; Belokovsky and Ivanchenko 1975; Schleihauf 1978; Czabanski and Koszyczyc 1979; Reischle 1979; Schleihauf, et al. 1984; Hinrichs 1986; Luedtke 1986; Maglischo, et al. 1986). Unlike stroke patterns drawn relative to stationary bodies, the patterns caught on film by Brown and Counsilman showed swimmers' actual hand movements during their underwater strokes. Typical stroke patterns for the four competitive strokes, drawn relative to a fixed point in the pool, are illustrated in figure 1.5.

Brown and Counsilman believed that the lateral and vertical components of swimmers' hand motions, given their magnitude, had to be propulsive and thus doubted that Newton's action-reaction principle could be the primary mechanism for human swimming propulsion. In their search for another physical law that could explain how lateral and vertical movements of the limbs could generate propulsion, they settled on Bernoulli's theorem, which I will describe next.

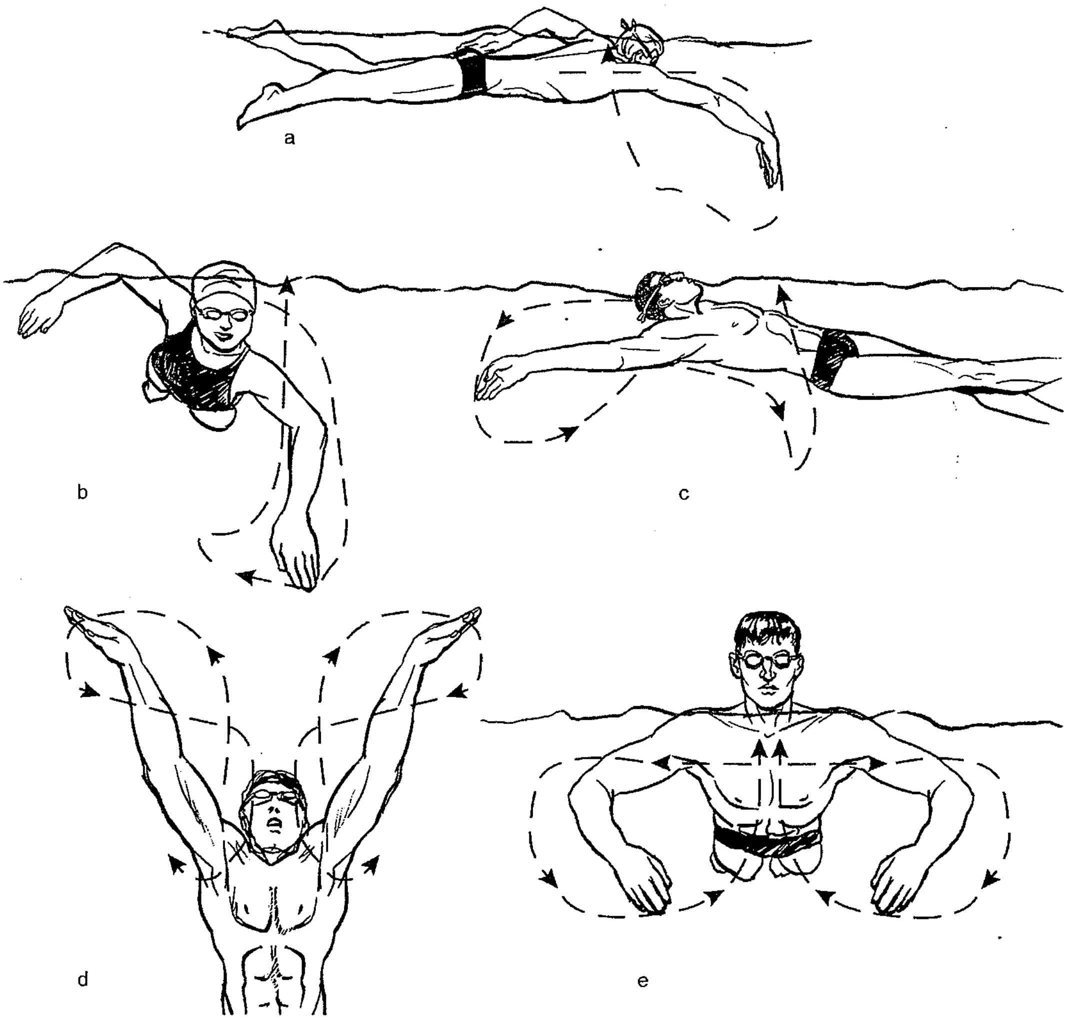


Figure 1.5 Patterns for the four competitive strokes drawn relative to a fixed point: *(a)* side and *(b)* front views of the front crawl, *(c)* side view of the back crawl, *(d)* underneath view of the butterfly, and *(e)* front view of the breaststroke.

Bernoulli's Theorem

Daniel Bernoulli was a Swiss scientist who first identified the inverse relationship between the velocity of fluid flow and pressure. He found that, for an ideal fluid, pressure was lower when a fluid was flowing rapidly, and it was higher when the fluid velocity was flowing at a slower rate of speed. Bernoulli's theorem provides an explanation for the way lift forces are produced when foil-shaped objects move through fluids, or when fluids flow over those objects. Bernoulli's theorem can best be explained with regard to aerodynamics. The example can also be applied to hydrodynamics, however, because air and water are both fluids.

When an airplane travels forward, the relative motion of the air streams immediately in front of the wing will be backward, exerting a drag force that acts in the opposite direction the airplane is moving. The wing must split the streams of air in order to pass through them. Consequently, some of the streams pass over the wing while others pass underneath. In figure 1.6, this air stream motion is shown by the small arrows representing the relative flow of air.

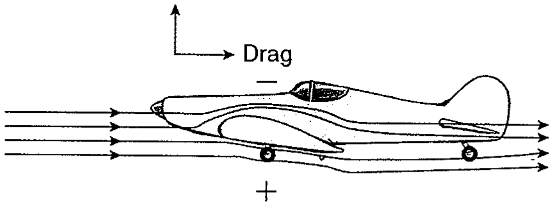


Figure 1.6 An example of the role played by Bernoulli's theorem in airplane flight.

Wings are shaped so that the speed of the air traveling over the top is faster than the air flowing underneath. Because the upper surface of the wing is rounded, and thus longer than the underside, the velocity of the air flowing over the top must accelerate to reach the back side of the wing at the same time as the air flowing underneath. In accordance with Bernoulli's theorem, this increase in velocity causes the air molecules that pass over the top of the wing to spread further apart, thus reducing the pressure relative to the pressure of the air passing underneath the wing. Objects tend to move from areas of high pressure to low pressure, so once the pressure differential between the underside and upper side of the wing is great enough, it will push the airplane upward and keep it aloft. As indicated earlier, the upward force exerted by that pressure differential is termed *lift*, and as illustrated in figure 1.6, it is being exerted perpendicular to the direction of the drag force.

Counsilman and Brown suggested that, because the human hand was shaped like a wing, it could be used to produce lift in a manner similar to the way it was produced on airfoils. An example of the way that swimming propulsion might result from the application of Bernoulli's theorem is shown in figure 1.7.

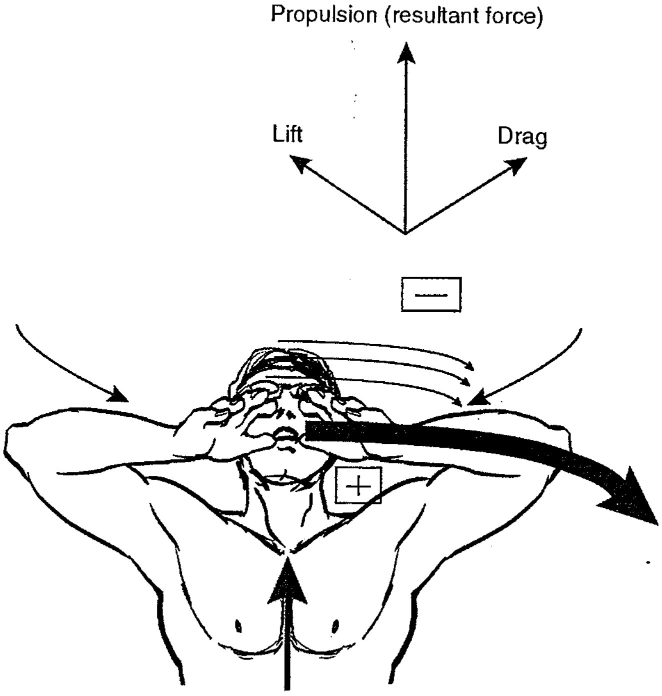


Figure 1.7 The application of Bernoulli's theorem to swimming propulsion.

The illustration in figure 1.7 shows an underneath view of a butterfly swimmer sweeping his hands back and in under his body. In doing so, drag forces, indicated by the drag vector above the swimmer's left hand, will be exerted in the opposite direction from which his hands are moving. That is, the drag forces will be exerted outward and forward. According to Bernoulli's theorem, the water flowing over the longer upper surfaces of the swimmer's hands (illustrated by the small arrows above the swimmer's left hand) will be accelerated so that it reaches the little finger side of the hand at the same time as the water flowing underneath his hand (illustrated by the large arrow underneath the swimmer's left hand). Consequently, the water pressure will be lower above the swimmer's hands, where the water is traveling more quickly, than underneath his hands, where the water is flowing more slowly. This difference in pressure is indicated by the + and – signs below and above the swimmer's left hand. These pressure differentials produce lift forces, which as we know act perpendicular to the direction of drag forces. The direction of the lift force is indicated by the lift vector above the swimmer's left hand.

The situation with human swimming propulsion is somewhat more complex than was indicated by the simplified example with the airplane in figure 1.6 (see page 11). A swimmer's forward motion, labeled *propulsion* or *resultant force* in figure 1.7 (page 11), is actually caused by a combination of the lift and drag forces produced by the swimmer's body. His hands move diagonally backward, causing the drag and lift forces to be exerted forward diagonally rather than directly. The combination of portions of these two forces produces a component of force that is aimed directly forward. This is the force that accelerates the swimmer forward. (Remember, because this illustration is an underneath view, the vector that is pointing up actually represents force in a forward direction.) To be perfectly accurate, the propulsive force is actually exerted against the swimmer's hand and arm. However, when the swimmer resists that force by continuing to press his hands in and back, the propulsive force is transferred to his suspended body, which accelerates forward past his arms.

The Bernoulli theorem has gained wide acceptance during the past two decades because it provided a scientific rationale for the diagonal stroking motions swimmers were using. Recently, however, a number of experts have come to doubt its application to human swimming propulsion. Some research in recent years suggests that Bernoulli's theorem is not involved in swimming propulsion at all.

Criticisms of Bernoulli's Theorem

The primary criticism concerning Bernoulli's theorem is that it may not apply to human swimming propulsion. Bernoulli's theorem only applies when the flow of water over the upper side of a foil remains attached to that foil, that is, if the water was able to pass over the foil with no separation of the boundary layer. The boundary layer consists of water molecules that remain in contact with an object as it moves through them. An intact boundary layer indicates low turbulence and low pressure, which result in a greater pressure differential between the underside of the foil where the pressure is higher and the upper side of the foil where the pressure is lower. When turbulence increases, water molecules pull away from the upper side of a foil and the boundary layer is said to have separated. Thus, a separated boundary layer indicates turbulence and an increase in pressure above the foil. This, in turn, reduces the pressure differential between the underside and upper side of the foil and reduces the lift force. *Consequently, an intact, or attached, boundary layer is essential for lift forces to be produced by the Bernoulli mechanism.* When the boundary layer separates, those conditions necessary for the Bernoulli mechanism to produce lift are no longer present.

There is good evidence now that the limbs of humans are not and never have been sufficiently smooth and foil-like to enable the flow of water to remain attached to the upper side of swimmers' hands as it flows around them. Therefore, it is doubtful that the Bernoulli mechanism is responsible for swimming propulsion. For now, I will describe the results of some research that tends to discredit Bernoulli's theorem as a propulsive mechanism. Before doing so, however, I would like to describe how hand *angles of attack* are measured because I will be referring to them regularly throughout this and other chapters.

Angles of Attack. A great deal of attention has been focused on hand angles of attack in connection with Bernoulli's theorem. This is because the angle of attack was believed to play an important role in creating the pressure differential between the undersides and upper sides of the hand that resulted in the production of lift force. The angle of attack is the angle formed by the inclination of the palm of the hand to the direction it is moving through the water. For example, at 90°, the palm of the hand would be facing squarely in the direction the hand is moving. At 0°, the edge of the hand, either the thumb edge or the little finger edge, would be facing in the direction the hand is moving.

The illustrations in figure 1.8 provide an example of how an angle of attack is measured. It is important to know how the hand is moving through the water in order to understand this measurement. Knowing which part of the hand is leading and passes through a section of water first, and thus which side is trailing so that it passes through that section of water last, determines the direction of the drag force and therefore the direction of the lift force. As mentioned earlier, drag force will be exerted in a direction opposite the direction the hand is moving through the water. For inward movements, the thumb edge of the hand would be leading. That is, the thumb would pass through a section of water first and the little finger would pass through that same section of water last. The direction of drag force, then, would be exerted across the hand from the thumb to the little finger side of the hand. Conversely, during outward movements, the little finger would be leading and the drag force would be exerted from the little finger toward the thumb. Likewise, the fingertips would be the leading edge of the hand during the first downward motion of the arm at the beginning of an underwater stroke during the front crawl and backstroke. In other words, the fingertips would pass through a section of water first and the heel of the hand would pass through that section last, so the drag force would be directed from the fingertips past the wrists. During upward movements of the arm, the heel of the hand would pass through the water first, with the hand and fingers following, and the drag force would act in a direction from the wrists past the fingertips.

Water does not always flow directly under the middle of the palm from the leading to the trailing edge. Instead, it usually flows at an angle. The direction of this water

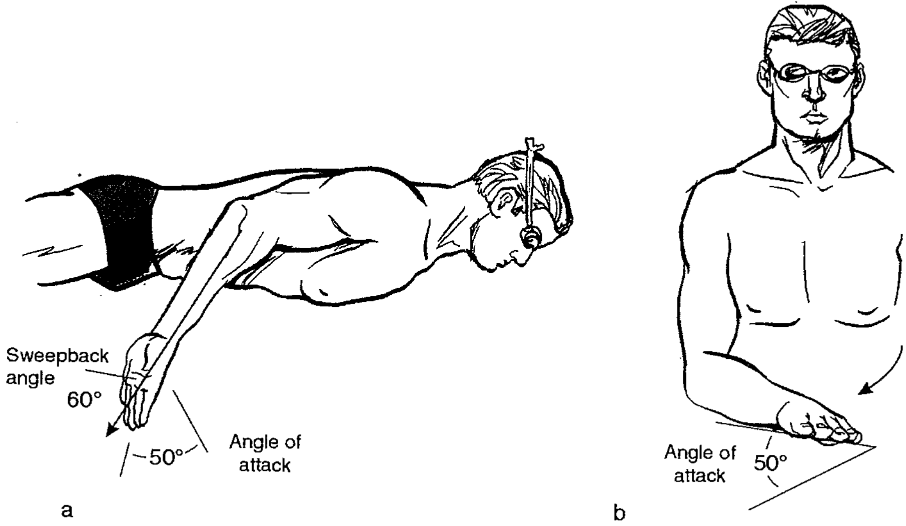


Figure 1.8 Side and underneath views of a front crawl swimmer finishing the propulsive phase of his underwater armstroke. A sweepback angle is illustrated by the swimmer in *(a)*, and an angle of attack is illustrated by the swimmer in *(b)*.

flow is called the *sweepback angle.* The line down the back of the swimmer's forearm and across his palm in figure 1.8a shows the sweepback angle. This swimmer's hand is moving out, up, and back, and his hand is angled out and up. Thus the relative flow of water is down past the swimmer's palm, from the wrist edge on the little finger side of his hand toward his fingertips on the thumb side of his hand.

The angle of attack of the hand indicates its inclination in the direction of the relative flow of water past the swimmer's palm. The drawings in figure 1.8a and b indicate that this swimmer is using an angle of attack of 50°. The angle of attack is a three-dimensional measurement and therefore cannot be represented accurately in two dimensions. For this reason, the hand position is shown from both side and underneath views.

With that explanation, then, I will return to a description of some studies that dispute Bernoulli's principle as a propulsive mechanism. There are four studies I would like to describe. The first was a master's thesis conducted by Ferrell at Cortland State University. The second is by a rocket scientist and swimming parent named Bixler. The third study was conducted by Holt and Holt at Dalhousie University, and the fourth and most recent study was conducted by Toussaint and colleagues from the Institute for Fundamental and Clinical Human Movement Science in Amsterdam.

Ferrell's Research. Ferrell (1991) used three fiberglass resin models of swimmers' hands to study their potential for producing lift by means of Bernoulli's principle. He placed *tufts* (small latex strips in lengths of approximately 1 in) on the hand models and then moved them through the water at various angles of attack. The drawings in figure 1.9 illustrate Ferrell's fiberglass hand with tufts attached. The tufts were affixed to the back of the hand, each tuft attached at only one end so that the other end would wave freely in the water. Using a gravity-driven device, the hand was moved through the water at speeds of 0.30 to 3 m/sec and at angles of attack ranging from 0° to 40° from two different orientations. All trials simulated an insweep with the thumb side of the hand sweeping across the water first. Forty-five different trials were conducted in all, and each trial was videotaped to observe how the hand's movement affected the tufts attached to it.

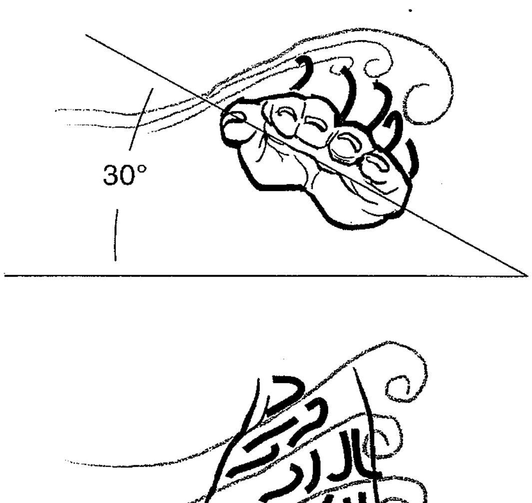


Figure 1.9 Video image reproduction of Ferrell's fiberglass hand model with tufts attached.

Adapted from Ferrell 1991.

The idea behind this procedure was to use the tufts as a vehicle for visualizing the pattern of water flow around the hand. If the boundary layer was attached, the tufts would all be pushed back against the upper surface of the hand toward the little finger side. That is, opposite the direction the hand was moving through the water. Conversely, if the boundary layer had separated as the water passed over the top of the hand, the tufts would be waving about in random directions.

Ferrell found no incidence of the boundary layer remaining attached. The wildly random movements of the tufts indicated that the water was so turbulent that the boundary layer could not remain intact, even when the hand was moving slowly and at acute angles of attack. Figure 1.9 illustrates the movement of the tufts when the fiberglass hand was moving through the water in an insweep motion, at a high speed, and at an angle of attack of 30°. You can see that the tufts are waving about in a random fashion.

Ferrell concluded that the turbulence exhibited by the tufts indicated a separation of the boundary layer over the top of the hand, which in turn negated any possibility that lift forces of Bernoullian origin could be produced at the angles of attack and hand velocities used by competitive swimmers.

Bixler's Research. Bixler (1999) used a novel approach to study the flow of water around swimmers' hands. An engineer by profession, he modeled the surface of a swimmer's hand and arm on a computer, and then used an analysis program to calculate, among other factors, the direction and velocity of fluid flow, pressure changes within the fluids, and their resulting effect on the lift and drag forces. This procedure, known as *computational fluid dynamics*, is a well-established methodology in the engineering community for solving complex flow problems with a computer. According to Bixler, you can think of the method as similar to a wind tunnel in a computer.

Using the computer to simulate water flow around his model, Bixler demonstrated that the water pulled away before it could pass around the model. This led him to conclude, "The fact that the boundary layer separates is important because it shows that Bernoulli's equation should not be used to explain the lift that swimmers generate with their hands." He stated further, "One of the assumptions made by Bernoulli in deriving his equation was that the flow of a fluid was frictionless, which means that the boundary layer remained attached."

I want to make it clear that the results of Ferrell and Bixler do not mean that lift forces are not produced by swimmers. Rather, they indicate that the Bernoulli effect could not be responsible for those lift forces.

Bixler also compared his hand model to a combined hand/arm model for ability to produce lift at various angles of attack and orientations to the water. The combined hand/arm model was even less foil-like. The simulated hand/arm model produced large drag and minimal lift coefficients at all angles of attack. In fact, when coefficients for the combined hand/arm model were calculated, the drag coefficients it produced exceeded the lift coefficients by a considerable margin at all angles of attack. It is doubtful, therefore, that the hands and arms of swimmers could produce lift through the mechanism of Bernoulli's principle when they lack so many of the characteristics of an airfoil.

The Research of Holt and Holt. Studies using water channels and plaster models of human limbs have certainly added to our knowledge of swimming propulsion. If you are like me, however, you like to see results generated by human subjects. In this respect, the results of two other studies also cast doubt on the application of Bernoulli's principle to human swimming propulsion. The first of these was conducted by Holt and Holt (1989).

These researchers had a group of swimmers complete identical distance time trials of 100 yd with and without fin-like baffles attached across the backs of their hands. The purpose of the baffles was to disrupt the flow of water so that the boundary layer would separate and lift could not be produced by the Bernoulli effect. The swimmers' times were, on average, only 2% slower when they used the baffles. This caused the authors to conclude that, at best, Bernoulli's principle played only a minor role in swimming propulsion.

The Research of Toussaint, van den Berg, and Beek. Toussaint, van den Berg, and Beek (2000) employed the tufts technique to examine the direction of water flow around the arms of athletes during actual swimming. They attached tufts to the fronts of swimmers' hands and forearms and then filmed them as they swam down the pool at slow, moderate, and fast speeds. They were surprised to find that some water was flowing down the front of the swimmers' forearms and hands during the propulsive phases of their underwater strokes. The three had assumed that the direction of water flow would be opposite the direction of the swimmers' hands and arms. This downward direction of water flow, which they termed *axial* force, would cause turbulence over the top of the hand and make it impossible to maintain an intact boundary layer. Consequently, they concluded that the swimmers' hands could not function as hydrofoils that generated lift forces according to Bernoulli's principle.

The Vortex Theory

The vortex theory has been offered to explain how lift forces could play a major role in swimming propulsion, even when the boundary layer separates as swimmers move their limbs through the water. Cecil Colwin (1992) has been the foremost proponent of the role of vortex formation in swimming propulsion. He believes the formation of vortices can maintain a pressure differential between the undersides and upper sides of swimmers' hands, even when water flow is turbulent.

A vortex is a mass of rotating fluid. The illustration in figure 1.10 shows how the formation of a vortex could increase the lift force on a foil. The process begins with the formation of a starting vortex. Some of the water molecules that pass over the trailing edges of the foil and some that pass under those trailing edges will roll up, toward the top side of the foil, because the water pressure is lower above the foil than underneath it. These water molecules travel not only up but also forward, over the top of the foil, forming the starting vortex. According to Newton's action-reaction law, a vortex moving in one direction will create a countervortex of equal magnitude swirling in the opposite direction. This countervortex is termed a *bound vortex.*

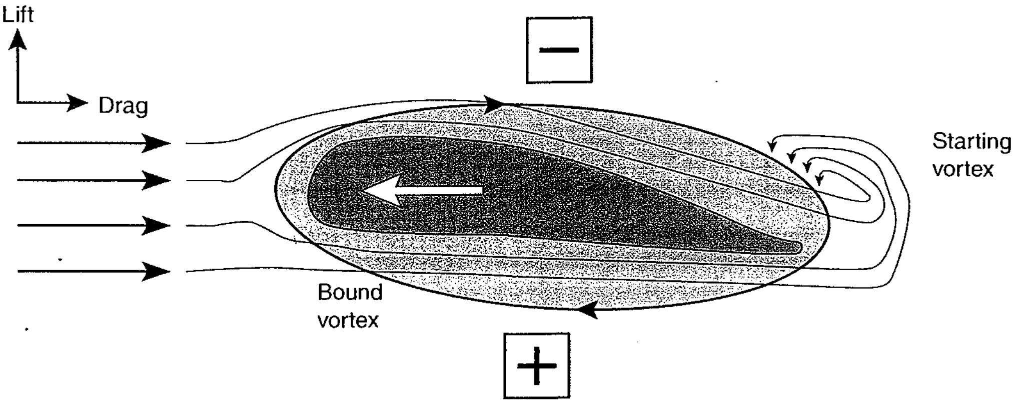


Figure 1.10 The formation of a bound vortex around an airfoil.

A bound vortex acts like a layer of fluid that is circulating around the foil in the opposite direction from the starting vortex. That is, it rotates in a clockwise direction from front to rear over the top of the foil and from rear to front underneath. Because of this, the force of the countervortex above the foil will be acting in the same direction as the relative flow of water over the top of the foil, from front to rear. In doing so, it increases the speed of water flow over the upper surface of the foil, which, in turn, causes a further decrease of the pressure above that surface. At the same time, the force of the countervortex underneath the foil is exerted in the opposite direction of water flow. Therefore, the countervortex will slow the velocity of that fluid and cause a further increase of pressure under the foil. The result of these actions is that the pressure differential needed for the production of lift forces will be enhanced between the undersides (+) and upper sides (–) of the foil, even when the actual flow of water around the foil is unsteady.

Having said this, I should make it clear that a bound vortex is not a physical reality. That is, a layer of water is not actually circulating around the foil in the manner I just described. Nevertheless, the force associated with the formation of a starting vortex must result in the production of a counterforce of equal magnitude. This counterforce will act like a countervortex and increase the pressure differential between the undersides and upper sides of a foil as though there were a layer of water circulating opposite the direction of the starting vortex. That counterforce will continue to enhance the pressure differential between the undersides (+) and upper sides (–) of the foil until the starting vortex is washed away. The starting vortex is usually washed away in the form of a whirling mass of water molecules when there is a sudden change in foil direction, speed, and/or angle of attack.

Colwin believes that swimmers propel themselves through the water with rotational limb movements that cause the formation and shedding of vortices with each change of direction they make during their underwater strokes. Efficient swimmers, in his opinion, cleverly manipulate the formation and shedding of vortices by controlling the shape and movements of their limbs in order to create propulsion of two types: *foil* and *fling-ring.* In general, he believes that foil propulsion takes place in the first half of the underwater stroke while the fling-ring mechanism is used, most often, to produce propulsion during the second half of the stroke. Colwin has also suggested that the fling-ring mechanism creates propulsion when the legs change directions from down to up, or vice versa, during kicks. I will now describe the proposed mechanisms of foil and fling-ring propulsion more thoroughly.

Foil Propulsion. Foil propulsion is a result of the lift forces produced when a starting vortex is formed and before it is washed away, or shed. The flow of fluid over the hands must be steady to prevent the shedding of a starting vortex. Skilled swimmers are believed to establish this steady flow by careful orientation of the hands at the beginning of the underwater stroke. Once this flow is established, swimmers maintain it by careful acceleration and orientation of the limbs so that the fluid does not break away from them. They can only maintain steady fluid flow around the hands for a small portion of each underwater stroke, however, because the limbs are constantly changing direction, speed, and angle of attack. Consequently, the starting vortex must be shed and a new one formed whenever swimmers make a major change in direction, speed, or angle of attack with the limbs. Colwin believes that the factor separating skilled swimmers from those who are not so skilled is the ability of the former to control their limb movements so that starting vortices are maintained throughout a particular stroke phase and then shed at the proper time.

Fling-Ring Propulsion. Fling-ring propulsion occurs at major transition points in the underwater stroke when the starting vortices are shed. Water that is flung backward from the limbs after a sudden change in speed, direction, or angle of attack causes a counterforce of equal magnitude that will accelerate swimmers forward. An example of the way this phenomenon is supposed to increase swimming propulsion is illustrated for a front crawl swimmer in figure 1.11.

The swimmer in this illustration is shown executing the final propulsive phase of his underwater armstroke. When he changes the direction of his hand from in to out at the beginning of this movement, he creates a starting vortex that is carried with his hand until it decelerates just before reaching the surface. At that point, the starting vortex is shed backward, resulting in an acceleration of the swimmer's forward velocity.

The vortex theory of swimming propulsion is based on sound principles of aerodynamics. If it actually operates during human swimming, it would mean that lift forces make a considerable contribution to

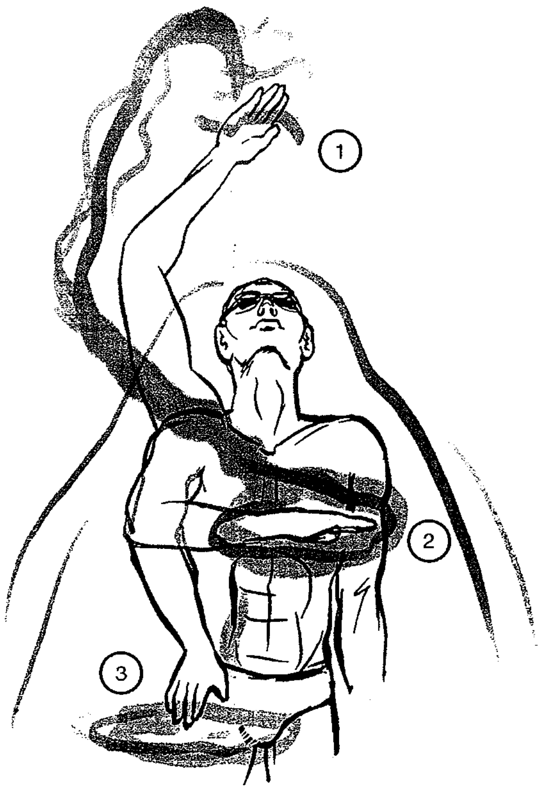


Figure 1.11 An example of the fling-ring mechanism for a front crawl swimmer completing the propulsive phase of his underwater armstroke.

Adapted from Colwin 1984.

propulsion even when the boundary layer separates. Unfortunately, there are many difficulties associated with proving and disproving this theory.

The major problem in proving this theory is determining whether swimmers can actually establish a bound vortex around the hands and feet during their underwater propulsive efforts. If a bound vortex cannot be maintained, even for short distances, its effect on increasing lift force and vortex shedding would not be available for foil and fling-ring propulsion.

Vortices are certainly visible trailing off the hands, arms, and feet of swimmers. Nevertheless, there is no proof that these trailing masses of turbulent water result from the creation and shedding of bound vortices. In fact, the available evidence indicates that a bound vortex will not develop around such small and poorly streamlined objects as swimmers' hands and arms. A bound vortex needs time to develop and the fact that the boundary layer separates so quickly as it passes over the human hand makes it doubtful that there will be enough time to form a starting vortex that develops into a bound vortex.

Center of mass forward velocity patterns of swimmers also create doubt about the efficacy of the foil and fling-ring mechanism for producing propulsion. If they were operating, you would expect to see swimmers' bodies accelerate forward as they make major changes of direction and limb velocity during their underwater strokes. But these center of mass tracings indicate that swimmers actually decelerate during those times. The common pattern is that the body will accelerate to peak velocity during the middle of each propulsive phase of the underwater armstroke and decelerate near the end. The only exception to this general observation occurs during the end of the underwater armstroke in butterfly, backstroke, and the front crawl.

Newton's Third Law of Motion

I consider the evidence that Bernoulli's principle is not involved in swimming propulsion quite compelling. I also believe that the evidence currently available does not support the notion that propulsion is the result of forming and shedding vortices. In my opinion, Newton's third law of motion, the law of action-reaction, offers the most likely explanation for human swimming propulsion.

The counterforce swimmers produce when they push diagonally backward against the water with their limbs provides the force that propels their bodies forward. This counterforce is a combination of the lift and drag forces they produce with their limbs because, for reasons that will be discussed later, they do not push that water directly backward. Nevertheless, I believe that the act of pushing water in a predominantly backward direction creates the propulsive force that accelerates a swimmer's body forward. While this is the theory of propulsion I have come to accept after several years of study, I cannot guarantee that it is, in all respects, an accurate explanation of human propulsive mechanisms. At the present time, however, it seems to be the most logical explanation based on the available evidence.

Questions Regarding Newtonian Propulsion

There were several questions I had to answer before I could come to my present viewpoint that Newton's laws of motion were responsible for propulsion in competitive swimming. The first issue concerned why swimmers' hands traveled laterally and vertically during so much of their underwater armstrokes.

Q *Why do swimmers use diagonal stroking patterns if their goal is to push water back?*

This is a question that might logically come to mind. This was, perhaps, the most important issue I had to resolve before I could accept that human swimming propulsion resulted from pushing water back with the limbs. A straight backward movement of the limbs would seem to be the most effective method for producing the largest propulsive counterforce, yet stroke patterns showed universally that swimmers moved the limbs in lateral and vertical directions as much as or more than they moved them backward during their underwater strokes. After much consideration, I believe that I can provide some credible explanations for their diagonal stroking patterns. I describe them in the following sections.

A *Diagonal stroking movements probably increase distance per stroke and overall propulsive force per stroke cycle.*

Perhaps the most compelling reason for stroking diagonally backward was presented by Counsilman (1977) when he reasoned that swimmers moved the hands in S-shaped patterns to get the limbs away from water they had previously accelerated backward and into adjacent streams of slower moving water that could be accelerated back with less effort. Thus, swimmers should be able to gain more distance per stroke at slower rates of turnover and lower expenditures of muscular effort by pushing against several segments of slowly moving water.

You might question whether the lateral and vertical components of swimmers' stroking movements would reduce the amount of propulsive force they could produce compared to simply pushing water directly backward. In fact, diagonal stroking movements result in a larger amount of water being moved backward with less muscular effort during the entire underwater armstroke while, at the same time, causing only a small reduction in propulsive force in each phase of that stroke. Bixler (1999) demonstrated this with his computer-generated hand/arm model. He calculated that the propulsive force swimmers produced with a diagonal stroking movement was only slightly lower than the propulsive force they could produce by pushing water directly backward. The differences in propulsive force he calculated from a straight backward push and two diagonal backward pushes are shown in figure 1.12. The stroke patterns and hands at the end of each bar provide a visual image of the stroking angles and hand angles of attack represented by that bar. An underneath view of a front crawl swimmer's right armstroke at mid-stroke under the body, the hands represent mirror images, so you can follow the pattern with your right hand.

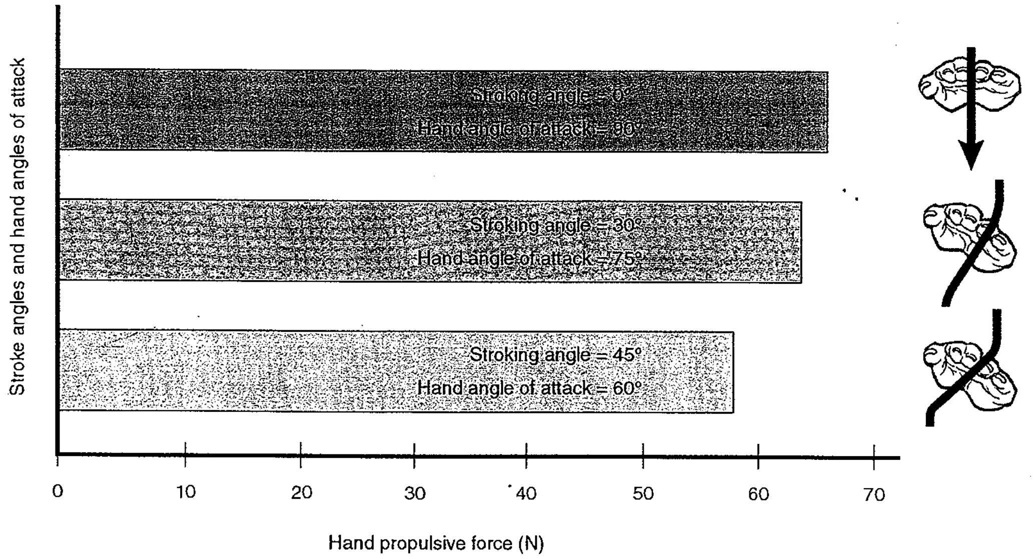


Figure 1.12 The differences in propulsive force calculated from a straight backward push and two diagonal backward pushes.

Adapted from Bixler 1999.

When compared to pushing the hand directly backward (stroking angle of 0° with a hand angle of attack of 90° propulsive force was reduced by only 2 newtons (N) (65 N vs. 63 N) when the stroking angle was changed to 30° and the hand angle of attack was 75°. It was reduced by only 8 N (65 N vs. 57 N) when the stroking angle was 45° and the hand angle of attack was 60°.

The stroke path would be much shorter if swimmers pushed straight back from the beginning to the end of their underwater armstrokes. They would also have to use a great amount of muscular force to accelerate the arms and hands back rapidly enough to maintain pressure against the water they set in motion. Since the distance is short and the limbs must accelerate rapidly, the time required for the arms to travel that distance would also be short. Hence, swimmers would travel forward only a short distance with each stroke and they would require fast rates of turnover to be competitive. Consequently, it seems reasonable that, compared to pushing directly backward, stroking over a longer path with less muscular effort would more than compensate for the slight amount of propulsive force that might be lost. If, as Bixler (1999) suggests, swimmers can generate nearly the same amount of propulsive force with a diagonally backward pull, it makes sense to use that pull. Swimmers should be able to save a significant amount of energy by increasing their distance per stroke and reducing their turnover rates, even if these adjustments should come at the expense of a small decrease in propulsive force. I suspect, however, that the amount of propulsive force generated with one complete underwater armstroke is greater with a longer stroking pattern in which the limbs move diagonally backward than it would be with a straight backward push over a shorter distance.

Another point of contention is that lateral and vertical stroking movements could increase drag by causing the body to lose streamlining. While this is true, any lateral and vertical movements of the body that could potentially increase resistive drag could be reduced or eliminated by body rotation in the front crawl and backstroke, and by undulation in the butterfly and, perhaps, breaststroke. Certain counterbalancing actions by the legs and arms can also help to set a straight course so that the overall propulsive thrust gained from each stroke cycle is greater than it would be from pushing them directly backward.

A *Lateral and vertical stroking movements are needed to apply force more effectively.*

There are other compelling reasons that swimmers must include lateral and vertical limb movements in their stroking patterns. The reasons the arms move upward and downward can be explained in the following manner. After entry, front crawl and backstroke swimmers must move the arms down a considerable distance from the surface, approximately 50 to 70 cm (20 to 28 in), in order to place them in a backward-facing position at the catch. Once they reach a depth that is sufficient for this purpose, they must then bring the arms up and out of the water to prepare for another underwater stroke. Consequently, the arms must travel down and up during various phases of their underwater armstrokes.

Swimmers should not push back against the water with the arms and hands while they are traveling down to the catch position. They should, and do, apply force against the water while they are traveling up, however. Swimmers apparently choose to stroke diagonally up and back, rather than directly back so that the hands will be ready to exit the water when their ability to produce propulsive force has ended. If they pushed the arms directly back from the catch position, the propulsive phase of each stroke would end with the arms 50 to 70 cm (1.5 to 2 ft) underwater, producing a considerable amount of resistive drag on the way to the surface. As compared to stroking diagonally up and back to the surface, dragging the arms up through the water would probably reduce average forward velocity per stroke.

The most likely reasons for swimmers' side-to-side arm movements are the following. Swimmers must move the arms out and in to position them for better applications of propulsive force during different phases of the armstroke. For example, swimmers can move the arms to the catch position more rapidly and with less resistive drag if they move them to the side, away from the body, rather than directly under the midline, during the first half of the underwater armstroke. Then, in those strokes where it is feasible to do so, they need to bring the hands under the midline where they can apply propulsive force more effectively mid-stroke. Finally, in the butterfly and the front crawl, they must move the hands out from underneath their bodies in order to get them to the surface for another stroke.

A *Diagonal stroking motions are needed to overcome inertia.*

The final reason for diagonal stroking patterns concerns the fact that swimmers can reduce muscular effort by overcoming the inertia of the limbs with gradual changes in direction. *Inertia* is an expression of Newton's first law of motion, the law of inertia, and can be stated as follows: A body part that is moving in a particular direction will continue moving in that direction until it is forced to change directions by the application of muscular force (Hay and Reid 1988).

The force required to change directions can be reduced considerably by doing so gradually over a greater distance rather than quickly over a short distance. Sudden changes of direction require swimmers to use additional muscular effort both to move in one direction and then accelerate in a new direction. Sudden changes of limb direction also exert torque on a suspended body that disrupts its alignment and increases water resistance to forward progress. On the other hand, less effort is required to overcome inertia if changes of limb direction are completed gradually over a longer distance. This is done by starting the change of direction before movement in the previous direction has been completed, termed *rounding off.* There is no need for braking when a motion is rounded off. Nor is a sudden and large acceleration required in a new direction. The change of direction can be negotiated by gradually slowing, not stopping, the movement in one direction, followed by a gradual, rather than sudden, acceleration in the new direction.

Q *Are swimmers sculling or paddling their hands through the water?*

Once I understood why swimmers used diagonal stroking patterns rather than straight backward movements, the next question that needed to be answered was how they were using their limbs to move water back. This question goes to the heart of how swimmers exert propulsive force. Do they displace water backward by sculling the edges of the hands laterally and vertically through the water like propeller blades, or do they push them diagonally backward through the water like paddles? The answer to this question depends on your definition of the terms *sculling* and *paddling*. Pure sculling involves propeller-like stroking motions that are made in lateral and vertical directions with no backward component, whereas pure paddling involves straight backward pushes with no lateral and vertical component. Obviously, the diagonal sweeps used during the propulsive phases of the stroke contain elements of motion that could be described as either sculling or paddling. Consequently, if you define *sculling* as any pattern of limb motion that is not directly backward, you would characterize swimmers' strokes as sculling. If you define backward movements of swimmers' arms as paddling, however, even though they contain some lateral and vertical components, you would say that swimmers are paddling.

The term swimming coaches choose should be one that will convey the essence of the propulsive effort. I believe that characterizing stroking movements as paddling motions does that better than describing them as sculling motions. There are three primary reasons for my preference. I will explain each of these in the next three sections.

A *There is good evidence that drag makes a greater contribution than lift to the propulsive forces produced by swimmers.*

Swimmers propel themselves with a combination of lift and drag forces. You might wonder why it is important to know which of the two forces, lift or drag, makes the greater contribution. It is because the force that contributes most determines the emphasis of propulsive movement. If lift forces make the greater contribution, swimmers should execute large lateral and vertical propeller-like sweeps with the limbs and those sweeps should have a minimal backward component. In other words, swimmers would use sculling motions for propulsion. Conversely, if the contribution of drag force is greater, as I believe it is, swimmers should put their effort into pushing the limbs back against the water during the propulsive phases of their strokes. In other words, they should use the limbs like paddles to push back against the water, even though their stroke patterns would, of necessity, contain some lateral and vertical components. With this in mind, I will now share with you the research that led me to my present opinion that swimmers use the limbs like paddles to push back against the water.

sub A

Studies on Lift and Drag with Plaster Hand Models

Lift and drag forces are vector quantities because they have both direction and magnitude. Both of these quantities must be portrayed accurately in order to understand their relationship to the production of propulsive forces. There is no difficulty in determining the directions of the lift and drag forces swimmers produce during various phases of their underwater armstrokes. The drag forces are exerted in the opposite direction that the hands are moving and the lift forces are exerted in a direction perpendicular to the drag force. The difficulty lies in determining the magnitude of these two forces.

The magnitude of each is indicated by the length of their respective vectors. If lift force were the greater of the two, that vector would be drawn proportionally longer by an amount that represents the difference between it and the length of the drag force vector. If propulsion were drag dominated, the drag vector would be the longer of the two. Figure 1.13 shows vector diagrams of *(a)* lift-dominated propulsion and *(b)* drag-dominated propulsion. My contention is that swimming propulsion is drag dominated. I believe that skilled swimmers intuitively choose stroking directions and hand angles of attack that maximize the amount of drag force they produce, and that in doing so they use the hands and arms like paddles to push back against the water.

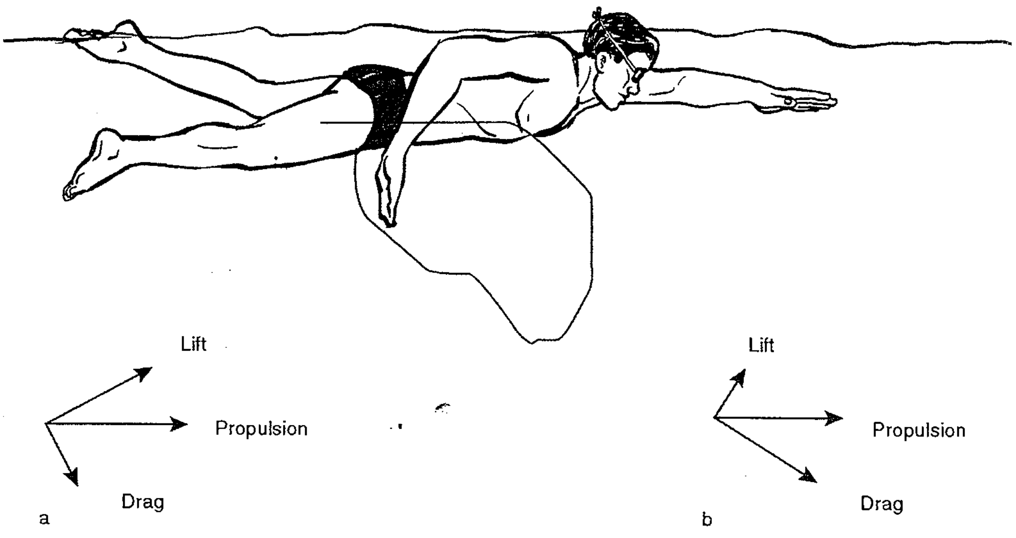


Figure 1.13 Examples of lift-dominated and drag-dominated propulsion during the upsweep of the front crawl. Lift-dominated propulsion is demonstrated by the vector in *(a)*. Drag-dominated propulsion is illustrated by the vector in *(b)*.

There are several reasons to believe that swimmers choose combinations of stroking patterns and hand angles of attack that maximize the contribution of drag forces to the propulsive force they produce. The large hand angles of attack they use during the propulsive phases of their armstrokes is one of these. Large hand angles of attack produce more drag than lift forces. This has been shown in several studies where plaster hands were suspended in water channels or moved through the water at many different angles of attack. The results of one of these studies (Schleihauf 1979) are depicted by bar graphs in figure 1.14.

Schleihauf suspended a plaster model of a swimmer's hand in a water channel and pushed water past the hand at a constant velocity of 2.13 m/sec (7 ft/sec). He repeated this at 10 increments with the hand pitched at angles of attack between 0° and 90°. He also positioned the hand at several different orientations—so that water flowed across the hand from the thumb side to the little finger side, little finger side to thumb side, fingertips to wrist, and wrist to fingertips—in an attempt to simulate all of the various stroking hand movements. These different orientations to the water flow are called *sweepback angles.* The bar graphs in figure 1.14 show, for each angle of attack, the average lift and drag coefficients that were produced at all of these sweepback angles.

Notice that the lift coefficients for the plaster hand were greater than the drag coefficients at angles of attack between 10° and 30°. Lift and drag coefficients were nearly equal at a 40 angle of attack, and drag coefficients predominated at greater angles of attack. There is evidence, which I will present later, that shows that the majority of skilled swimmers, for whom this information is available, use hand angles of attack between 50° and 70° during the propulsive phases of their underwater strokes in at least three of the four competitive strokes. The breaststroke is the only possible exception, although I believe that when more measurements become available, we will find that most breaststroke swimmers also use large hand angles of attack. Consequently, swimmers appear to choose angles of attack that will maximize the production of drag forces rather than lift forces.

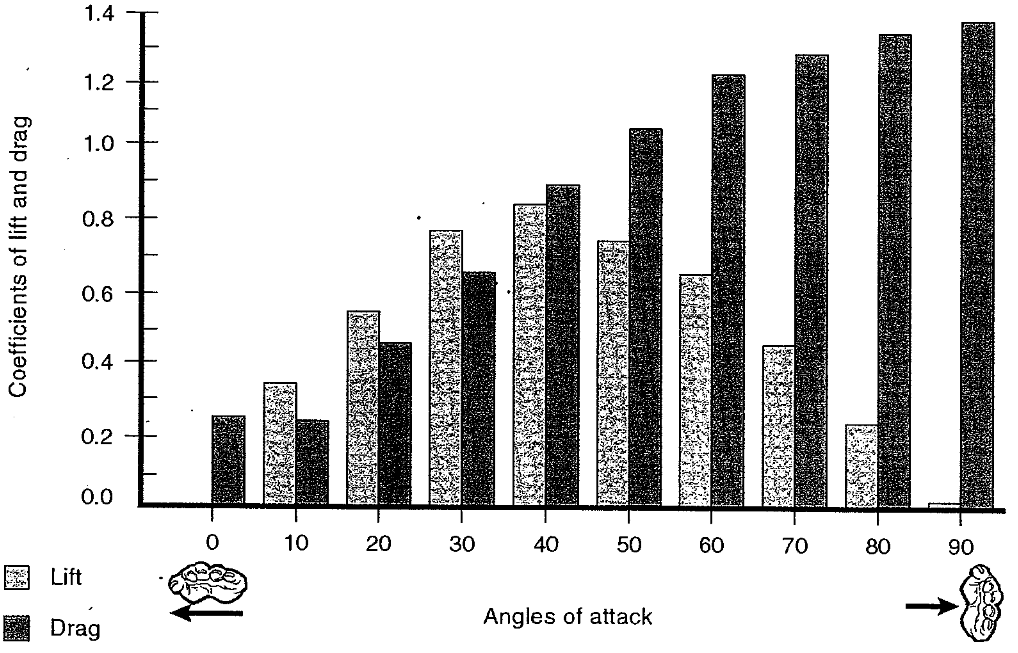


Figure 1.14 Coefficients of lift and drag measured on a plaster hand model suspended in a water channel. The coefficients shown are averages computed for a complete range of sweepback angles at a variety of angles of attack, ranging from 0° to 90°.

Adapted from Schleihauf 1979.

sub A

Measuring Absolute Values for Lift and Drag Forces

Another reason for believing that swimmers intuitively maximize the contributions of drag force has to do with the fact that coefficients may not be the best way to estimate the relative contributions of lift and drag forces to propulsion. "A large coefficient doesn't necessarily mean that a large force is applied" (Bixler 1999). Coefficients are, after all, only indexes that express how streamlined a particular object is for producing lift or minimizing drag. For this reason, an examination of the actual magnitudes of the drag and lift forces produced at each angle of attack should provide a more accurate representation of the role of each in swimming propulsion. Cappaert (1992), Berger et al. (1995), and Bixler (1999) have all reported the magnitudes of lift and drag forces in three separate studies. Their results provide even more convincing evidence that drag is the dominant propulsive force in human swimming.

Using hand models that were dragged through the water at velocities between 0.3 and 3 m/sec, Berger, de Groot, and Hollander showed that absolute values for the drag forces produced by the hand models exceeded those of the lift forces by considerable margins *at all angles of attack*. The values for drag forces were slightly more than double those for lift forces, even at angles of attack between 20° and 40°, and the drag forces were more than three times as great at larger angles of attack.

In the second study, Cappaert suspended a hand model in a swimming flume at a variety of angles of attack and pushed water past the model at velocities of 1, 1.5, and 2 m/sec. She did not report the absolute values for the lift and drag forces at each angle of attack. Instead, she reported the average for each force at all angles of attack. Her results showed that the average drag force was nearly six times greater than the lift force at the angles of attack she measured (17.5 N for drag force vs. 3.2 N for lift force).

Bixler also calculated the actual magnitudes of lift and drag forces produced by his computerized hand/arm model at a number of different angles of attack. The drag forces exceeded those of lift by a considerable margin at all angles of attack when the thumb was the leading edge in a simulated insweep motion. Drag forces for the arm and hand combined increased from approximately 30 N to more than 60 N as the angle of attack increased from 0° to 75°, while lift forces were in the range of 20 to 30 N through the same range. The drag and lift forces produced with an orientation where the little finger was leading were similar in value, although drag forces tended to be slightly higher. Drag forces were in the range of 35 to 50 N at angles of attack between 45° and 75°. Lift forces were in the range of 25 to 34 N for the same angles of attack.

Finally, Bixler estimated the propulsive forces that could be produced by his hand/arm model at various angles of attack. He calculated that drag forces contributed approximately 70% of the propulsive force at the angles of attack most commonly used by swimmers when the thumb was leading in a simulated insweep motion. His calculations showed that the forces of lift and drag tended to make nearly equal contributions when the little finger was leading in a simulated outsweeping motion, however. His results also showed that the greatest amounts of propulsive force were produced when the hand angles of attack were between 60° and 90° when the hands were nearly perpendicular to the direction they were moving.

All three of these studies indicate that when the absolute magnitude of lift and drag forces are measured on hand models, the drag forces are by far the larger of the two. Bixler's study was the only one suggesting that lift forces may play a larger role in human swimming, and only when the hand is sweeping out with the little finger side leading. There is only one situation where competitive swimmers actually sweep the hands through the water with the little finger side leading, however, and that is when backstroke swimmers sweep the hands down near the completion of their underwater strokes. When butterfly and front crawl swimmers sweep the hands out from underneath the body near the end of their underwater armstrokes, they also sweep them up so that the palms of the hands are leading much more than the little finger side. In the butterfly and breaststroke, swimmers tend to lead with the fingertips when they sweep the hands out in the first part of their strokes so that the fingertips lead rather than the little finger side of the hands.

sub A

Measuring Lift and Drag Forces Under Conditions of Unsteady Water Flow

One thing to remember about the studies I just described is that they were conducted under conditions of steady water flow. In the Schleihauf and Cappaert studies, hand models were held in stationary positions at unchanging angles of attack while water was pushed by them at steady rates of speed. When Berger and her associates took measurements, their hand model was moved through the water at a steady rate of speed without changing its stroking angle or angle of attack. And in the Bixler study, a computer-generated hand/arm model remained stationary at several different attack and sweepback angles while the flow of water was simulated past them.

There are two serious pitfalls to measuring forces under conditions of steady water flow or limb movement. The most serious of these is that water flow around the hand and arm is unsteady during actual human swimming. Neither limbs nor water travel at a constant speed but instead are always accelerating or decelerating. In addition, different portions of the limbs travel through the water at different speeds depending on their length from the shoulder joint, which is the center of rotation for the arm. These different and constantly changing limb speeds also cause the water to flow around the arm at different speeds.

The second pitfall concerns the complicated three-dimensional relationship of a swimming stroke. Swimmers' limbs do not travel through the water in a constant direction with an unchanging angle of attack. They change directions and angles of attack several times during each underwater armstroke. The constantly changing combinations of stroking directions, with regards to how much the arm is moving down, in, out, or up at any given point, combined with the almost endless combinations of stroking angles, limb angles of attack, and changing limb velocities used during one underwater armstroke, make it extremely difficult to simulate the actual limb movements of a swimmer's stroke with a model in a water channel.

Realizing these pitfalls, Thayer (1990) tried to approximate an actual swimming stroke with a motor-driven hand/arm model in order to measure lift and drag forces under conditions of unsteady water flow. She attached 127 pressure sensors to her hand/arm model in order to measure, among other things, the lift and drag forces. She moved it through the water in a manner that simulated the changing attack and stroking angles swimmers use during the various underwater phases of the front crawl stroke. Her hand/arm model was constantly changing its orientation to the water and its angles of attack as it traveled through the water, just as an actual hand and arm would do during swimming. This caused continual changes in the flow rates and turbulence of the water surrounding the hand/arm model, resulting in conditions of unsteady water flow.

Once she had collected data on the moving hand/arm model, Thayer also measured the lift and drag forces produced on that same model under conditions of steady water flow using the method of Schleihauf and Cappaert. She then compared the measures of lift and drag collected under conditions of steady water flow to the values measured on the moving hand/arm model under conditions of unsteady water flow. Thayer's results can be seen in the line graphs in figure 1.15.

A comparison of the two sets of drag force measurements revealed that the drag forces produced by a moving hand/arm model were 10 to 20 N greater than the drag forces measured when water was pushed past the same hand/arm model at a steady velocity. Conversely, lift forces measured on the moving hand/arm model were lower through the middle of the underwater stroke than the lift forces that were measured at similar sweepback angles and angles of attack when the hand/arm model was stationary. The lift forces for the moving hand/arm model were higher than the steady flow values near the end of the stroke, but only slightly. In layman's terms, when compared

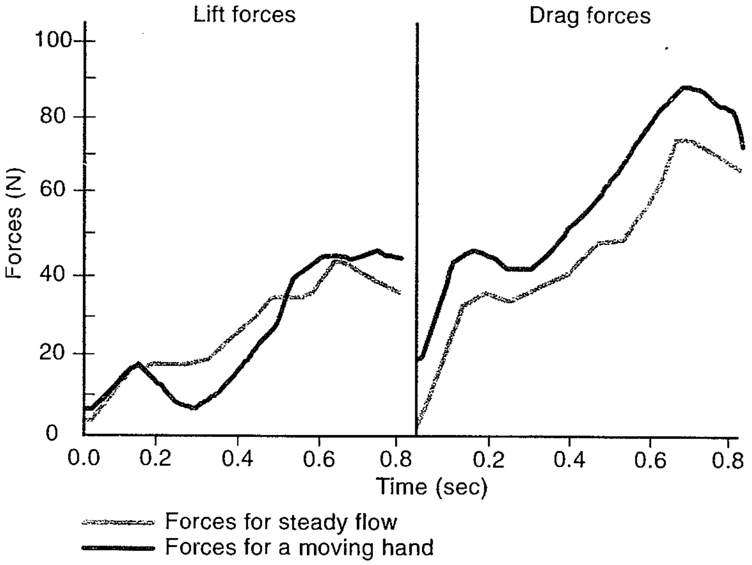


Figure 1.15 A comparison of lift and drag forces produced by a hand model moved through the water and a suspended hand model that had water pushed past it at a steady speed.

Adapted from Thayer 1990.

to a hand/arm model suspended in a tank of flowing water, a model moving through water in a simulated swimming stroke creates considerably more drag force in all phases of the underwater stroke and considerably lower lift forces during the middle of the stroke. These results suggest that the drag forces created when swimmers are actually moving through water will be greater than the drag forces created when stationary hand/arm models are moved through water in a static position at a constant rate of speed or have water pushed past them at a uniform speed. In other words, swimmers are probably producing considerably more drag force during actual free swimming than studies with plaster hand/arm models indicate.

The drag forces produced by the moving hand/arm model in Thayer's study were two to three times greater than the lift forces it produced during all phases of its simulated underwater stroke. Thus, athletes may be producing two to three times more drag than lift with their hands and arms during actual swimming.

A *Velocity patterns show that swimmers accelerate the body forward only when the arms are traveling backward.*

It is generally believed that swimmers' hands and arms do not travel back, or at least not very much, during their underwater strokes. Thus, you might logically ask, "How can swimmers push water back if they are not moving their limbs backward?" The answer to this question is that the limbs do move backward, at least during the propulsive phases of their underwater strokes.

The notion that swimmers' hands did not travel back during their underwater strokes resulted from stroke patterns like the one shown in figure 1.16. A side view of one underwater armstroke pattern for a front crawl swimmer, it is drawn relative to a fixed point in the swimming pool. You'll notice that the swimmer's hand leaves the water ahead of the point where it entered. Illustrations like this had a significant influence on those of us who came to accept the notion that lift was the major propulsive mechanism in human swimming. These patterns were new. We did not know which portions of the pattern were propulsive and which were not. Consequently, many of us took the fact that the hands left the water ahead of the point where they entered as evidence that swimmers were not pushing the hands backward during their underwater armstrokes.

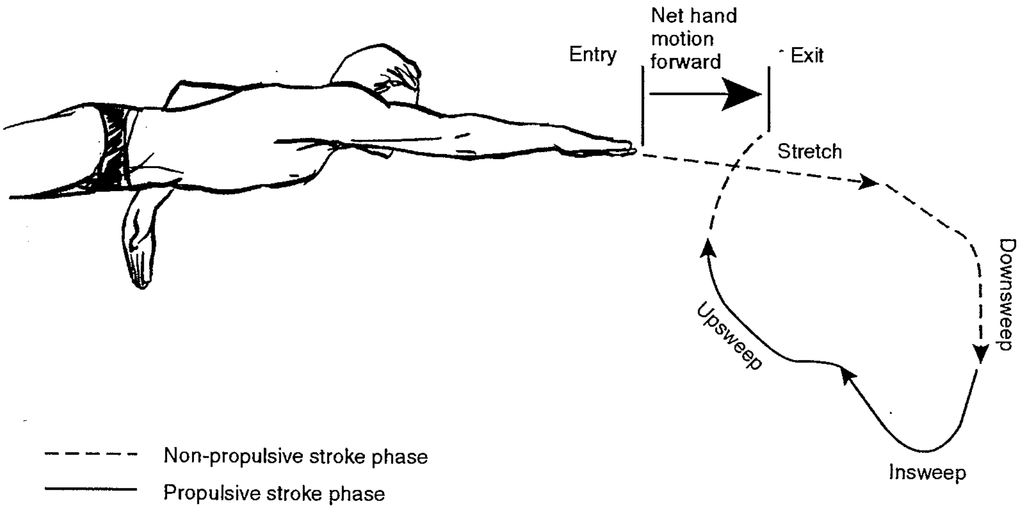


Figure 1.16 Side view of a front crawl stroke pattern showing the points of hand entry into and exit from the water.

Adapted from Schleihauf 1997.

In actuality, the arm is stretched forward after entry while the other arm finishes its underwater stroke. Then it travels down and forward to the catch point, where swimmers begin to accelerate the body forward. Both of these events cause the hands to end up quite a distance forward of their entry points before swimmers actually begin to accelerate the body forward with them. When they do, the stroke pattern shows that the hand actually travels diagonally backward for a considerable time before it leaves the water.

When the stroke patterns like those in figure 1.16 are combined with a center of mass forward velocity pattern for the same swimmer, it becomes clear that swimmers only accelerate the body forward during their underwater strokes when the hands are moving back. The illustration in figure 1.17 shows a side view pattern, drawn relative to a fixed point in the pool, for the underwater portion of Kieren Perkins's left armstroke. The graph at the bottom shows his forward velocity during that stroke, as recorded during his record-setting 1,500 m swim at the 1992 Olympic Games.

After completing the propulsive phase of his right armstroke, Perkins's forward speed decelerates as he sweeps his left hand down and forward. His forward velocity continues to decelerate until his hand begins moving back near the end of that downsweep, the point where he makes his catch. His forward velocity then increases, in two pulses, through the middle of his underwater stroke until his hand starts moving forward again as it nears the surface of the water.

This graph demonstrates clearly that swimmers are not accelerating the body forward with the arms from the instant the hands enter the water in front of them until they leave the water back near the hips (breaststroke excepted). It also demonstrates what I have witnessed with all competitive strokes. That is, the body only accelerates forward when the hands are moving backward during their underwater strokes.

The velocity patterns shown in figures 1.18, 1.19, 1.20, and 1.21 illustrate this point for the remaining three competitive strokes. They show clearly that swimmers are only accelerating the body forward when the hands are moving diagonally backward. Conversely, forward velocity declines whenever the hands are moving forward, such as in the early phases of their underwater strokes, when the hands and arms are moving into position for the catch, and at the end of their underwater strokes when the hands and arms start moving forward just before they leave the water.

These forward velocity patterns were constructed as part of a biomechanical analysis of medal-winning swimmers at the 1992 Summer Olympic Games. Cappaert (1993)

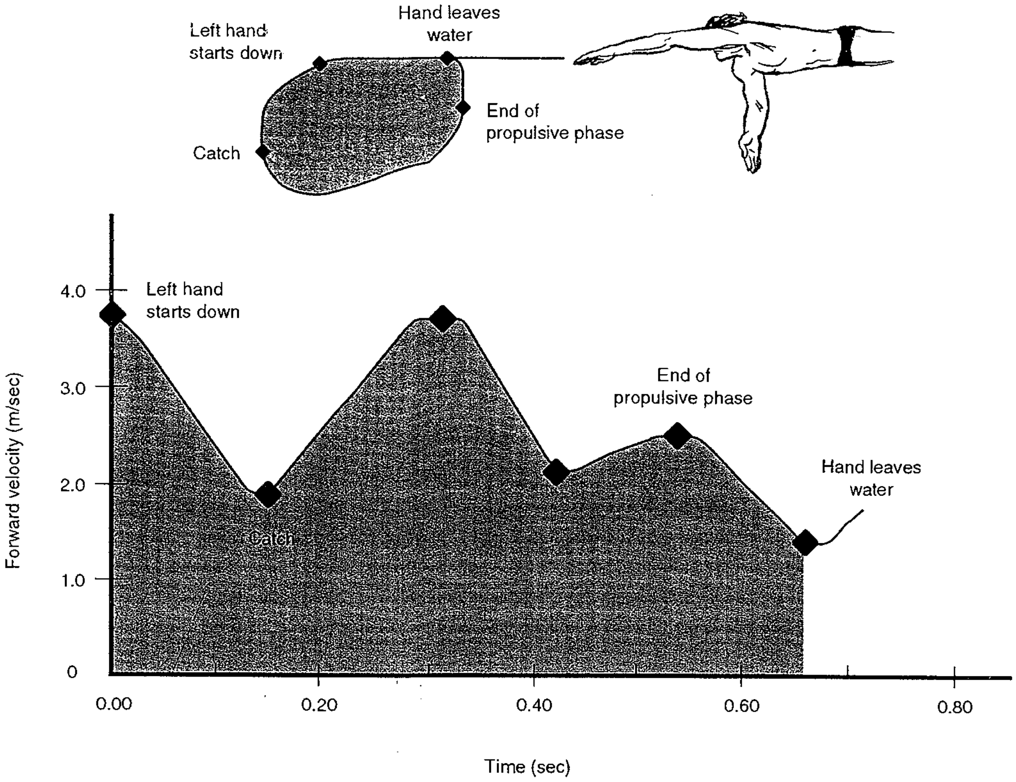


Figure 1.17 Side view stroke pattern and forward velocity graph for the left armstroke of Kieren Perkins.

Adapted from Cappaert 1993.

measured hand angles of attack and forward velocities for medal winners as part of a larger biomechanical analysis of their strokes. She also produced hand stroke patterns for those same swimmers. The calculations were made from videotapes shot during actual Olympic competition.

Perkins's forward velocity pattern was shown in figure 1.17. The patterns of four other swimmers, one from each competitive stroke, illustrate the relationship between stroking directions and forward velocity. The swimmers: Alexander Popov for the front crawl, Pablo Morales for the butterfly, Martin Lopez-Zubero for the backstroke, and Mike Barrowman for the breaststroke.

A stroke pattern and forward velocity graph for Alexander Popov's right armstroke are shown from a side view in figure 1.18. Both the stroke pattern and center of mass velocity tracings were calculated from videos taken during the 100 m freestyle. The point in the stroke pattern where Popov begins to accelerate forward is marked with the letter A. The end of the propulsive phases of his underwater armstroke is marked on the stroke pattern with the letter B. These same indicators, A and B, are marked on the velocity tracing to show the effect of his arm movements on forward velocity.

As is evident, he begins to accelerate his body forward as his right hand nears its deepest point and, more importantly, when it begins to move back at point A. Forward propulsion continues, although not without some small periods of deceleration, until his hand approaches the surface and stops moving back at point B, in preparation for exiting the water.

A similar graph and hand pattern are illustrated for butterfly swimmer Pablo Morales in figure 1.19. These data were collected from videos taken during the 100 m butterfly at the 1992 Olympic Games. Once again, the propulsive phases of his underwater armstroke begin at point A and end at point B. His hands move forward and outward

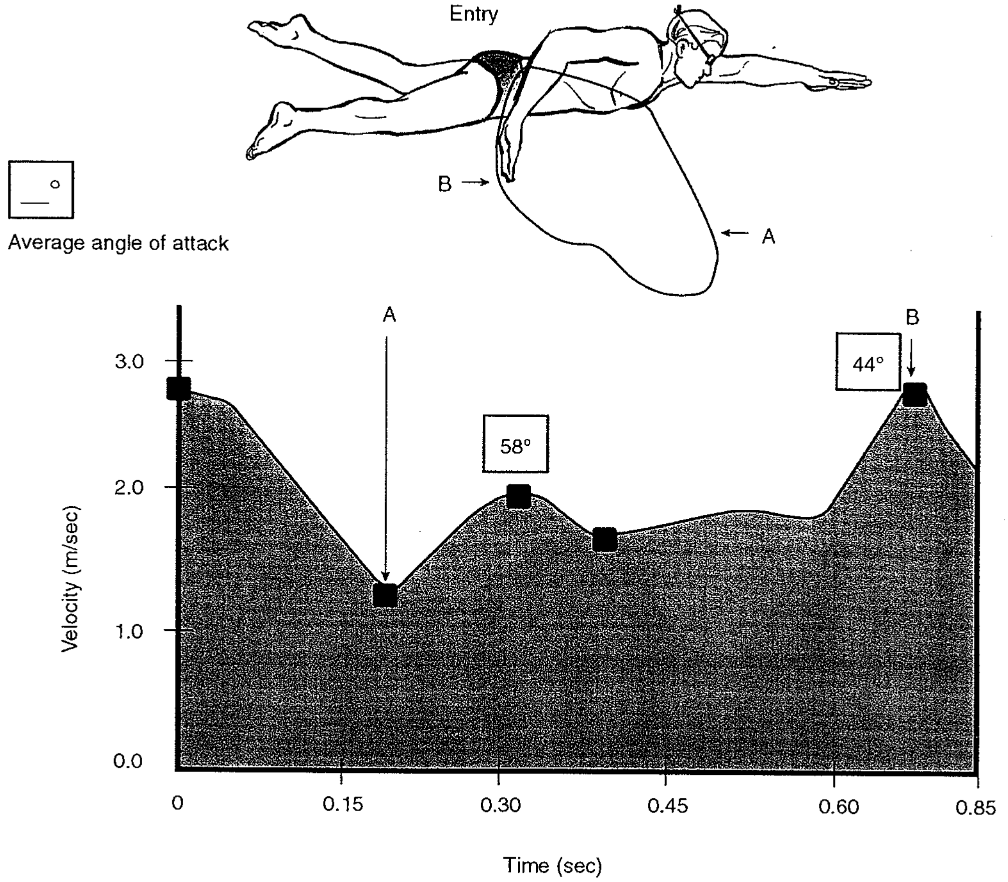


Figure 1.18 Side view stroke pattern and forward velocity graph for the right armstroke of Alexander Popov. The numbers above the propulsive peaks for his insweep and upsweep indicate the average angle of attack of his hand during that particular propulsive stroke phase.

Adapted from Cappaert 1993.

for a short time after they enter the water. Propulsion begins at point A when they are moving down and back. It ends before they have finished pushing back at point B, where his hands also make a marked change of direction toward the surface.

The left-hand stroke pattern and a center of mass velocity graph for backstroker Martin Lopez-Zubero are illustrated in figure 1.20 on page 31. These data were collected during the heats of the 200 m backstroke at the 1992 Olympic Games.

Propulsion begins for Lopez-Zubero at point A, shortly after entry, when his hand begins moving back as well as down. He continues to accelerate his body forward, through three propulsive peaks, as his hand travels diagonally backward. Propulsion ends at point B when his hand begins moving forward during its upward path toward the surface.

The center of mass velocity graph and hand stroke pattern in figure 1.21 (page 32) are for breaststroker Mike Barrowman. The stroke pattern is drawn from an underneath view so that the forward and backward movements of his hands can be seen. These data were collected from videos taken during the heats of the 200 m breaststroke at the 1992 Summer Olympics.

Breaststrokers use hand stroke patterns that are more nearly perpendicular to their forward motion than swimmers of other strokes. Even so, you can see that Barrowman does not begin to accelerate his body forward until point A, where the direction of his hands becomes somewhat back as well as out. From point A, his hands stroke out and back and then in and back to point B, where he begins to decelerate. His forward velocity continues at an accelerated pace, so long as his hands are traveling back. Notice,

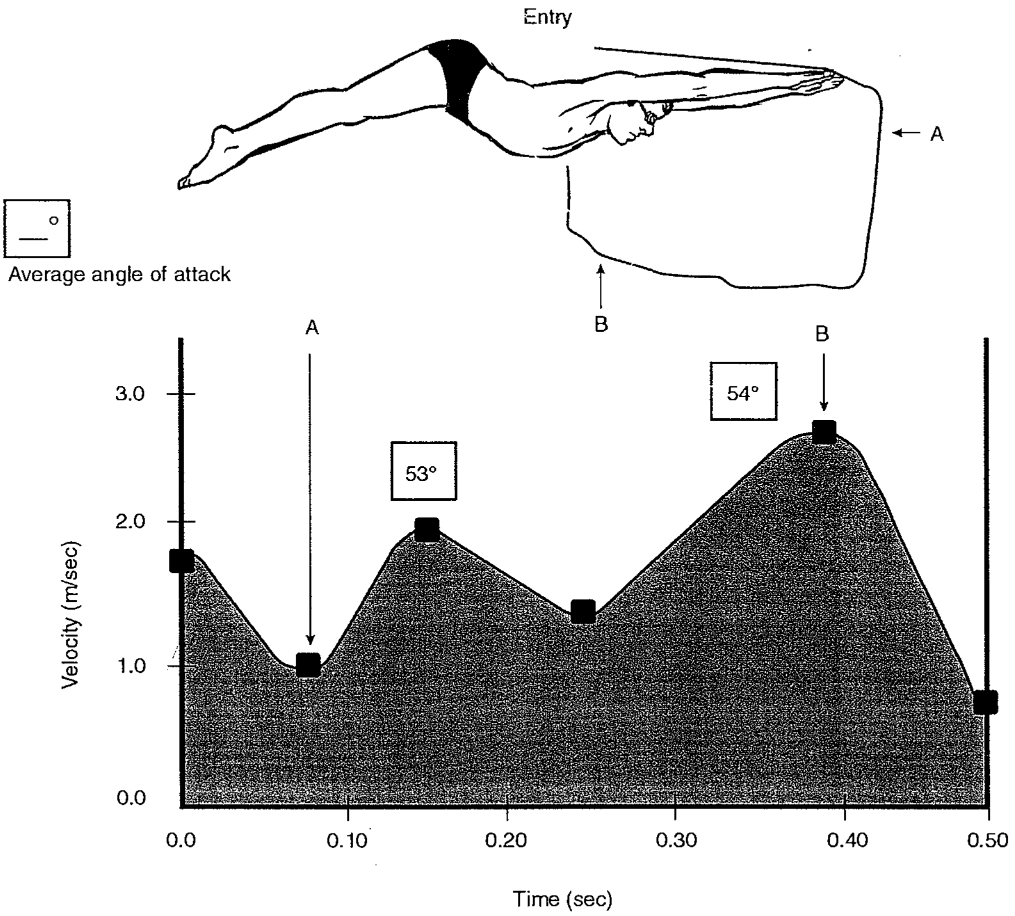


Figure 1.19 Side view stroke pattern and center of mass velocity tracing for Pablo Morales. The numbers above the propulsive peaks indicate the average angle of attack of his hands during that particular propulsive stroke phase.

Adapted from Cappaert 1993.

however, that he decelerates while his hands are moving forward, as through the last portion of his arm pull before recovery.

It is apparent to me, from these hand stroke patterns and forward velocity graphs, and from hundreds of others that I have studied, that swimmers' hands need to be moving diagonally backward in order for them to accelerate their bodies forward. The forward velocity of the body decelerates during the first portion of the underwater armstroke as well as near the end, when the hands are moving diagonally forward. It only accelerates forward during those portions of the underwater armstroke when the hands are moving backward, although not directly backward. The various decelerations between the propulsive phases of their underwater strokes (between points A and B in figures 1.18 to 1.21) are, for the most part, periods when these swimmers made major directional changes with their hands and arms. Although their hands were usually moving backward during these changes of direction, their hand velocities decreased, and that caused a momentary reduction in the forward velocity of their bodies that continued until their hands were accelerating, once again, in a new direction.

One could argue in favor of sculling over paddling because swimmers are stroking diagonally backward and because lift forces are contributing to their propulsive force when they accelerate forward. Nevertheless, the fact that they only accelerate forward when the limbs are traveling back indicates, at least to me, that they are trying to maximize the contribution of drag forces to their propulsive efforts. This can best be accomplished by using the largest possible surface areas to push back against the water. In

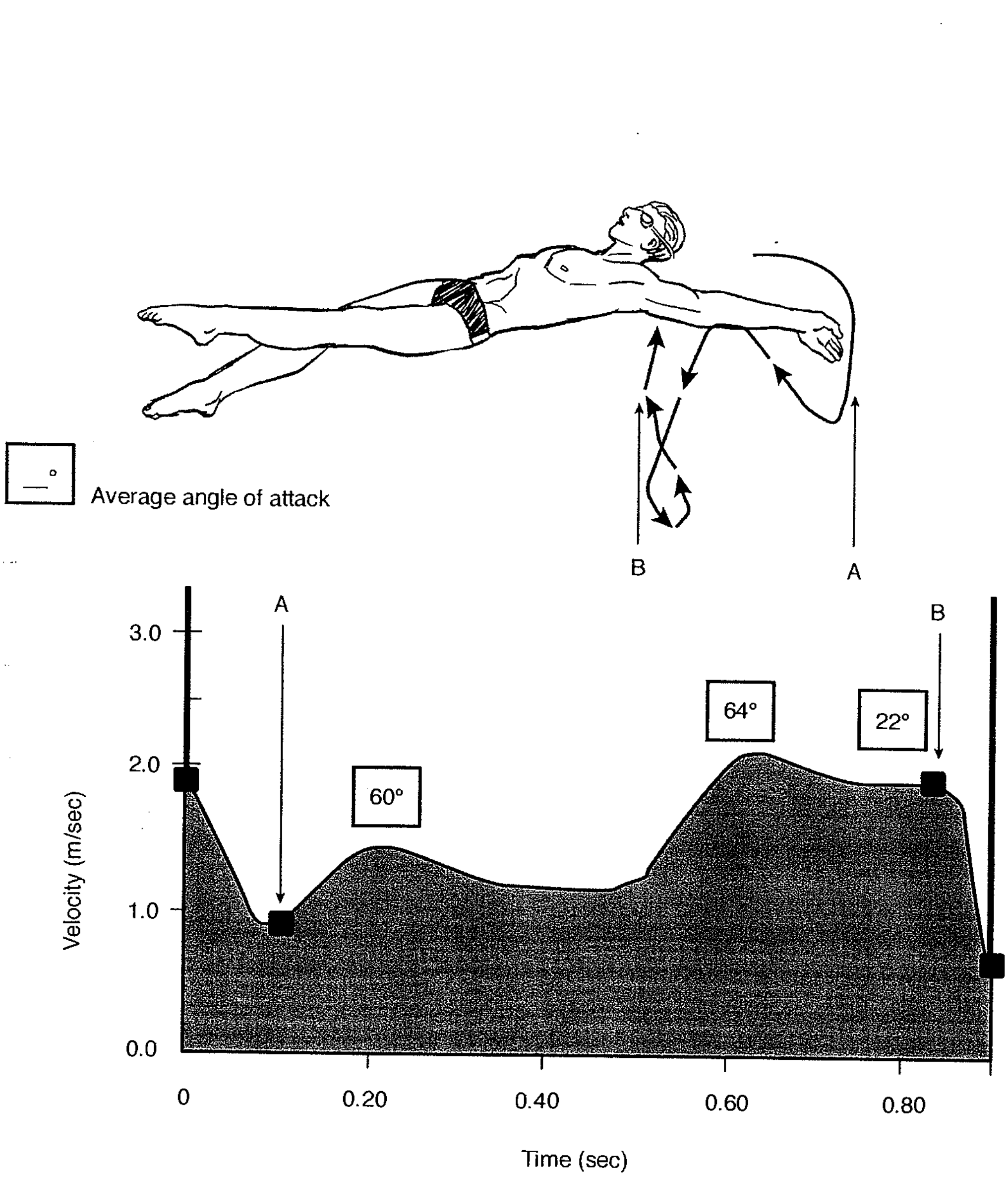


Figure 1.20 Side view stroke pattern and center of mass velocity tracing for the left armstroke of Martin Lopez-Zubero. The numbers above the propulsive peaks indicate the average angle of attack of his left hand during that particular propulsive phase.

Adapted from Cappaert 1993.

other words, it can best be accomplished when swimmers use the limbs like paddles, even as they sweep them in circular paths through the water.

Further support for paddling can be gained from the fact that these velocity patterns also suggest that *pure* sculling motions, those that are entirely lateral and vertical in nature with no backward component, do not accelerate swimmers forward. They demonstrate that swimmers only accelerate forward when the hands are moving back.

The hand angles of attack used by swimmers seem to be an attempt to keep the palms of the hands oriented backward while they stroke them diagonally through the water.

Another indication that skilled swimmers are using the hands and arms like paddles rather than hydrofoils comes from the fact that they always have the hands and forearms facing back, almost perpendicular to their forward direction of motion, even though they are moving them through the water in diagonal paths. An example of this limb orientation is illustrated by drawings *(a)* and *(b)* in figure 1.22, side and underneath views of a front crawl swimmer completing the upsweep of his underwater stroke. Notice that in both views the swimmer's hand and arm are facing almost directly back. This backward orientation probably has a significant bearing on the propulsive force he can produce, even though his arms are actually traveling in a circular path. It appears

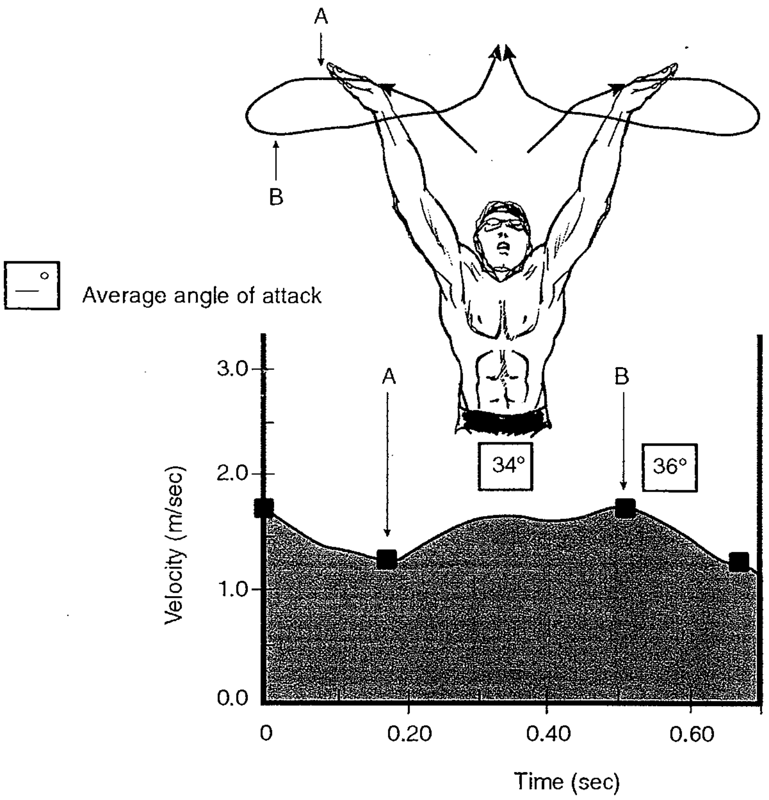


Figure 1.21 Mike Barrowman's stroke pattern and center of mass velocity graph during one armstroke. The stroke pattern is shown from an underneath view. The numbers above each propulsive phase indicate the average angle of attack of his hands during that particular phase.

Adapted from Cappaert 1993.

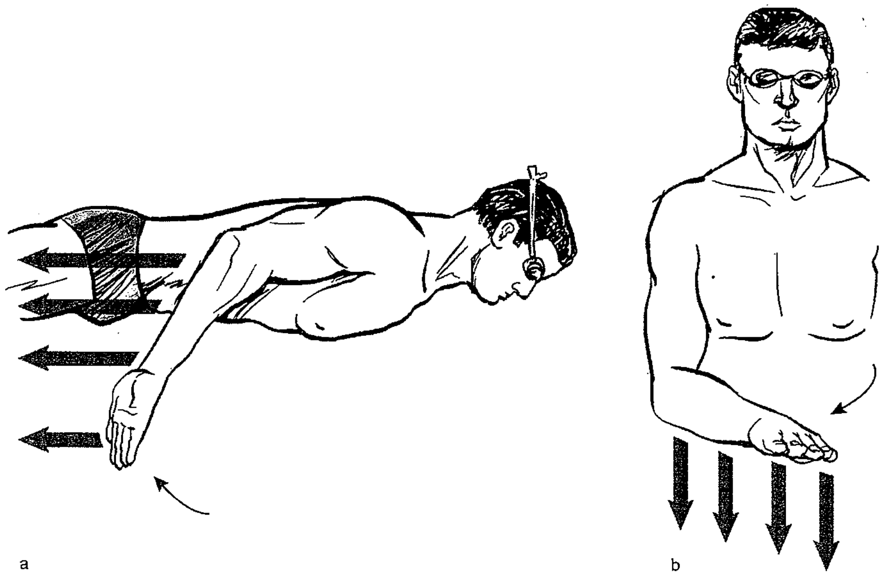


Figure 1.22 The upsweep in the front crawl stroke shown *(a)* from a side view and *(b)* from an underneath view. These illustrations show the manner in which swimmers seem to push backward against the water while they are actually sweeping the hands and arms upward and outward, toward the surface. Notice that the swimmer's hand and forearm, although moving diagonally upward *(a)* and outward *(b)*, are facing backward.

that the swimmer is trying to push directly back against the water with his hands and arms while they are moving diagonally up, out, and back. Put a different way, swimmers do not push the arms straight back through the water. Rather, they seem to push back against the water as they stroke diagonally through it.

Unfortunately, no hydrodynamics expert has attempted to explain the mechanism that may be at work here. I suspect that successive streams of nonmoving or slowly moving water molecules are being displaced backward by swimmers' diagonal arm sweeps, so long as the sweeping motion has a backward component and to the extent that the largest practicable surfaces of the palm of the hand and arm are oriented backward. This method of backward water displacement is illustrated by the arrows behind the swimmer's arm in figure 1.22. It is interesting to note that Bixler (1999) came to a similar conclusion as a result of his computer modeling of fluid forces when he stated that, throughout a wide range of stroking angles, the one common denominator for maximum hand propulsion was that "the palm should face directly backward." The hand angles of attack that have been measured during swimming may not result from swimmers' attempts to make foil-like propulsive stroking motions that maximize lift forces. They may, instead, be an attempt to maintain a backward orientation with the hands and arms as they travel in diagonal directions during their underwater strokes in order to maximize drag forces. I now believe that procedures for matching the correct hand angle of attack with the proper stroking angle, presented by myself and others, have made the teaching of stroke mechanics far more complex than it needs to be. All swimmers need to do is maintain the hands and arms in a mostly backward-facing position while they stroke them diagonally through the water and they will find themselves using the proper angles of attack quite naturally.

The easiest way for swimmers to find and maintain the correct hand angle of attack for a particular phase of the underwater armstroke is to feel they are stroking in a traditional S pattern relative to the body. They should also feel that the arms and hands are maintained almost perpendicular to the direction the limbs are moving relative to the body. The illustrations in figures 1.23 and 1.24 may help to clarify this point.

The two stroke patterns in figure 1.23 show an underneath view of a freestyler's right underwater armstroke. The pattern in *(a)* is drawn relative to the swimmer's body. The pattern in *(b)* is from the same view but was drawn relative to a fixed point in the pool. Patterns such as the one in *(a)* represent what swimmers feel they are doing. In reality, however, the hands are traveling in and out under the body in a path much more like the one shown in *(b)*. The hands travel more in and out than back because the body is also moving forward past the arms at the same time the arms are traveling diagonally backward.

Clearly, then, the actual stroke patterns swimmers use are considerably more diagonal in nature than the ones they feel they are using. Consequently, if they keep the palms

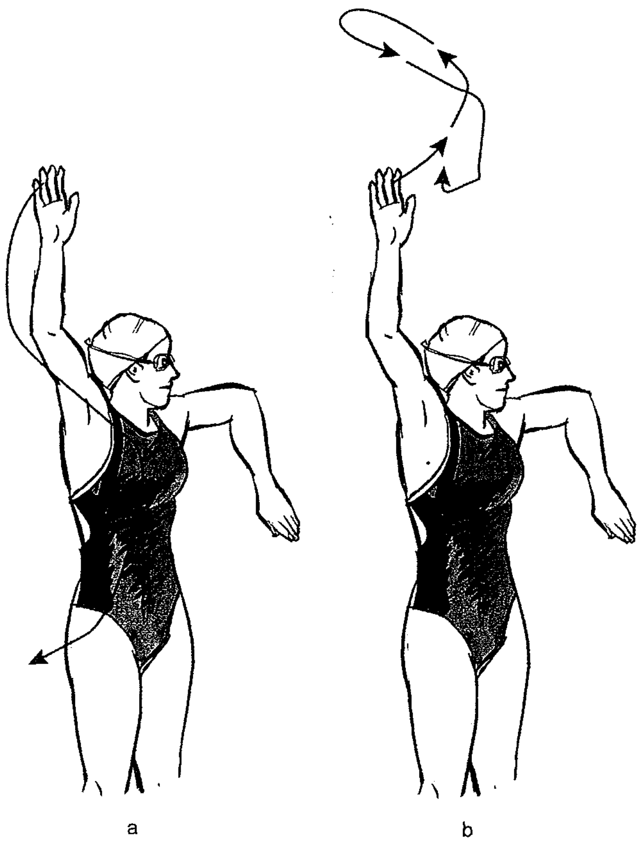


Figure 1.23 Two front crawl stroke patterns, drawn *(a)* relative to the swimmer's body and *(b)* relative to a fixed point in the pool.

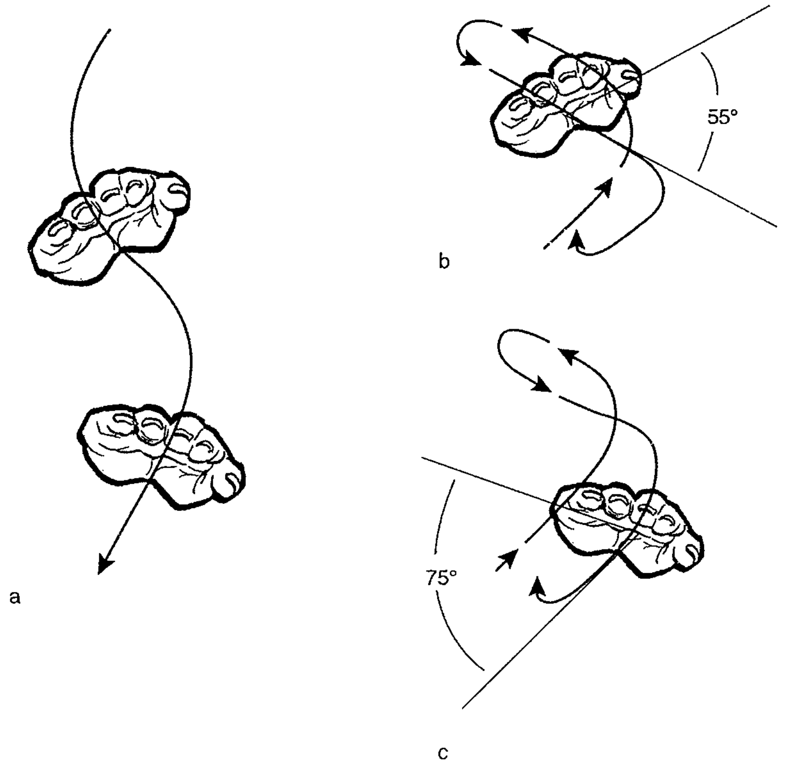


Figure 1.24 Right armstroke patterns. Illustration *(a)* shows a stroke pattern drawn relative to a swimmer's body, with hands superimposed at points along the insweep and upsweep. These hands are pitched perpendicular to the direction they are moving. The stroke patterns in *(b)* and *(c)* are drawn relative to a fixed point in the pool. The insweep is illustrated in *(b)* and the upsweep is illustrated in *(c)*. Notice that when the hands from illustration *(a)* are superimposed on the patterns in *(b)* and *(c)*, the angle of attack lessens because the true pattern of motion is considerably more diagonal.

of the hands perpendicular to the direction they believe the arms are moving, the hand angles of attack will actually be somewhat less than perpendicular to their true direction of motion. In fact, actual hand angles of attack will range from 40° to 70° of the real directions the hands are moving, almost perpendicular to their forward motion. As a result, they won't be pushing as much water up or out as one might think but rather will be pushing it back to a considerable extent.

The illustrations in figure 1.24 help to clarify this complicated point. They show the same two right armstroke patterns illustrated in figure 1.23 (see page 33), but in this figure, swimmers' hands are superimposed along the patterns. The hands in figure 1.24a show the angles of attack swimmers feel they are using when they visualize their stroking patterns relative to the body. These are always perpendicular to the direction they believe the hands are moving. The hand inclinations in figures 1.24b and 1.24c are identical to those in figure 1.24a, but the stroke patterns are drawn relative to a fixed point in the pool and represent true stroking patterns. The portion of the stroke that corresponds to the insweep is pictured in figure 1.24b and the upsweep is shown in figure 1.24c. Notice that hand angles of attack become less than perpendicular to the actual directions the hands are moving when the stroke patterns are drawn relative to a fixed point in the pool.

The point is that swimmers kinesthetically feel as though they are pushing the hands and arms back against the water, like paddles, as they travel in and out under the body. The hands are never really perpendicular to their true direction of motion, however. In reality, they are pitched at lesser angles of attack. This, I believe, is an attempt to push water back with the hands and arms, even while they are stroking them diagonally through the water. They cannot and should not keep the limbs facing directly backward. They must turn them out, in, down, or up slightly in the same directions they are moving in order to make an effective paddle. This is because the surface area of the palms and the undersides of the arms that could be used for pushing back against the water would be reduced considerably if the limbs were facing directly back instead of angled slightly in the direction they are moving. Angling the limbs directly back would cause the edges of the hands to slice laterally or vertically into the water, or worse, it might cause the tops of the hands to push a large amount of water in some direction other than back. Either situation would decrease forward velocity by a considerable amount.

For the sake of accuracy, I want to point out that the illustrations in figures 1.23b and 1.24b and c are examples only and do not represent the actual stroke paths and angles of attack swimmers use in the front crawl. Those paths are three-dimensional and include vertical movements of the hand and arm that cannot be illustrated from an underneath view. Nevertheless, I believe that these drawings accurately illustrate the relationships between hand angles of attack as well as the difference between the stroking patterns swimmers actually use and those they feel they are using.

All of the answers to my questions regarding Newtonian propulsion have reinforced my belief that Newton's action-reaction principle is primarily responsible for propulsion in competitive swimming.

Contributions of the Forearm to Swimming Propulsion

Until now, I have focused exclusively on the propulsive forces produced by the hand. I believe the forearm and perhaps the upper arm are effective propelling surfaces that have been largely ignored. A few researchers have investigated the propelling effectiveness of the forearm, however. One of these was Cappaert (1992). She reported that the average drag force produced by a forearm/hand unit at all angles of attack studied were approximately 50% greater than those produced by the hand alone. Although smaller than the drag forces, lift forces were nevertheless more than 100% greater for the combined forearm/hand units than they were for the hand alone. A bar graph of those results appears in figure 1.25.

The data in this figure resulted from Cappaert's measurements of force for her hand model at a water velocity of 2 m/sec and her forearm model at a water velocity of 1.5 m/sec. She did this so that the combined force of the hand/forearm models would be more similar to actual swimming. As mentioned earlier, these two parts of the limb travel at different speeds during actual swimming, with the hand moving faster than the forearm. Because the arm and hand rotate at the shoulder joint, the linear velocity of the hand will be greater than that of the forearm simply because the hand is further from the center of rotation.

When the drag force produced by the forearm model at a water velocity of 1.5 m/sec was added to the drag force produced by the hand model at a water velocity of 2 m/sec, the combined drag force increased by nearly 50%, from 17.5 N for the hand

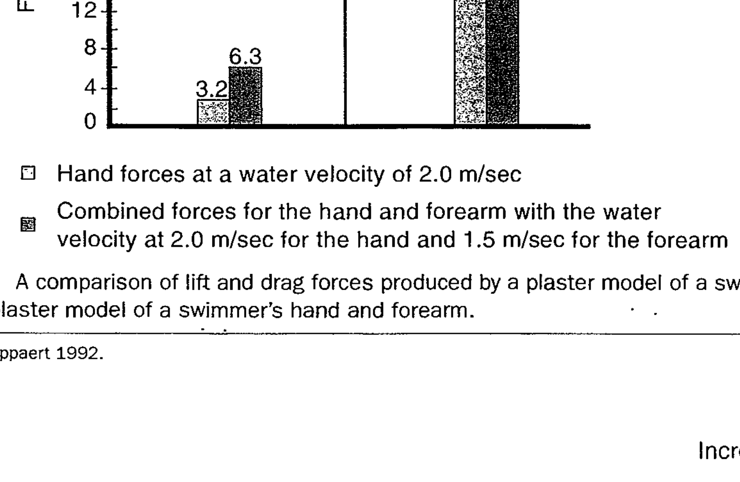


Figure 1.25 A comparison of lift and drag forces produced by a plaster model of a swimmer's hand and a plaster model of a swimmer's hand and forearm.

Adapted from Cappaert 1992.

alone to a total of 26.2 N for the combined hand/forearm. The lift forces increased more than 100%, from 3.1 N for the hand alone to 6.3 N for the hand/forearm. Cappaert concluded the following: "The hand and forearm working together during the pulling pattern have a greater potential for generating forces than the hand alone."

Bixler (1999) compared lift and drag coefficients for his computer-generated hand/arm model. His results also suggest that the forearm contributes significantly to the total propulsive force during the armstroke. Using a velocity of 2 m/sec for the hand and 1.5 m/sec for the arm, the propulsive force produced by his model was in the neighborhood of 50 to 60 N at the stroke angles and hand angles of attack used most frequently by skilled swimmers. Propulsive hand forces were between 35 and 43 N at those same stroke angles and angles of attack. Thus, the addition of the forearm to the model appeared to increase propulsive force approximately 27% over the amount produced by the hand alone. He calculated these forces for stroke angles between 45° to 60° and hand angles of attack between 60° and 75° during both inward and outward stroking motions.

Schleihauf (1984) also reported on the contribution of the forearm to propulsion in the front crawl. His results were based on mathematical calculations of the propulsive force produced by the hands and forearms of actual swimmers. They showed that in the front crawl stroke, the forearms produced a significant amount of propulsive force during the middle of the underwater stroke when swimmers brought the hands in under their bodies and then started them out and up. The effective propulsive force produced by the forearms was in the neighborhood of 15 N for most of that period. The hands were producing approximately 50 N of effective propulsive force during the same phase, so the forearms contributed approximately 23% to the total propulsive force.

In reality, the results from these three researchers are academic. That is, they do not mirror the true differences between the velocities of the hand and forearm in actual swimming. When water is forced past hand and arm models that are suspended in channels or simulated by computer, its velocity will be the same at all points on the models. The same will be true when a hand/arm model is pushed through the water at a constant rate of speed. In actual swimming, however, the velocity of the forearm and, to a lesser extent, the hand varies all along their length, depending on the distance of a particular segment from the shoulder. In other words, in actual swimming, the lower part of the forearm would be traveling somewhat more slowly than the hand but more quickly than the middle and the upper portion of the forearm. Consequently, calculations that involve the use of one velocity for all parts of the hand and then another, arbitrarily slower, velocity for all segments of the forearm will obviously be less than totally accurate. It is no wonder, then, that the estimates these three researchers made concerning the propulsive contribution of the forearm differ so widely.

This fact notwithstanding, the results from all three studies do indicate that the forearm can contribute significantly to the total propulsive force swimmers create during armstrokes. If we make the assumption that the difference between the velocity of the fastest moving part of the hand (the fingertips) and the slowest moving part of the forearm (near the elbow) was in the neighborhood of 0.5 m/sec, the forearm would be contributing between 27% (according to Bixler's calculations) and 38% or more (according to Cappaert's calculations) of the total propulsive force of the armstroke.

Unfortunately, we cannot calculate the actual contribution the forearm makes to swimming propulsion until there is research where the propulsive force of the hand and forearm are measured according to the complicated relationship that exists between their differing velocities. In the absence of such research, the results of these three studies strongly suggest that the forearm can make a significant contribution to the total propulsive force swimmers produce with their strokes, even though the exact value of that contribution is not known at this time.

Propulsion From the Legs

In the 1960s and early 1970s, the prevailing opinion among swimming experts was that the legs did not contribute to propulsion in three of the four competitive strokes because they moved up and down instead of back. The exception was in the breaststroke, where the legs did push back. This opinion changed in the late 1970s. The role of the legs was reexamined when lift propulsion came into vogue and we began to think that the kick's contribution to propulsion might be much greater than we had imagined. Since that time, there has been a reawakening of interest in the contribution that kicks make to forward speed, and rightly so.

I believe that the flutter kicks used in the front crawl and backstrokes and the dolphin kick used in the butterfly are major contributors to swimming speed. I will now cite the results of two studies that support the kick as a propelling agent.

Watkins and Gordon (1983) had a group of 33 male and female competitive swimmers complete short swims at maximum speed with a full front crawl stroke (pulling and kicking) and when pulling only. During the pulling trials, swimmers' legs were supported by a pull-buoy. They found that the swimmers could only pull at 90% of full-stroke sprint speed when they were not kicking. Consequently, the kick increased speed by approximately 10% on average.

The most convincing work on leg propulsion was conducted by Hollander and his associates (1988), who used a MAD (measuring active drag) system to measure propulsive force during full-stroke swimming and while pulling with the arms only. Figure 1.26 is an illustration of the MAD system.

The MAD system consists of a series of pads mounted on underwater poles. The pads are also underwater and are spaced evenly down the length of the pool so that swimmers can reach forward, grip a pad, and push back against it with one arm after the other as they swim down the pool. The spacing of the pads is established through trials with swimmers so that their stroke rhythms remain as normal as possible during

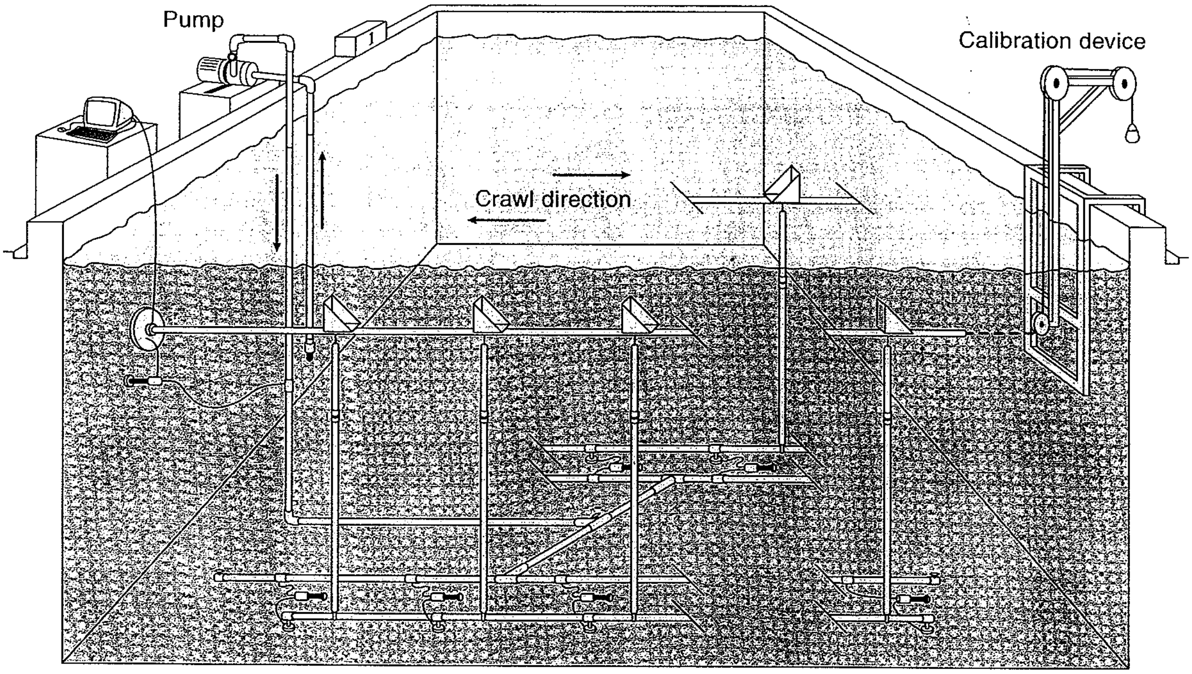


Figure 1.26 A schematic of the MAD system.

Adapted from Toussaint 1988.

testing. Each pad is attached to a force transducer interfaced with a computer so that the force swimmers apply as they push against the pad can be measured. Because there is no slippage when swimmers push against the pad, all of the force they apply will be propulsive. None is lost or used for other purposes such as stabilization. Consequently, the effect of any particular experimental treatment on propulsive force can be measured directly by the amount of force swimmers can apply against the pads.

Hollander and his colleagues tested 18 male and female Dutch national and Olympic-level swimmers under each of two conditions:

1. While swimming the full front crawl (arms and legs) at maximum speed
2. While pulling the front crawl (arms only) with the legs supported by a pull-buoy

The mean force subjects produced during full-stroke swimming was, on average, approximately 12% greater than when they were pulling. Hollander and his colleagues concluded, therefore, that the kick contributed an average of 12% to propulsion during full-stroke swimming.

Interestingly enough, these researchers found that some athletes gained a considerable amount of additional propulsive force from their kicks while others actually lost propulsive force when they swam with a full stroke. This means that the kick can either increase or decrease propulsive force, depending on how well it is performed. Some swimmers derived up to 27% more propulsive force from full-stroke swimming, while others produced as much as 6% more propulsive force from pulling only.

Little research is available about the contribution of the dolphin kick to butterfly swimming. I would assume that it contributes even more than the flutter kick contributes to the propulsion of front-crawl swimmers, however. The backstroke flutter kick probably contributes at least as much to propulsion as the flutter kick in the front crawl.

The kick is now accepted by most experts as an important propulsive agent, but the mechanism responsible for that propulsion remains a mystery. I believe that Newton's action-reaction principle is also responsible for kicking propulsion. It is relatively easy to understand how breaststroke swimmers could use the soles of the feet to push water back during the kick. It is not so easy to understand how they can do this in the flutter and dolphin kicks, however, because the legs travel up and down much more than back during these kicks.

An examination of the path swimmers' feet travel through the water reveals that there is a small amount of backward motion early in the downbeat of the front crawl flutter kick and the dolphin kick, and also during the upbeat of the backstroke flutter kick. It is probably during these short periods when the feet are moving back that swimmers accelerate their bodies forward with the flutter and dolphin kicks. Figure 1.27 shows patterns of the downbeat and upbeat of the dolphin kick in the butterfly stroke and the upbeat and downbeat of the flutter kick in the backstroke. The kicking pattern for the front crawl flutter kick is similar to that of the dolphin kick.

The lines representing the paths of the feet in figure 1.27a and c show that the feet do travel back as well as down during the first half of the downbeat for the butterfly swimmer and during the first half of the upbeat for the backstroke swimmer. The vector diagrams indicate the way that propulsive force could be produced from a combination of the lift and drag forces swimmers produce with the legs as they sweep them down and back. Notice that there is only a small period of time during these kicks when swimmers are actually pushing water back. The feet travel down or up to a much greater extent and they also travel to the side in the backstroke, although that motion is not visible from the side views in this figure. Thus, swimmers probably accelerate the body forward during only the first portion of the downbeat of the front crawl and the upbeat of the backstroke flutter kick, but the cost is high because only a small amount of the total force produced is used for this purpose. This observation is in keeping with two commonly known facts about flutter kicking:

1. Swimmers cannot propel themselves forward as rapidly with the legs as they can with the arms
2. The energy cost for producing propulsive force by kicking is much higher than the cost for producing the same amount of propulsive force with the armstroke alone

Based on the vector diagrams for the second half of the downbeat of the dolphin kick in figure 1.27a and for the upbeat of the backstroke flutter kick in figure 1.27c, I have concluded that these portions of the flutter kick are not propulsive. This is because all of the combined force of lift and drag will be directed upward, as indicated by the vector diagrams. Therefore, the primary purpose of the second half of the downbeat of the front crawl flutter kick and the corresponding phase of the upbeat of the back crawl flutter kick is probably to stabilize the hips at the surface in order to maintain good horizontal and lateral alignment. I do believe, however, that butterfly swimmers gain propulsion during the second half of the downbeat of the dolphin kick by using a mechanism I have termed the *reverse body wave,* which will be described in chapter 3.

The upbeats of the front crawl flutter kick and the dolphin kick and the downbeat of the back crawl flutter kick are probably only effective for maintaining body alignment and do not serve any propulsive function. I have based this assumption on the fact that the feet never move back during the upbeats of the flutter and dolphin kicks nor the downbeat of the backstroke flutter kick. As shown in the kick patterns in figure 1.27, the swimmers' feet are moving up and forward in the front crawl flutter and dolphin kicks and down and forward during the backstroke flutter kick. The vector diagrams show that during the upbeats of the dolphin and front crawl flutter kicks, all of the combined force of lift and drag would be directed downward. This force would be directed upward for backstroke swimmers during the upbeat of the flutter kick.

The actual magnitude of lift and drag forces swimmers produce with the feet is not known, although I suspect they produce more drag than lift. This is because vector diagrams indicate that the hips would be pulled downward if swimmers produced more lift than drag during the downbeat of the dolphin and front crawl flutter kicks and that the hips would be pushed upward during the upbeat of the backstroke flutter

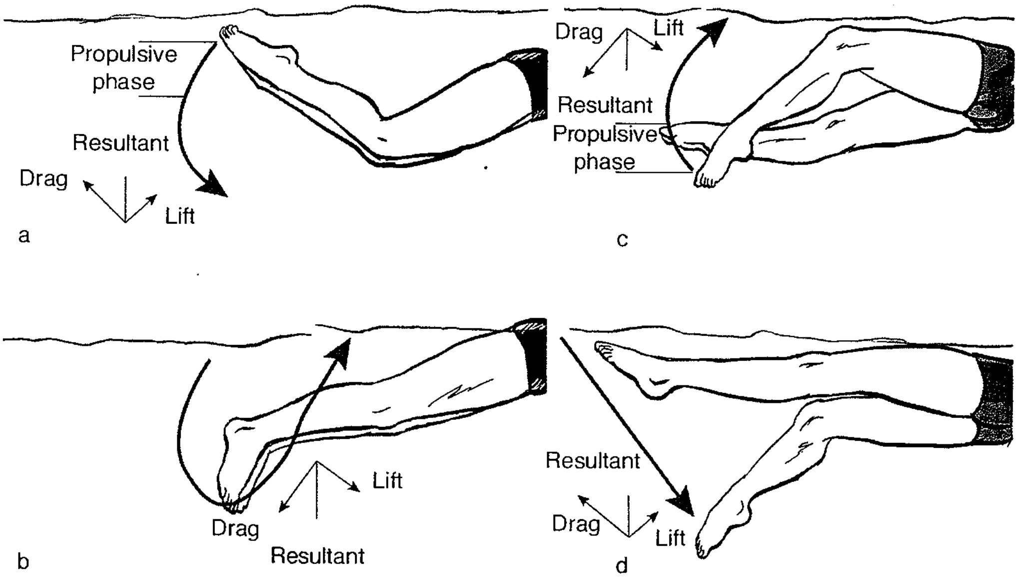


Figure 1.27 Patterns of the *(a)* downbeat and *(b)* upbeat of the dolphin kick in the butterfly stroke and the *(c)* upbeat and *(d)* downbeat of the flutter kick in the backstroke.

kick. Vector diagrams in which lift forces are greater than drag forces have been constructed for the downbeat of the dolphin kick and the upbeat of the backstroke flutter kick in figures 1.28, *(a)* and *(b)* respectively.

As shown, if the lift forces produced by the feet were equal to or greater than the drag forces they produced, the dominant force (lift) would be directed down and forward during the downbeat of the front crawl flutter and dolphin kicks, pulling the hips down. This, of course, is just the opposite of the actual effect of the downbeat of these two kicks, in which the hips tend to be pushed up when swimmers kick down. Likewise, a large lift force would tend to push the hips up during the upbeat of the backstroke flutter kick. This, too, is the opposite effect produced during the upbeat of the flutter kick, in which the hips tend to be pushed down during the upbeat. Consequently, it is doubtful that lift forces predominate during kicking movements.

Colwin (1992) has proposed that the fling-ring mechanism may be responsible for kicking propulsion. The fling-ring mechanism for the downbeat of the dolphin kick, illustrated in figure 1.29, has been proposed to operate in the following manner. During the downbeat, the swimmer carries water downward with the feet. That water is thrust back rapidly when the feet reach the end of the downbeat and change directions

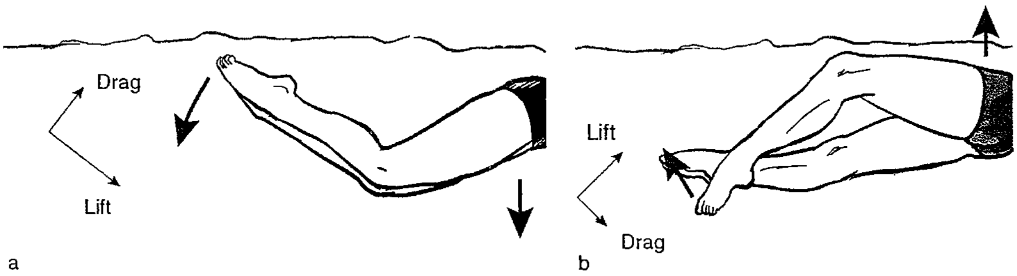


Figure 1.28 Lift-dominated propulsion during the kick. The vector diagram in drawing *(a)* shows the effect of lift-dominated propulsion during the downbeat of the butterfly dolphin kick. The vector diagram in drawing *(b)* shows the same effect for the upbeat of the back crawl flutter kick.

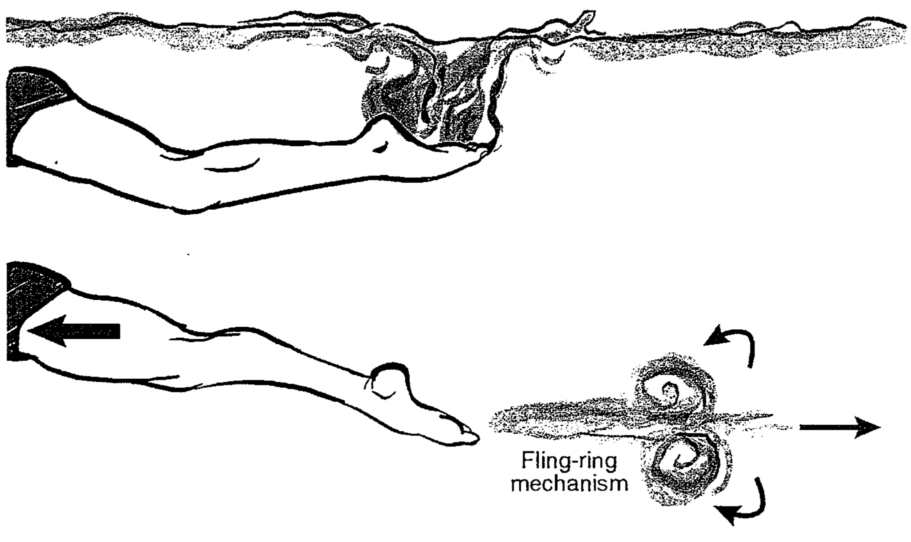


Figure 1.29 An example of how the fling-ring mechanism might propel a swimmer forward during the downbeat of the dolphin or flutter kicks.

Adapted from Colwin 1984.

to start up. The backward thrust of the water creates forward propulsion because it creates a counterforce that pushes the body forward. I doubt that the fling-ring mechanism really propels swimmers forward in this manner, however. As previously explained, propulsion from this mechanism depends on the ability to maintain the effect of a bound vortex with the feet as swimmers move them down through the water. This mechanism, although possible with air- and hydrofoils, is not likely to occur with humans because of the poor foil characteristics of the feet. Human feet are even less foil-like than human hands, which, as indicated previously, are also not very foil-like. It is doubtful, therefore, that a steady flow of water could be maintained around the feet while they are kicking down.

Another reason I doubt that the fling-ring mechanism is propulsive during the kick is because the timing of kicking propulsion does not fit with the time water would be thrust back by the feet. If the fling-ring mechanism is operating, forward velocity should accelerate at the completion of the downbeat of the flutter and dolphin kicks and the upbeat of the backstroke flutter kick. But my observations of center of mass tracings for swimmers who were kicking on a board showed that the biggest acceleration in forward velocity took place during the first half of the downbeat in the front crawl and butterfly strokes and during the first half of the upbeat in the backstroke. They decelerated during the second half of the downbeat in the front crawl and butterfly, and in the second half of the upbeat in the backstroke. They also decelerated during the change of direction from down to up, which is the time when the water would supposedly be thrust back with the fling-ring mechanism.

So if the kick is so inefficient for producing propulsive force, why can some swimmers actually kick faster underwater than they can swim on the surface? As will be explained in chapter 3, body undulation probably accounts for some of the speed from the dolphin kick. It cannot account for the fact that some swimmers can dolphin kick faster underwater than they can swim full strokes on the surface, however. The superior speed of the underwater dolphin kick can probably be explained by the fact that swimmers are underwater, where drag is lower, and by the greater number of propulsive thrusts they apply during every second of kicking. Lyttle and colleagues (1999) reported that, compared to the surface, resistive drag is reduced by as much as 18% at a depth of 0.40 m. Consequently, swimmers would not have to supply as much propulsive force to achieve the same speed when swimming underwater as they would on the surface. Swimmers also move the legs at a rate in excess of 150 kicks/min when they dolphin kick underwater, as compared to a maximum stroking rate in the neighborhood of 60 stroke cycles/min for full-stroke swimming. These extremely rapid leg movements probably allow some swimmers, at least for a short time, to attain faster velocities underwater than they can on the surface.

Key Points Supporting Newtonian Propulsion

As mentioned earlier, no one has yet been able to explain the mechanisms involved in swimming propulsion. All we have are theories concerning the physical laws involved and the way they are applied. I have tried to present and critique the most popular theories in this chapter. I have also proposed Newton's third law of motion, the action-reaction principle, as the most likely mechanism. Following are the major points I have made in support of that contention:

- *Pushing water backward is probably responsible for human swimming propulsion.* Newton's action-reaction principle is applied in the following manner: When swimmers push water backward, they receive a counterforce that accelerates the body forward. They do not and should not push that water directly back, however, because the structure and function of the shoulder joints and the requirements of effective stroking make this method less effective than stroking diagonally through the water.

- *Swimmers use the hands like paddles, not propellers.* They push them back against the water rather than slice them through the water. They push their limbs back to maximize the contribution of drag forces to propulsion because drag is a more effective propulsive force than lift. That conclusion seems obvious from the hand angles of attack that were measured on skilled swimmers during the propulsive phases of their underwater armstrokes. In most cases, swimmers intuitively choose to use larger angles of attack that maximize the contribution of drag forces rather than smaller angles where the contribution of lift forces would be greater.

- *World-class swimmers are always moving their hands diagonally backward during the propulsive phases of their underwater armstrokes.* Conversely, the forward velocity of swimmers will decelerate when they use sculling-like vertical and lateral hand sweeps that do not contain a backward component. Forward velocity decelerates even more markedly when the hands are moving diagonally forward.

- *Skilled swimmers try to keep the hands almost perpendicular to the forward direction the body is moving during the propulsive phases of their underwater armstrokes.* Skilled swimmers in the front crawl, backstroke, and butterfly prefer to use hand angles of attack between 50° and 70° during these propulsive phases. This appears to be an attempt to keep the greatest possible surface area of the hands and arms facing back as they stroke diagonally through the water. This range of hand angles favors the production of drag forces over lift forces.

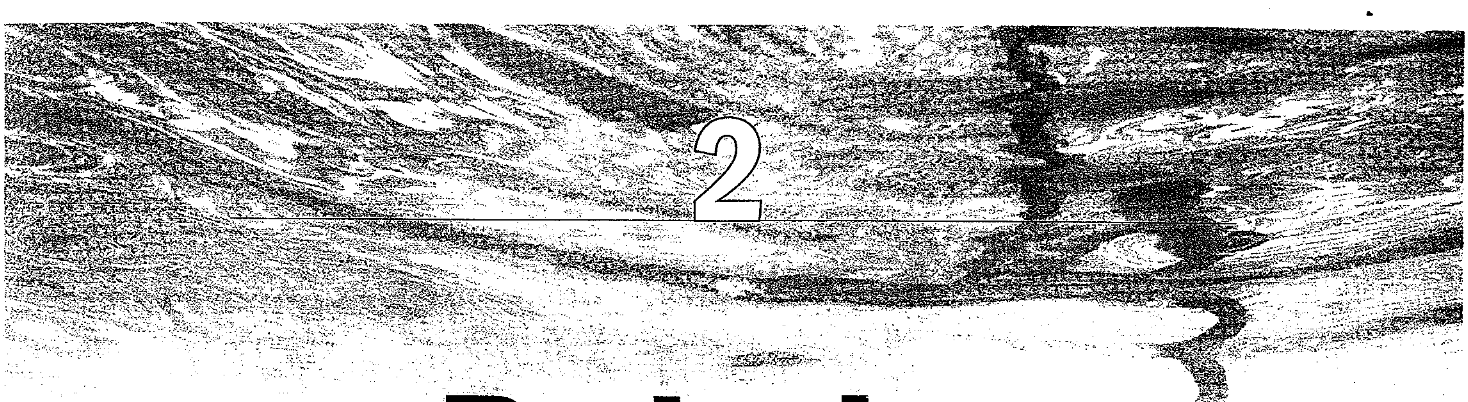
  I believe that breaststroke swimmers should also keep the hands facing almost perpendicular to their forward direction, even though the available data shows that some prefer to use smaller angles of attack.

- *Swimmers need not be overly concerned with hand angles of attack during the propulsive phases of underwater armstrokes.* They need only move the arms through the water in the traditional S patterns relative to the body. In doing so, they will be using hand angles of attack that are very close to ideal for the actual directions the limbs are moving relative to a fixed point in the pool.

- *Though minor, the role of lift in swimming propulsion must be considered.* Swimmers' stroking motions produce lift as well as drag forces. Although the amount lift forces contribute to total propulsive force is controversial, any contribution they make must be considered significant.

- *The forearm and, perhaps, the upper arm play significant roles in swimming propulsion.* The results of Cappaert, Bixler, and Schleihauf suggest that the forearm contributes 15% to 38% of the total propulsive force swimmers produce with armstrokes. It seems reasonable, then, to conclude that the arm contributes significantly to propulsion, especially considering the additional surface area provided by the forearm.

- *Propulsion from the kick is probably achieved by pushing back against the water.* Patterns of foot movement reveal that the legs travel back during the first part of the downbeats in the front crawl flutter and dolphin kicks and during the first part of the upbeat of the backstroke flutter kick. Center of mass tracings indicate that swimmers propel the body forward faster during those same phases. Swimmers also appear to be pushing back against the water with the soles of the feet during the most propulsive phase of the breaststroke kick, which lends additional support to the notion that leg propulsion probably results from the application of Newton's action-reaction law.



2

Reducing Resistance

New in this edition:

- A discussion of active vs. passive drag and methods for measuring both
- A discussion of the effects of buoyancy on swimming speed
- A discussion of the concept of interference drag

Water is 1,000 times more dense than air, so when the body moves forward through it, the water resists its movement with a force substantially greater than the resistance of air. That force, as indicated in the previous chapter, is resistive drag. Swimmers will accelerate forward so long as the propulsive forces they apply are greater than the resistive drag forces holding them back. By the same token, they will decelerate when the resistive drag forces exceed those of propulsion. Changes in the relative amounts of propulsive and resistive drag forces are the reason swimmers' forward velocity either accelerates or decelerates at various times during each stroke cycle.

Swimmers encounter resistive drag as they move forward because they must actually push streams of water molecules out of their way to open a hole in the water for the body to pass through. Swimmers should try to reduce the resistive drag they encounter as they travel down the pool to maintain a faster average forward velocity with less effort. The only exceptions to this statement are for the arms and legs, and only then, when swimmers are making propulsive movements with those limbs. The recovery movements of the arms and legs should be made in a manner that reduces resistive drag.

The resistive drag swimmers encounter is directly proportional to the turbulence they create as they swim down the pool. Unfortunately, because the human body is not nearly so streamlined as those of fish and aquatic mammals, swimmers will encounter a considerable amount of resistive drag, even when perfectly streamlined. A factor that increases drag even more is the constant and drastic change in the orientation of the body to the water (Clarys 1979). Consequently, swimmers will create turbulence as they move through the water. They cannot eliminate this turbulence, but they can reduce it by using a number of techniques described in this and the following chapters on each competitive stroke.

The Importance of Reducing Resistive Drag

In the past, techniques for reducing resistive drag have been overshadowed by methods for improving propulsive force. Recently, however, there has been a resurgence of interest in the role that reducing drag plays in fast swimming. Many experts now believe, and rightly so, that reducing resistive drag can improve swimming speed even more than skills that increase propulsive forces. In fact, in one study involving competitors at the 1992 Olympic Games, the researchers reported that

> . . . elite athletes do not use significant (sic) higher propulsive forces from their arms and legs. Rather, they have better whole body streamlining which reduces the drag forces from the water. Therefore, they can achieve faster swimming velocities using similar propulsion as non-elite athletes (Cappaert, Pease, and Troup 1996).

The reason that reducing water resistance is so important to fast swimming can be illustrated by the graphs in figure 2.1.

The graph in figure 2.1a shows a typical center of mass velocity pattern for one underwater front crawl armstroke during two major periods of acceleration (insweep and upsweep) and three major periods of deceleration (downsweep, the transition between the insweep and upsweep, and arm recovery). Average armstroke velocity can be determined by calculating the height of these peaks (accelerations) and valleys (decelerations), and the amount of time spent in each stroke phase. In figure 2.1a, the average velocity was 1.98 m/sec.

The graph in figure 2.1b shows the hypothetical effect better streamlining would have on the swimmer's average velocity for one stroke. Better streamlining reduced the amount of deceleration during the deceleration periods of the stroke cycle. In this case, streamlining increased the swimmer's average velocity per stroke to 2.04 m/sec. The example in figure 2.1b does not go far enough, however. When this swimmer streamlines his body, he will also accelerate forward more during propulsive phases of his stroke cycle because there will be less resistance to his propulsive efforts. The actual effect of streamlining is better represented by the graph in figure 2.1c.

In this case, the swimmer decelerates less and accelerates more so that his average velocity becomes 2.07 m/sec for that one armstroke. To bring the importance of good streamlining into clearer perspective, the average velocity in figure 2.1a would result in a time of 50.50 for the 100 m, whereas the average velocity in figure 2.1c would compute to a time of 48.31 for the same distance. Clearly, reducing resistive drag can considerably improve performance.

Obviously, the example in figure 2.1 is a hypothetical one that does not factor in the influences of such circumstances as lateral dominance, fatigue, and the start and turn. Nevertheless, the point it makes is valid. Swimmers who reduce resistive drag can increase their average velocity per stroke cycle. Best of all, they can do so without increasing their muscular effort. Techniques for reducing resistive drag will be presented later in this chapter. First, however, I want to discuss the causes of resistive drag.

Laminar and Turbulent Characteristics of Water Movement

Water consists of hydrogen and oxygen molecules. When moving uniformly in a nonturbulent manner, these molecules tend to be packed one on top of the other like

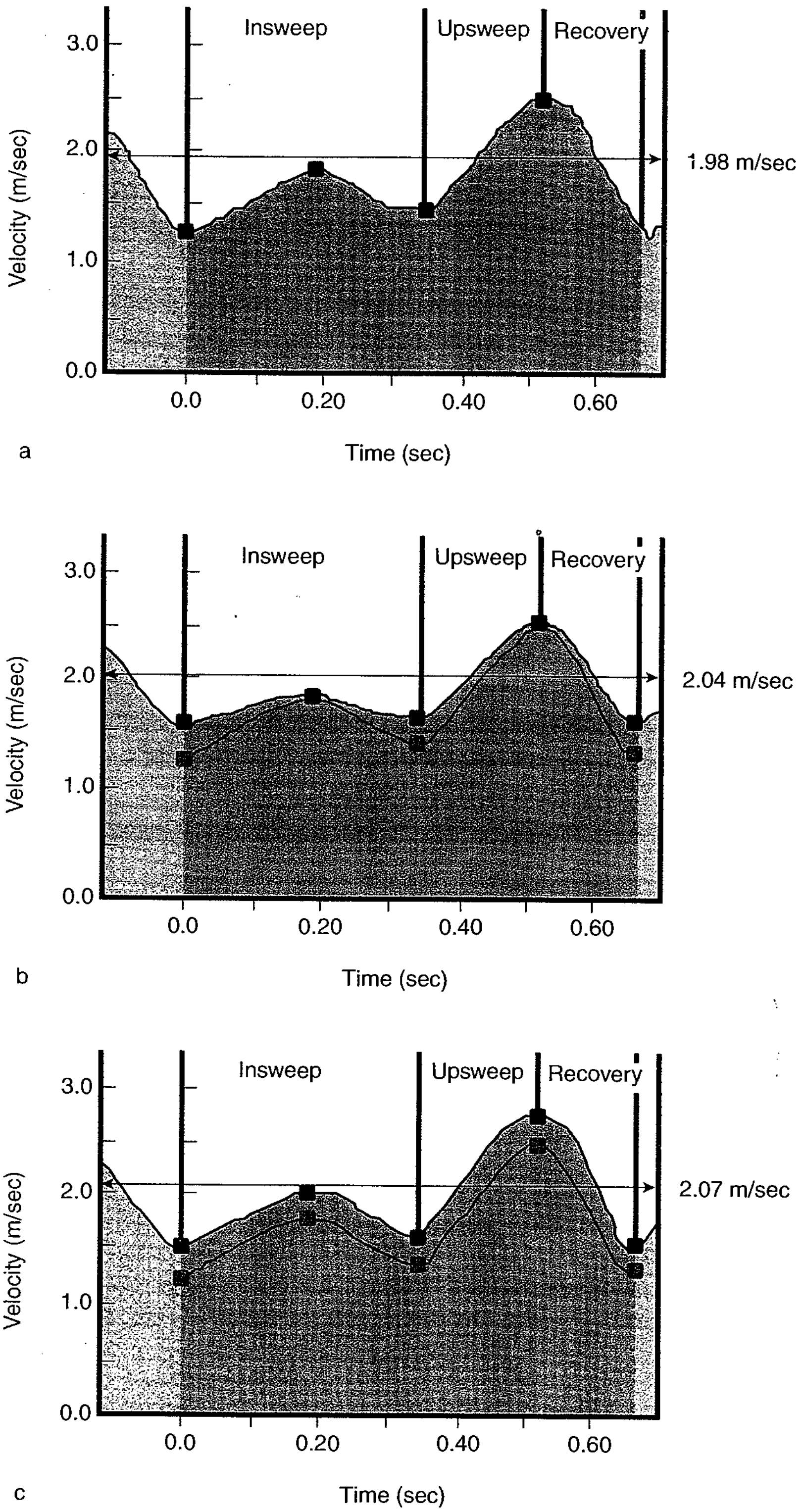


Figure 2.1 The effect of reducing drag on swimming velocity.

laminated sheets. For this reason, the flow of undisturbed water has been termed *laminar*. Swimmers disturb the laminar state of certain streams of water molecules when they move through them, causing them to become turbulent. As mentioned earlier, the sheets of water molecules must separate to the top and bottom and to both sides to make holes for swimmers' body parts to pass through. When this happens, the laminar flow of water molecules becomes disturbed and they start mixing wildly and rebounding from one another in random directions. Water flow is said to become turbulent when this happens. *Turbulent* water flow, then, refers to a wild and random movement of water molecules, whereas *laminar* flow refers to molecules that are all moving in the same direction at the same rate of speed. Laminar water flow creates the least possible amount of resistive drag. Turbulent water flow increases water pressure and resistive drag.

Water molecules that have become turbulent will intrude on adjacent laminar sheets farther out from the object, setting them in motion and causing an ever widening pattern of turbulence. This pattern is visible as whitewater at the surface but cannot be seen underwater. Turbulence, because of the wildly random movement of water molecules, increases the water pressure immediately in front of and to the sides of swimmers and tends to slow their forward velocity unless they exert enough additional propulsive force to overcome it. Some water molecules, rather than being pushed away, will actually become attached to swimmers' bodies. These molecules will be carried along as added mass, causing friction that also slows speed.

The sections of water immediately behind swimmers' bodies will remain turbulent and only partially filled with water molecules for a short time after they have passed through them. The pressure in the area behind will be considerably lower than the pressure in front because the holes created in the water do not immediately fill in as swimmers pass through and the molecules in that area remain turbulent for a short time. This area of lower pressure will tend to suck swimmers backward unless, once again, they increase propulsive force enough to overcome that tendency. The water molecules swirling in the areas swimmers have just passed through are termed *eddy currents. Cavitation* and *tail suction* have also been used to identify the reduction in pressure that tends to pull swimmers backward.

Turbulent water will, within a short time, fill in behind a swimmer who has just passed through it and laminar conditions will be reestablished. The time required for water to fill in the holes will depend on the size of those holes and the size of the pattern of turbulence they created. If the holes are large and the pattern of turbulence is great, they will require more time to fill in, creating a greater suction effect that will last for a longer time. Smaller holes produce smaller patterns of turbulence that fill in more quickly after swimmers pass through, so the suction effect will be smaller and will last a shorter amount of time.

Examples of the laminar and turbulent characteristics of water are illustrated in figure 2.2. In the illustration, laminar streams are represented by straight lines while turbulence is represented by swirls. As described earlier, the water set in motion immediately in front of and to the sides of the swimmer becomes turbulent and will increase the pressure in front of him or her. This area of higher pressure is indicated by the + sign in front of the swimmer. The – immediately behind the swimmer's body indicates the hole where the water molecules have not yet filled in. Eddy currents, or turbulence, are illustrated in this area (behind the swimmer's legs).

The combination of increased pressure in front of swimmers, where they have created a virtual wall of swirling water, and the reduced pressure behind them, where turbulent water has not yet filled in, will augment the pressure differential from front to back. In effect, swimmers will be pushed backward by the high pressure in front of their bodies and they will be pulled, or sucked, back by the low pressure behind them. This large pressure differential will, of course, reduce their forward velocity unless they increase propulsive force to overcome it.

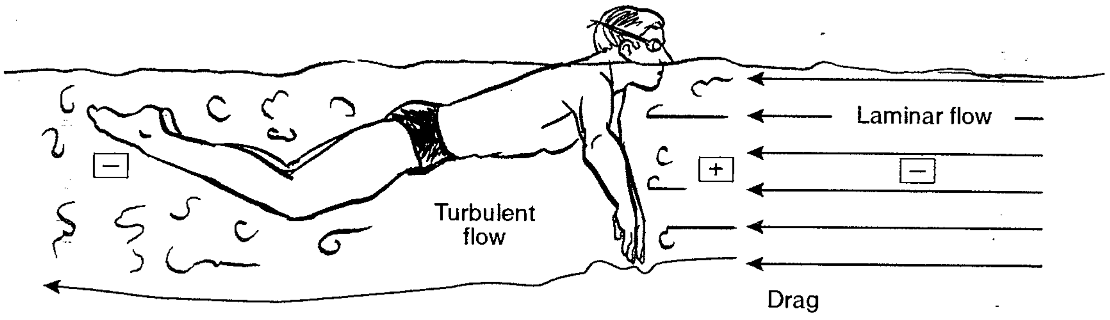


Figure 2.2 Turbulence caused by a swimmer's body moving into laminar streams.

Swimmers drag off one another in training and competition by following closely behind or to the side of other swimmers so that they can stroke in the pocket of whirling eddy currents where cavitation exists. Because the pressure immediately in front of the trailing swimmer is higher than the pressure in the pocket behind the leading swimmer, the trailing swimmer is pulled toward the area of low pressure. The advantage of dragging off other swimmers is that the pressure differential will do some of the work for trailing swimmers so that they can maintain a high velocity with less effort. In one report, it was calculated that dragging behind another swimmer could improve performance by 9.5 sec over 400 m (Chatard et al. 1998).

Waves

The movement of swimmers through water creates bow waves that rise up and press back against their bodies. The backward movement of these bow waves retards the forward speed of swimmers. The size of bow waves swells with increases in swimming speed, creating a wall of water that the athlete must swim through, which, in turn, causes a considerable increase in resistive drag. Bow waves exert such a powerful retarding effect on forward velocity that drag is increased by a factor of 8 when swimming speed is doubled (Northrip, Logan, and McKinney 1974). Other types of drag are only increased by a factor of 4 when swimming speed is doubled.

The size of bow waves and their resistive drag could be reduced by swimming slower, but this option is not available to athletes who want to win races. Therefore, large bow waves are a necessary evil to be dealt with. Swimmers should avoid any actions that will increase the size of bow waves unnecessarily. One such action is *hydroplaning*, or riding unnaturally high in the water. When swimmers arch the back and lift the head to attain a high body position, they increase the size of the bow wave unnecessarily, which reduces forward speed. Swimmers will hydroplane naturally in shorter races because they are moving faster. That is, the increase in water pressure immediately in front of and underneath them, which is caused by their increase in velocity, will tend to push the body higher in the water. This is a normal reaction to swimming fast and should not be avoided, but swimmers should not try to enhance it by arching the back and lifting the head.

Another way that swimmers increase the size of bow waves unnecessarily is by exaggerating the up and down movements of the body and head. In the butterfly and breaststroke, of course, a certain amount of body undulation is essential to breathe properly and create a wave-riding effect. Excessive undulation, however, is unnecessary and will only slow them down.

Front crawl and backstroke swimmers don't have a problem with undulation, but they can increase waves unnecessarily by lifting and throwing the head from side to side as they swim. Front-crawl swimmers should roll to the side and breathe without lifting the head from the water. Backstroke swimmers can keep the size of the bow wave to a minimum by swimming with a head position that is not unnecessarily high and by not moving the head from side to side.

During competition, swimmers must also deal with sources of wave drag over which they have no control. Some pools have more waves than others, of course, caused by poor gutter construction and inadequate lane lines, among other things. Athletes' performances are usually worse when they compete in these so-called slow pools. Because these waves affect all swimmers equally, however, they should not affect the outcome of races.

Measuring Resistive Drag

Obviously, resistive drag can have a significant detrimental effect on swimming speed. Some experts have speculated that the magnitude of resistive drag can be influenced by the size and shape of swimmers' bodies and, of course, by their swimming skill (Miyashita 1997; Ohmichi, Takamoto, and Miyashita 1983; Rouard and Billat 1990; Sidney et al.1997). Unfortunately, it has not been possible to measure the influence of these factors accurately. To do so would require measurements of *active* drag, the resistive drag exerted on a body that is constantly changing positions and speeds as it moves through the water. The methods for measuring resistive drag, in present use, measure only *passive* drag, the resistive drag created by objects that are towed through the water without any change in speed or position. Measures of passive drag have provided some useful information that can be applied to the positions swimmers should assume while gliding through the water. They have little, if any, practical value for determining the resistive drag athletes encounter when they are actually swimming, however.

There have been recent attempts to develop procedures for measuring active drag, but none have been validated (Hay 1988; Toussaint et al. 1988; Vaart et al. 1987). One method that has been pioneered is to add a counterweight of known hydrodynamic drag to a moving swimmer and then calculate how much that weight reduces velocity and/or increases energy expenditure as compared to free swimming (Kolmogorov and Duplishcheva 1992; Kolmogorov and Rumyantseva 1998). Swimmers are first towed through the water at a constant speed and in a static position, both with and without the counterweight attached, in order to determine the additional towing force required to overcome the counterweight. Then they swim through the water at the same speed while towing the counterweight. Once the passive drag of the counterweight is known, that value can be subtracted from the force required to overcome the weight during actual swimming. What is left is the force required to overcome water resistance during actual swimming, and that force is considered equal to active drag.

The accuracy of this method is dependent on two assumptions:

1. That swimmers exert the same amount of power when swimming freely and when towing the counterweight
2. That they swim with the same average velocity per stroke cycle when swimming freely and when towing the counterweight

Both of these assumptions, obviously, require a serious leap of faith, particularly if athletes are asked to swim at or near competition speeds. We must depend on them to exert the same effort when swimming with the counterweight that they used when swimming freely. This is an extremely difficult thing to do, even with the most cooperative subjects. In a recent study, Strojnik, Bednarik, and Strombelj (1998) reported that it was not very likely that swimmers would or could exert the same effort when they swam at maximum velocity both with and without a counterweight.

Another source of error is that the values for swimming with and without the counterweight must be converted to a constant average velocity by computer simulation. The factors taken into consideration by this computer model are the distance per stroke cycle, maximal and minimal velocities within each cycle, and time for the cycle. The possible error in converting values for swimming with and without a counterweight to a constant velocity are reportedly between 6% and 8% (Kolmogorov and Duplishcheva 1992). Consequently, it would be very difficult to arrive at accurate active drag values.

It would seem that the active drag swimmers encounter as they travel through the water with constantly changing body positions would be considerably greater than any measure of passive drag would indicate. Actual comparisons of measured values for active and passive drag have produced contradictory results, however. Glazkov and Denentyev (1977) stated that the resistance encountered when swimming freely is nearly double that of passive towing. These researchers used a bioenergetic approach in which active drag was determined by measuring the difference in energy expenditure between swimming with and without a counterweight. Their calculated values for active drag were then compared to values for passive drag. Kolmogorov and Duplishcheva (1992), however, reported that values for active drag were actually lower than values for passive drag in three of the four competitive strokes. The only exception was the breaststroke. These authors used a hydromechanical approach in which values for active drag were calculated mathematically from differences in speed when swimming with and without a counterweight and then compared to calculations for passive drag with and without a counterweight.

Whether the methods used in these studies actually measure active drag or some other aspect of the relationship between swimming force, energy expenditure and water resistance are still an open question. Although results from the two studies were contradictory, it seems reasonable that athletes should encounter more drag when they are constantly changing positions and velocities during actual swimming than when they are being towed at a constant speed in a constant, streamlined position. Therefore, the active drag swimmers encounter is probably higher than measures of passive drag indicate. How much higher is anybody's guess at this point. Clarys (1979) has estimated that the true values for active drag could be 85% to 300% greater than measures of passive drag at various swimming speeds.

Although we have no viable measures of active drag for support, most of us believe that some swimmers have distinct advantages over others, namely, in their ability (1) to assume better hydrodynamic body shapes during the four competitive strokes, and (2) to change from one shape to another within each stroke cycle with less disturbance of the water around them. Those shapes and methods of change will be discussed later in this chapter. First, however, I want to describe the factors involved in reducing or increasing resistive drag.

How Swimmers Create Resistive Drag

The four most important factors that determine the resistive drag swimmers encounter as they move through the water are

1. the space they take up in the water,
2. the shape they present to the water,
3. limb movements that push water forward instead of backward, and
4. the friction between the body and the streams of water that come in contact with it.

The resistive drag that results from the space swimmers occupy in the water and the shape they present to it has been termed *form* drag, for obvious reasons. It results from the forms swimmers present to the water as they move through it. I have termed the effect of limb movements that push water forward as *pushing* drag and the effect of friction is identified as *frictional* drag.

Form Drag

As indicated, form drag is a product of both the space swimmers' bodies take up and the shapes they present to the oncoming water. The space they take up is a function of body size and how well swimmers align the body both horizontally and laterally. Humans are not shaped to move through the water with a minimum of resistance. The best shape for this purpose is like that of fish and ocean mammals: smooth, with no blunt-shaped projections, and tapered at both front and back. Humans are neither smooth nor well tapered. Our shoulders project out from our necks at sharp angles, our bodies taper in at the waist and then out again at the hips, and our feet are more blunt than tapered at the ends of our legs. In addition, to swim our arms must constantly move forward against the water as they prepare for each new stroke cycle, and our legs and feet must move continuously outside our trunk lines in order to apply propulsive force.

The larger the human being, the more space he or she will take up in the water and the greater the resistive drag. Because larger athletes are usually stronger than their smaller counterparts, however, in most cases, larger athletes can make up for the added drag with their ability to apply more propulsive force. Female athletes are sometimes the exception to this rule. Some females add significantly more size than strength at puberty and then have difficulty equaling their earlier performances.

Other factors that determine the space swimmers take up in the water concern how they align the body horizontally and laterally. Swimmers take up less space in the water by keeping the body as horizontal as possible from head to toes. They also take up less space if they keep all segments within the widest part of the body, usually the shoulders. In other words, swimmers take up less space by not allowing the body to snake down the pool with legs and hips swinging from side to side. Propulsive movements can interfere with horizontal and lateral alignment, however, in some strokes more than in others. In all strokes, swimmers must kick and stroke in lateral and horizontal directions to apply propulsive force effectively. For the same reason, they must undulate the body in the butterfly and in the breaststroke. Therefore, swimmers must strike a compromise between aligning the body and sacrificing propulsion.

It is no wonder, then, that the space swimmers take up in the water has received the most attention where reducing resistive drag is concerned. But the shapes they present to the water probably have an even more profound effect on their forward speed. More-tapered shapes produce less resistive drag than blunt shapes. Consequently, even though swimmers are not well shaped for reducing drag, they must taper the blunt edges of the body as much as they possibly can, except when applying propulsive force with them.

Observation of world-class swimmers suggests that certain body types create less form drag because of the shapes they present to the water. For example, tall, lean swimmers with tapered bodies should have an advantage over those who are short and heavily muscled. Clarys (1979), however, found no relationship between body shape and drag measured during actual swimming. Perhaps even the most lean and tapered swimmers cannot remain streamlined enough to eliminate turbulence. Another possibility is that swimmers with less than ideal body types are able to eliminate their disadvantage by carefully tapering their body positions in the water. I will discuss the effect of space in the first part of this section and the influence of body shaping will be presented later.

The Effect of Body Space on Form Drag

The space swimmers take up in the water has both horizontal and lateral components. The horizontal component concerns the depth of the body. The lateral component refers to the space they occupy from side to side.

Horizontal Alignment. One method for reducing form drag is to remain as horizontal as possible to the water surface without reducing propulsive force. The illustrations in figure 2.3 contrast good and poor horizontal alignment for a front-crawl swimmer.

The swimmer in figure 2.3a has good horizontal alignment. His body is nearly horizontal with the surface and its downward inclination is minimal from head to toes. As

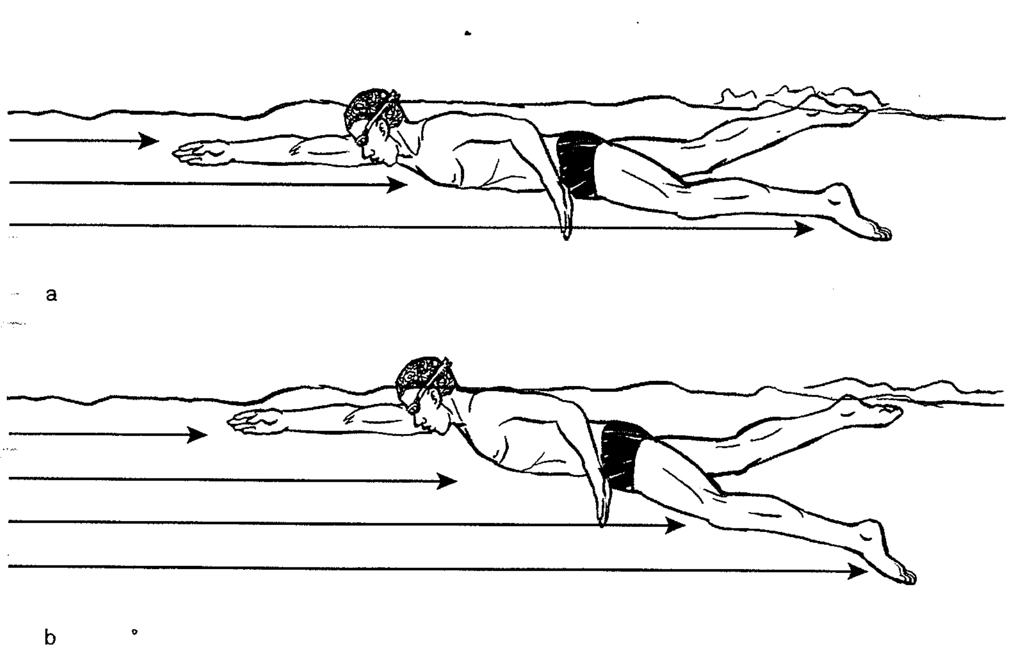


Figure 2.3 The effect on drag of the space swimmers take up in the water. The swimmer in *(a)* has a horizontal position in the water that allows his body to take up minimal space. The swimmer in *(b)* is attempting to hydroplane by kicking deeper. His body is inclined downward, causing him to take up more space in water.

a result, he takes up less space in the water than the swimmer in figure 2.3b. This swimmer is making the all-too-common mistake of trying to hydroplane through the water. He carries his head high with his back arched and thus has to kick hard and deep to maintain the weight of these body parts above the water. Consequently, his body is inclined downward from head to toes so that he disturbs many more streams of water molecules than the swimmer in figure 2.3a.

Where kicking is concerned, swimmers should strike a compromise between kicking deep enough to propel the body forward but not so deep that they take up more space than necessary. The ideal kick depth for each competitive stroke is described in the chapter where the mechanics of that stroke are discussed.

Good and poor horizontal alignment are contrasted for the remaining three competitive strokes in figure 2.4. The backstroke swimmer in figure 2.4a has good horizontal alignment because he keeps his head aligned with his body and does not drop his hips excessively. Contrast this with the backstroke swimmer in figure 2.4b who carries her head too high and her hips too low, thus taking up considerably more space in the water.

This general rule that swimmers should remain as horizontal as possible at the surface of the water applies equally to the front crawl and backstroke. The butterfly and breaststroke are exceptions to this rule, presenting a special situation where horizontal alignment is concerned. Body undulation and breathing mechanics will cause swimmers to be less than horizontal during certain periods of each stroke cycle. These undulating movements are necessary, however, because of the additional propulsion they provide. Swimmers in both strokes must strike a compromise between excessive undulation and moving the body up and down enough to produce adequate propulsive force.

The illustrations of butterfly and breaststroke swimmers show good horizontal alignment in figure 2.4a and poor horizontal alignment in figure 2.4b. As mentioned, undulation is an essential part of the propulsive aspects of these strokes. Therefore, maintaining good horizontal alignment is a matter of undulating the body from a horizontal position at the surface to an inclined position above the surface. Swimmers in these strokes should not allow undulating movements to press parts of the body too deep

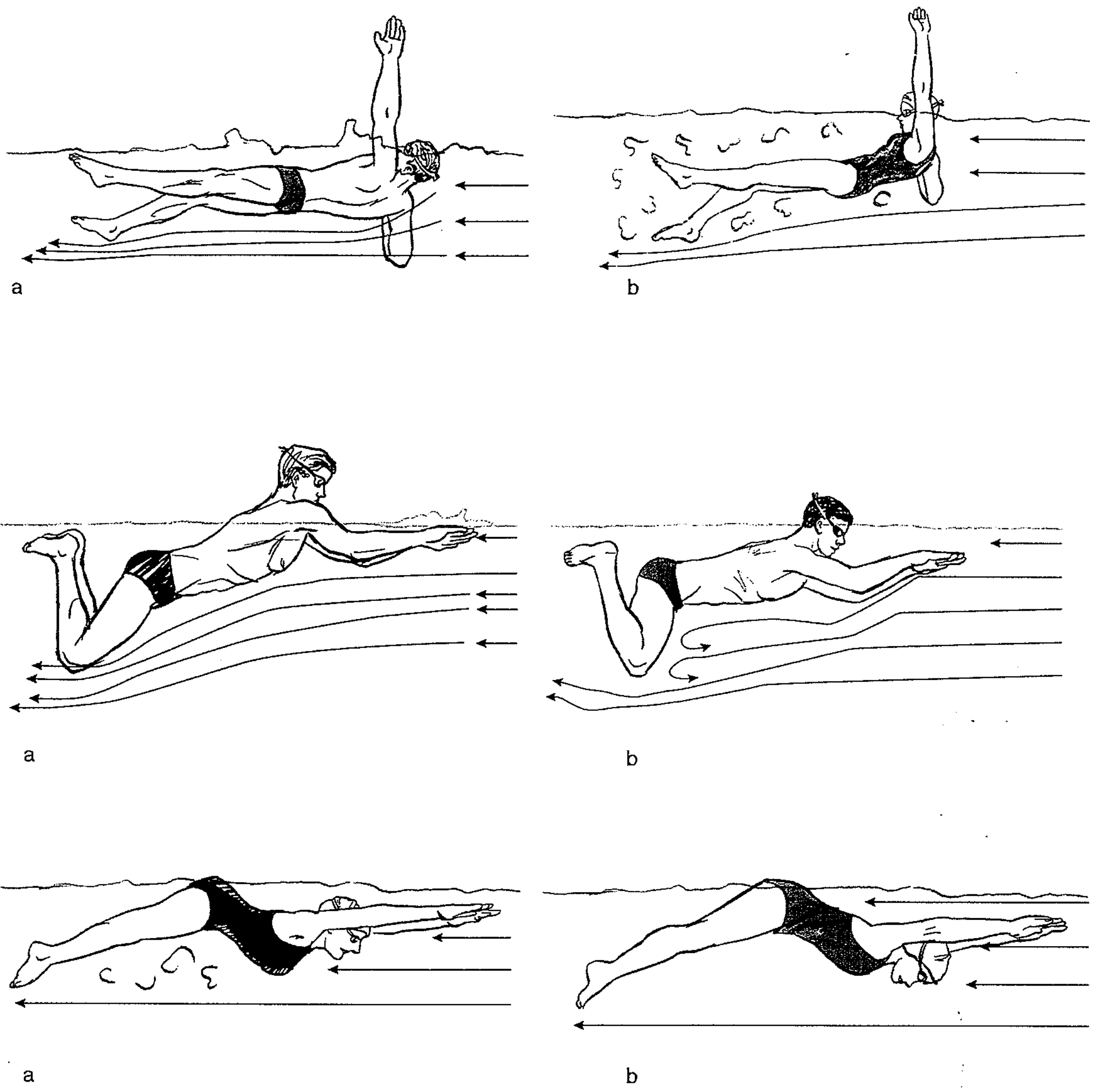


Figure 2.4 Good and poor horizontal alignment in the backstroke, breaststroke, and butterfly. The swimmers in *(a)* show good horizontal alignment, while examples of poor horizontal alignment for each of the strokes is shown in *(b)*.

into the water. Poor horizontal alignment can result from kicking too deep and/or dropping the hips too deep when they undulate downward. As will be explained, swimmers in both strokes will be propelled forward by wave action during the arm recovery if they undulate the body properly. They will lose that source of propulsion if they undulate excessively, however. I will have more to say about wave action in chapter 3.

Lateral Alignment. Excessive lateral motions will also increase form drag. Body parts, particularly the hips and legs, that swing laterally outside the water space occupied by the trunk will cause swimmers to encounter more water and, thus, more resistance as they move forward. Poor lateral alignment will only be a problem in the front and back crawl strokes, in which the alternating movements of the arms and legs have the potential to move the body through the water in a wiggling or snaking motion.

The illustrations in figure 2.5 show top views of front crawl swimmers with good and poor lateral alignment. The swimmer in figure 2.5a is streamlined while the one in figure 2.5b is wiggling excessively from side to side. These side-to-side movements of the hips and legs cause her to take up much more space in the water than the swimmer in *(a)*. Additionally, the side-to-side body movements cause her to push water sideward and forward. Both actions will increase resistive drag dramatically.

Additional Techniques for Reducing Form Drag. Front-crawl and butterfly swimmers who recover the arms high and overhead can easily disrupt their horizontal alignment. The weight of the arms will push the torso deeper into the water. Front-crawl swimmers should recover each arm to the side somewhat and it should be recovered with a flexed elbow to displace some of its weight outside the body. Butterfly swimmers should recover the arms to the sides for the same reason. Backstroke swimmers should recover the arms straight overhead, despite the detrimental effect this will have on their horizontal alignment. The alternative, recovering the arms to the sides, would disrupt lateral alignment even more.

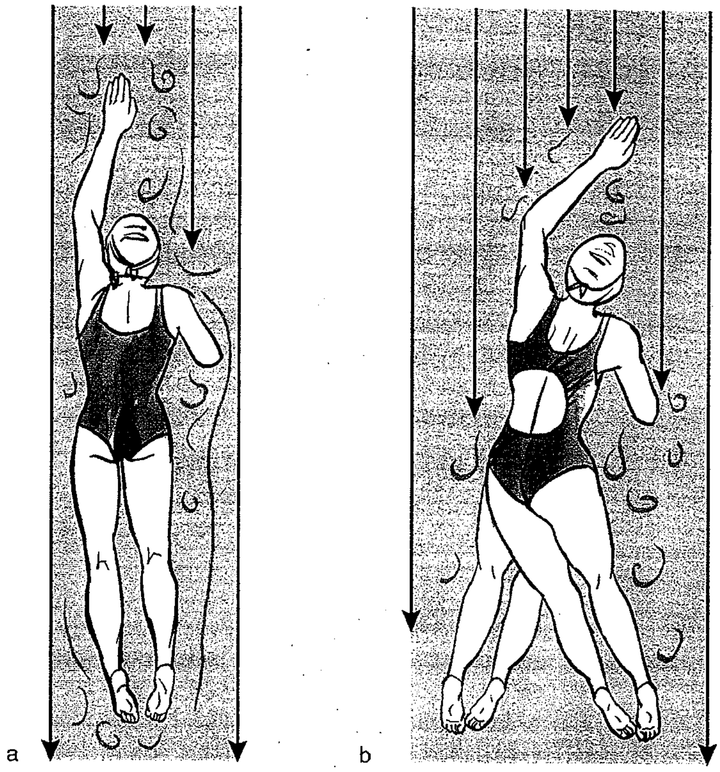


Figure 2.5 The effect of excessive side-to-side body movements on drag in the front crawl stroke. The swimmer in *(a)* has good lateral alignment. She is moving through a smaller space in the water because she is rolling from side to side. Contrast this with the swimmer in *(b)* whose hips and legs are swinging outside her shoulders.

In their efforts to swim fast, some swimmers use a number of incorrect stroking movements that can cause the body to swing from side to side. Backstroke and front-crawl swimmers can disrupt lateral alignment by swinging the hands across the midline of the body as they enter the arms into the water. Front-crawl swimmers can also disrupt lateral alignment by pulling the arms too far across the midline during the underwater phase of their armstrokes.

Both front-crawl and backstroke swimmers can cause the hips and legs to swing from side to side by recovering the arms over the water in a wide, lateral manner. A vigorous circular sideward swing of the recovering arm will tend to pull the hips outward and in the direction the arm is moving. Front-crawl swimmers need to use a high elbow recovery that minimizes the outward movements of the arms during recovery. As mentioned earlier, backstrokers should recover the arms directly overhead in an extended position to minimize the outward movements of the limbs and the resulting effect on lateral body alignment. Butterfly swimmers can recover the arms around to the sides without disrupting their lateral alignment. The potentially disruptive effect of swinging one arm to the side will be counteracted by a simultaneous outward swing of the other arm, in the opposite direction, so that the hips will not be pulled out to the side but will continue moving forward in a straight line.

Front-crawl and backstroke swimmers can also disrupt lateral alignment by pushing the arms out to the side excessively during the first part of their underwater armstrokes. A vigorous outward push of one arm will tend to push the body toward the opposite side. As will be explained in chapter 3, swimmers in these strokes cannot avoid moving the arms out to the sides, even somewhat, early in their underwater strokes. They must do so to place the arms in a good position to apply propulsive force as early as possible. Nevertheless, swimmers in both strokes should not move the arms out to the sides more than necessary to make a good catch, and under no circumstances should they vigorously push the arms to the side while making that catch.

Butterfly and breaststroke swimmers should sweep the arms out to the sides even more than front-crawl and backstroke swimmers when they make the catch. They do not need to be concerned about those sideward sweeps disrupting lateral body alignment for the same reason described with respect to arm recovery. Simultaneous sideward motions of each arm that are made in opposite directions cancel any tendency for their outward movement to push the body from side to side. Because strong outward pushes could decelerate forward speed, however, like in other strokes, outward movements of the arms should be gentle until the catch position has been reached.

Body Shaping and Form Drag

As indicated earlier, the shapes swimmers present to the water have a profound effect on the form drag they produce. Tapered objects encounter less water resistance than objects with square corners and convoluted shapes because they permit the streams of water molecules in front to change directions gradually as swimmers pass through them and the water is also permitted to fill in gradually behind. To minimize turbulence, and therefore form drag, streams of water molecules should be pushed out of the way gradually, not suddenly, as swimmers pass through them. Once the hole has been opened, the water should be allowed to fill in gradually behind the swimmers.

Filling in takes place because of pressure differentials. Streams of water molecules are pushed from areas where the pressure is greater toward areas of lower pressure, in this case, the area swimmers have just passed through. Because of this, the water will fill in gradually, not instantaneously, behind swimmers.

Bullet-shaped objects, characterized by a small frontal area that gradually widens at the middle and then tapers to a small rear area, produce the least amount of form drag as they move through the water. The tapered front end gradually displaces the streams of water molecules as the object passes through them, minimizing turbulence and reducing the number of adjacent streams away from the object that are affected by its movement. Therefore, the water pressure will not increase as much immediately in front of the object and the retarding effect of that water will not be as great. The tapered rear area allows the streams of water molecules to start filling in as soon as the widest part of the object has passed through. So, they fill in space the swimmer has just passed through much faster. This reduces the size of the low-pressure area of eddy currents in back, which tends to hold swimmers back. The effect of tapered shapes on form drag is illustrated by the bullet-shaped object in figure 2.6a. The effect of untapered shapes is illustrated by the rectangular-shaped object in figure 2.6b.

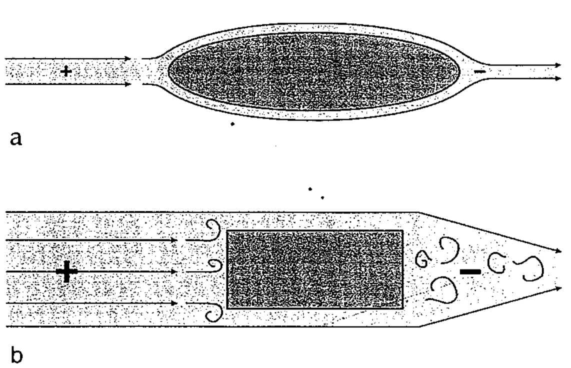


Figure 2.6 The effect of shape on drag. The cylindrical object in *(a)* has an excellent shape for reducing form drag because it is tapered at both ends. The object in *(b)* has a poor shape for reducing form drag, despite the fact that is has exactly the same surface area as the object in *(a)*. Its flat ends increase the number of laminar streams disrupted in front and increases the time required for laminar flow to be reestablished in back.

Adapted from Prandtl and O.G. Tietgens 1957.

In figure 2.6b, the large, square front end presents a flat surface to the front wall of water, causing it to encounter several streams of water molecules simultaneously. The effect is like throwing water against a wall. Those streams of water molecules are thrust back, up, down, and to either side of the object in a sudden random manner, causing them to collide with other molecules in an ever widening area of adjacent streams. This creates a great deal of turbulence that markedly increases the pressure in front of the object and retards its forward speed.

The square rear end of the box in figure 2.6b prevents these disrupted streams of water molecules from filling in until the object has passed completely through them. This results in a large, low-pressure area of eddy currents behind the object where the streams have not yet filled in. Because the process of filling in is gradual, this low-pressure area persists for a longer time after the object has passed through. The combination of a large increase of water pressure in front and an equally large and longer-lasting decrease of pressure behind will create a pressure differential between the front and rear of the object that will have a profound retarding effect on its forward motion.

Over the years, the shapes of boats, cars, airplanes, and other objects that travel through air and water have become progressively more tapered in front and back, and their form drag has been reduced considerably because of it. Unfortunately, the human body is not naturally tapered. Furthermore, swimmers cannot remain in a static position as they move through the water. They change positions constantly, presenting a variety of different shapes to the water in front and to the sides of their bodies. To counteract these disadvantages, it is important for swimmers to present the most tapered shapes they can to the water during the various phases of each stroke cycle. To do so, swimmers should try to apply the following two general rules in all strokes.

1. Swimmers should attempt to slide the entire body forward through the holes they open with the arms when the arms enter and slide forward through the water in front of them. The size of these holes can be thought of as encompassing the width and depth of the shoulders and trunk. Any non-propulsive body movements below that depth or outside that width will increase form drag.

2. Swimmers should attempt to slip the smallest and most tapered surface of all body parts forward through the water. The only times they should present flat surfaces to the water are when they are pushing back against it to accelerate the body forward. In particular, the hands should leave the water with the little finger leading, they should enter the water fingertips first, and they should slide forward with fingertips leading. Breaststrokers should keep the thighs tapered back during leg recovery.

Body Roll and Form Drag

The need to create propulsive forces does not permit athletes to stay in perfect horizontal and lateral alignment as they swim down the pool. Front-crawl and backstroke swimmers must roll the body from side to side to gain propulsive force, while breaststroke and butterfly swimmers need to move the body up and down in an undulating manner for the same reason. Rolling and undulating will increase form drag to some extent, but they increase propulsion even more. Consequently, in order to swim fast, athletes must balance the need to stay horizontally and laterally aligned with the need to apply propulsive force. Swimmers can go overboard with either effort, however. They can move the body around more than necessary in their desire to apply propulsion. By the same token, attempts to maintain the body in a static position that reduces resistive drag can reduce propulsion even more.

Some experts believe that rolling actually reduces form drag by allowing front-crawl and backstroke swimmers to spend more time on their sides, where they take up less space in the water. I suspect that side body positions produce at least as much, if not more, resistive drag as prone body positions, however. A flat torso that is horizontal with the surface should not necessarily take up more space than one turned to the side. In fact, in studies where passive drag has been measured, it was greater when swimmers were towed on their sides than when they were towed in a prone position (Counsilman 1955).

Swimmers who are on their sides may actually take up more space in a vertical direction than swimmers who are flat take up horizontally. Additionally, the act of rolling the body from side to side probably increases resistive drag compared to maintaining a prone position. Nevertheless, front-crawl and backstroke swimmers should roll the body from side to side, because doing so improves the propulsive force they can apply with the stroking arm and it facilitates the recovery of the other arm. These two advantages probably outweigh any increase in resistive drag caused by rolling. Swimmers in these strokes should not roll excessively from side to side under the mistaken notion that they are reducing form drag. The amount of body roll should be dictated by the vertical movements of the arms. Those movements should not be minimized in order to reduce rolling, nor should swimmers increase the vertical movements of the limbs beyond what is needed for efficient stroking simply to increase body roll.

The effect that rolling the body from side to side has on maintaining lateral alignment in the front crawl and backstroke will be described in this section because it is so important to efficient swimming. Illustrations like the ones in figures 2.3 through 2.5 really oversimplify the complex process of reducing form drag. Swimming is a dynamic activity where the body is constantly changing positions during every stroke cycle. Swimmers must reduce form drag to facilitate the application of propulsive force and reduce the potentially disruptive effects arm movements can have on horizontal and lateral alignment. Swimmers in the front and back crawl strokes really don't have a choice between rolling and swimming flat, even if flat body positions produce less form drag. Their choice is to roll or wiggle.

The body will swing from side to side if swimmers try to flatten body position as they travel down the pool. Because the body is suspended in the water, the up and down movements of the arms exert forces on the torso that cause it to follow in the same direction. If swimmers try to prevent the trunk and hips from rolling up and down in the same directions as the arms, the trunk and legs will swing out to the side.

The photos in figure 2.7 show swimmers at the point of maximum roll in the front crawl and backstroke. As shown, their bodies are rotated considerably from the horizontal. They will roll at least as much to the other side during their next armstrokes.

Rolling aids front-crawl and backstroke swimming speed in a number of ways. It allows swimmers to place the arms in more effective positions for exerting propulsive force and it permits them to kick diagonally, which helps to stabilize the trunk during alternating arm motions. It also minimizes lateral movements of the trunk, hips, and legs, as mentioned earlier.

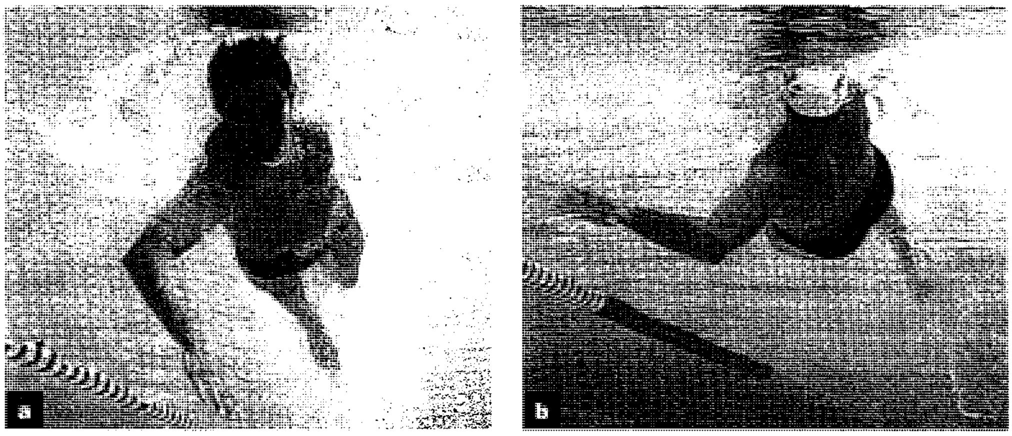


Figure 2.7 Front-crawl *(a)* and backstroke *(b)* swimmers at the points of maximum roll during their respective stroke cycles.

Front-crawl and backstroke swimmers should allow the body to follow the lead of the arms during the various phases of each stroke cycle. The action of rolling the body should be continuous throughout the stroke cycle, without hesitation or restraint. The body should always be rolling toward one side or the other. It should only be flat momentarily as it passes through the horizontal while rolling from one side toward the other. Swimmers should allow the shoulders and hips to move downward freely when the arm on the same side is moving downward, and they should allow them to roll upward with no delay when the arm is traveling upward. The right and left arms will always travel in opposition to one another during each stroke cycle in these two strokes. That is, one arm will be traveling downward while the other is moving upward. Therefore, the right and left sides of the body should also be moving in opposition to one another.

Ways That Rolling Can Increase Swimming Speed

- By placing the arms in better positions to deliver propulsive force
- By allowing diagonal kicking that stabilizes the body
- By minimizing lateral movements of the body

Buoyancy and Form Drag

It has long been assumed that greater buoyancy will reduce form drag. While the center of mass of swimmers is located in the hip area, the center of buoyancy is located in the area of the chest, where the lungs and, thus, the largest component of body air are located. Because this balance point is high on the trunk, the legs will tend to sink unless they have good buoyancy. Particular swimmers' buoyancy can easily be determined by having them lie in a prone position on the surface of the water with arms stretched overhead and legs extended behind. If the swimmers are very buoyant, their bodies will remain horizontal. If they are not, their legs will sink. The legs of somewhat buoyant swimmers will sink until they are somewhere between their previous horizontal position and a vertical position, but the swimmers will remain afloat. If swimmers are not at all buoyant, their legs will sink and pull the rest of the body under with them.

In the past, the influence of buoyancy on reducing resistive drag has been largely taken for granted. Now, however, several studies substantiate the belief that improved buoyancy will reduce resistive drag. Two separate studies, Pendergast et al. (1977) and Watkins and Gordon (1983), suggested that the legs of males tended to sink more readily than those of females when subjects of both genders had no support for their legs and pulled themselves through the water using only their arms. On average, females are more buoyant than males, which may be one reason more women use two-beat kicking rhythms. Because they are less buoyant, the majority of males probably require stronger two-beat kicks, two-beat crossover kicks, or four-beat and six-beat kicks to keep their legs near the surface when they swim.

It is common knowledge that an increase in the fat content of the body will improve buoyancy. This does not mean, however, that swimmers with more body fat have an advantage or that swimmers should try to increase body fat. More body fat means an increase in body surface area, which will increase form drag. Consequently, attempts to increase buoyancy by adding body fat may very well result in an even greater increase of form drag. Also, because muscle propels swimmers through the water, it stands to reason that they should train to be lean. This will provide greater propulsive force that should offset any slight reductions in buoyancy.

Swimming fast, in itself, will improve buoyancy somewhat, but apparently it does not completely negate the advantage of natural buoyancy. Velocity tends to improve buoyancy because of the upward force exerted by the water that swimmers push downward as they pass through it. Nevertheless, swimmers who lack buoyancy may need to kick somewhat more vigorously to keep their legs up. Being conscious about maintaining the upper body low in the water and horizontal with the surface during each of the competitive strokes will also help keep the legs elevated.

Pushing Drag

Pushing drag is a term used to identify a special form of wave drag. I chose to call attention to it because it has perhaps the most significant retarding effect of all forms of water resistance. In this case, swimmers apply Newton's action-reaction law in a way that works against them. They do this by pushing water forward, upward, downward, or to the sides with the trunk and limbs. The counterforces produced when swimmers push water in directions other than backward will tend to push the body in the opposite direction unless they are offset by other forces. One of the most common ways that swimmers produce pushing drag is by pushing the arms and legs forward vigorously against the water. For example, breaststroke swimmers will push some water forward with the hands and arms as they stretch during arm recovery. The backward counterforce produced will negate some of the propulsive force from the kick such that the body will not accelerate forward quite as rapidly as they might have. This is why it is so important for swimmers of all strokes to slide the hands and arms forward in a gentle and streamlined manner.

Figure 2.8 A butterfly swimmer creating interference drag during arm entry.

Front-crawl and butterfly swimmers who drag the arms forward through the surface of the water during recovery movements will also slow their forward velocity through the mechanism of pushing drag. Worse still is the effect on forward velocity when butterfly, front-crawl, and backstroke swimmers smash the arms into the water and push them forward in poorly streamlined positions. The photograph in figure 2.8 shows one way that recovery movements can increase resistive drag. The butterfly swimmer is making the all-too-common mistake of pushing her arms forward and in as her hands enter the water. *Swimmers who drag the arms through the water in this manner will reduce their speed by 30% within 1/16 sec.* This reduction of forward speed, when multiplied by several strokes over the length of a race, can have a devastating effect on performance.

Actually, the most extreme example of the slowing effect that pushing drag can have on forward velocity occurs during leg recovery in the breaststroke. The counterforce breaststrokers produce when they push the legs down and forward against the water can actually bring their forward velocity to a momentary standstill. Front-crawl, butterfly, and backstroke swimmers who kick incorrectly can also create resistive drag, in addition to minimizing propulsive force. Any pedaling motions that cause the thighs to push forward against the water will slow forward velocity.

Kicking too deep can also cause pushing drag in the front crawl and butterfly. When swimmers kick deeper than they need to in order to gain propulsion, they not only increase the space they take up in the water, but they also push some water forward with the legs. The drawing in figure 2.9 illustrates the retarding effect of kicking too deeply. Foot kick patterns show that swimmers who kick too deep actually push the feet forward through the water during the last portion of their downbeats. This will, of course, create a counterforce that reduces forward velocity.

When swimmers push downward or upward against the water with the limbs, the counterforce tends to push the body upward or downward in the opposite direction and decelerate their forward speed. As explained in chapter 1, however, upward and downward limb movements are essential to propulsion and stroke continuity. These vertical motions should not be excessive, nor should they be executed with great force

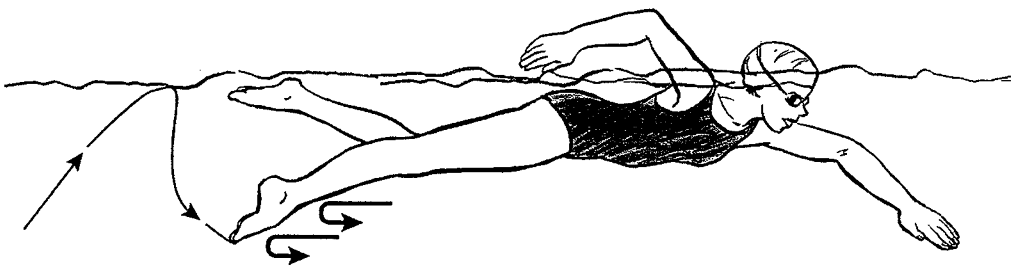


Figure 2.9 The effect of kicking too deeply on resistive drag.

unless the limbs are also moving backward during a propulsive phase of the stroke cycle. To put this more specifically, swimmers in the front crawl and backstroke should move the arms downward to the catch as gently as possible. They should also allow the fingertips to lead the motion in order to improve the streamlined shape of the hands.

Front-crawl and butterfly swimmers should not push up against the water with the arms during the last several inches before the arms leave the water. The propulsive phase of the armstrokes in these two swimming styles are completed several inches below the surface when the arms stop moving backward and start recovering forward. In effect, pushing upward against the water before the hands reach the surface pushes water up and forward. I will describe the detrimental effect of this all-too-common, but nonetheless incorrect, stroke technique in more detail in the next chapter.

Sideward movements of the legs and arms are also an integral part of the four competitive strokes. Sideward leg movements probably have a stabilizing effect on the torsos of front-crawl and backstroke swimmers. In addition to the propulsion they supply, the legs probably counterbalance the vertical and lateral movements of the arms so that the trunks and hips of these swimmers are not pushed excessively upward, downward, or sideward.

Sideward movements during the propulsive phases of the armstroke are necessary. Swimmers use them to position the arms to apply propulsive force more effectively. They should not make a conscious effort to push water inward or outward, however. Excessively long or powerful sideward motions tend to push the bodies of front crawl and backstroke swimmers out of lateral alignment and increase their resistive drag.

Front-crawl and backstroke swimmers must be cautious when they slide the arms downward and outward during the first third of their underwater armstrokes. These are not propulsive phases of the stroke, and if they push the hands and arms outward with too much force, the counterforce will push the body out of alignment in the opposite direction and increase resistive drag. Consequently, they should keep their lateral motions to a minimum, and these motions should be made gently and lead with the fingertips for better streamlining until the arms reach the catch position. Then, and only then, should they apply a large amount of backward force.

For breaststroke and butterfly swimmers, the largest sideward arm movements take place during the first portion of the underwater armstrokes. They slide the hands and arms out in order to position them to push water backward. The counterforces produced by simultaneous outsweeps of the arms will cancel one another so that swimmers in these strokes will not push the body out of lateral alignment. Butterfly and breaststroke swimmers are prone to use too little, rather than too much, lateral arm movement during the propulsive phases of their armstrokes. They generally need to sweep the hands outward more beyond shoulder width for this purpose. Those sideward movements before the catch should be made gently and in a streamlined manner, however. A large amount of sideward force will reduce forward velocity, even if it does not disrupt lateral alignment. Additionally, the force produced is unnecessary and will only predispose swimmers to fatigue earlier in their races.

Wiggling, or snaking, down the pool can be a cause of pushing drag in the front crawl and backstrokes. As indicated earlier, these same movements increase form drag by increasing the space swimmers take up in the water. At the same time, however, they also cause them to push water outward and forward with the trunk and hips. Clearly, then, wiggling will have a very profound retarding effect on forward velocity.

Interference Drag

Movements of the trunk and limbs disturb the water around them, setting it in motion and causing it to become turbulent. Other body parts that are in close proximity will be affected by that turbulence such that the resistive drag they encounter will be increased. Two examples of interference drag are

- the effect the movement of one leg will have on the other as they pass one another during the flutter kick, and
- the effect the underwater movements of the arms will have on the trunk as the arms sweep in and out from underneath the body.

Very little is known about the effect of interference drag on competitive swimmers. At the present time, there are no studies that address its effect on swimming speed. It seems obvious, however, that there should be some consequence when one body part moves through water that has been disturbed by another body part. It seems reasonable to assume that unnecessary, vigorous, forceful movements of any body parts should retard forward speed through the mechanism of interference drag. Consequently, a vigorous snaking of the trunk or legs should interfere with propulsion. By the same token, if the arms push water forcefully and unnecessarily into the trunk, interference drag should retard forward speed. Finally, vigorous upward movements of the legs in the flutter kick as well as kicking wide unnecessarily should exert a retarding effect on forward speed through the mechanism of interference drag, simply because the other leg must deal with additional water turbulence for a longer period of time.

Frictional Drag

As swimmers move forward, friction between the skin and the water causes a stream of water molecules in contact with the skin. Those water molecules are pulled along with the skin and, in turn, exert a frictional effect on molecules in adjacent streams, pulling them along as well. This pattern will continue in layer by layer of adjacent water streams until, at some distance from the body, the amount of friction between water molecules is insufficient to cause any further effect. Those streams of water that are pulled forward with the body are collectively known as the *boundary layer.* The boundary layer will increase the work required for swimmers to accelerate the body forward because of the added mass of water they are pulling along with them.

The boundary layer is certain to be pulled away from the body within a very short time, however, because the water molecules being pulled forward will collide with other molecules immediately in front of it. The water molecules that were pulled away will rebound randomly into the paths of adjacent streams, creating a widening path of turbulence. When the amount of turbulence becomes sufficiently large, the boundary layer is said to separate. That is, the layers of water molecules that were being pulled along by the swimmers will now be swirling around them in a wild and random manner. Unfortunately, this simply trades the retarding effect of the added water mass being pulled along for an even more potent form of resistive drag. The resulting turbulence increases the pressure immediately in front of and to the sides of swimmers, and the pressure differential between front and rear will reduce their forward velocity unless they apply enough additional propulsive force to maintain it.

The photograph and drawing in figure 2.10 illustrate how boundary layers react to frictional forces. The photo shows the actual movement of fluid past a foil that has been

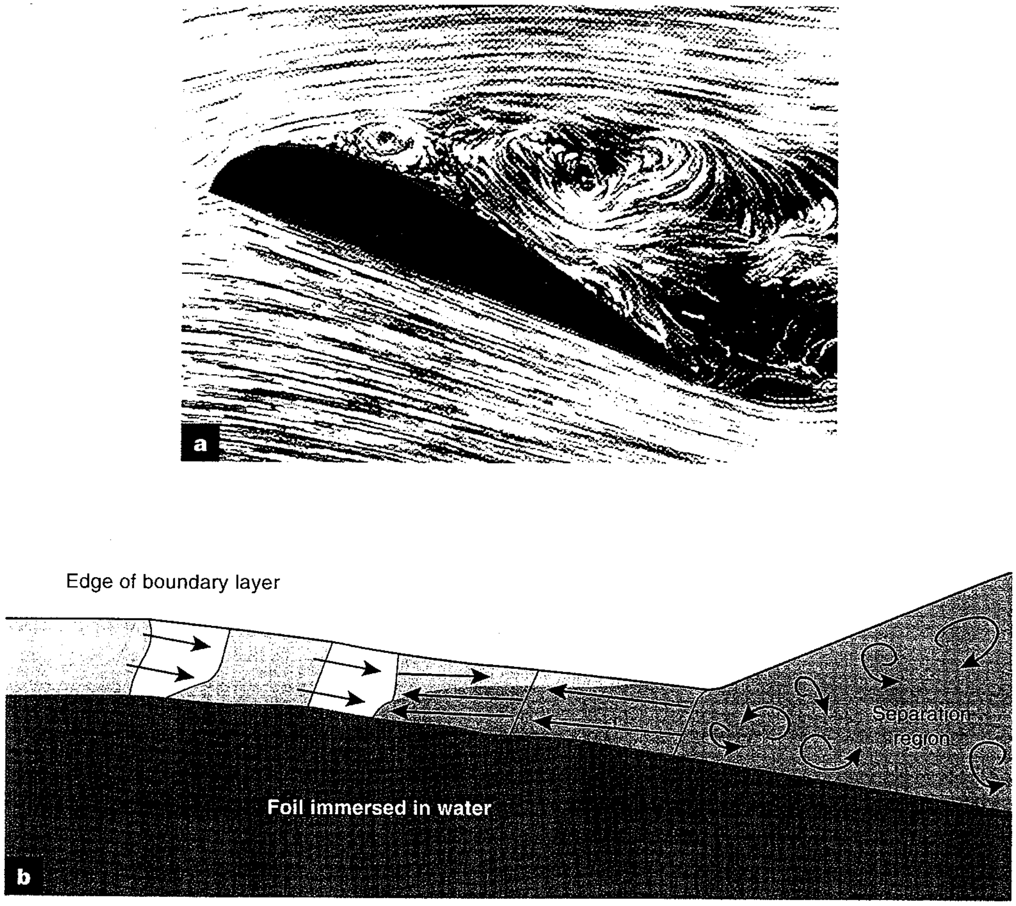


Figure 2.10 The effect of frictional drag on the boundary layer. Photo *(a)* shows the actual movement of fluids around an immersed foil. Drawing *(b)* depicts the reason for the increasing turbulence of that fluid.

Adapted from Prandtl and O.G. Tietgens 1957.

immersed in an air tunnel. Notice the circular area of turbulence at the rear. This is where the boundary layer has separated. The drawing illustrates the movements of water molecules that cause the boundary layer to separate. First of all, the foil surface creates friction, which will cause a boundary layer of fluid to reverse directions and travel with it. Then, when the water molecules in that boundary layer immediately collide with others, both behind and to the side, they create a pattern of turbulence that, at some distant point, will cause the boundary layer to separate completely from the surface of the foil.

Some researchers believe that frictional drag is negligible where swimmers are concerned, because humans are so poorly streamlined that wave and form drag cause the boundary layer to separate almost immediately when water starts around their bodies (Clarys 1979). Hay and Thayer (1989) conducted a study that refutes this opinion, however. They were able to study the pattern of water flow around the body by attaching plastic tufts to it. When swimmers were filmed underwater, the waving motion of the tufts demonstrated the direction of the water in the boundary layer. These researchers concluded that an intact boundary layer could be maintained on certain surfaces of the body as swimmers moved forward through the water. A swimmer with tufts is shown in figure 2.11. This swimmer is doing the dolphin kick with a kickboard. You can see areas on the front of her trunk, on her thighs, and on her lower legs where the tufts are uniformly pressed back against these surfaces.

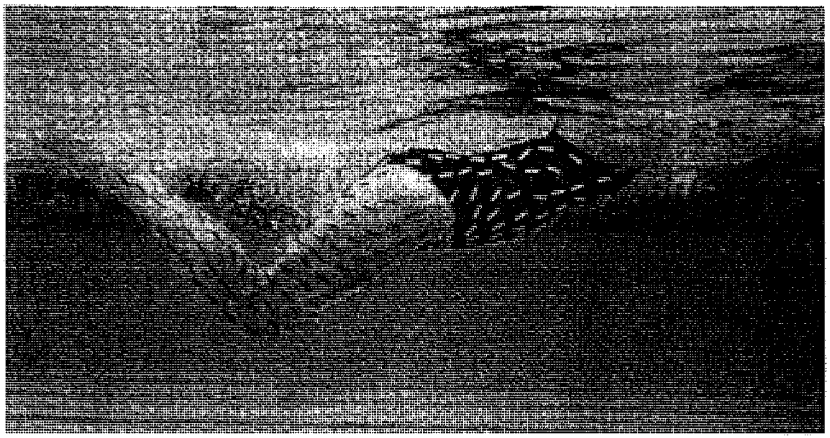


Figure 2.11 A swimmer wearing tufts.

Reprinted from Hay and Thayer 1989.

The principal factors that influence the amount of frictional drag exerted on objects are

- the surface area of the object,
- the velocity of the object, and
- the roughness of its surface.

Swimmers have no control over surface area. Likewise, speed can only be controlled to the extent that early portions of a race can be paced. That leaves surface smoothness as the source of frictional drag most amenable to reduction.

Obviously, smooth surfaces cause less friction than rough surfaces. Smooth surfaces reduce the friction between the water and the skin so that swimmers pull fewer water molecules along with them in the boundary layer. That, in turn, results in less turbulence when the boundary layer separates. This may explain why swimmers almost universally improve their performances when they wear low-friction suits, such as the new bodysuits that cover a large area of the body, and when they wear caps that shape their heads more hydrodynamically and reduce the drag of flowing hair. It also explains why swimmers improve their times when they shave down before important contests.

Regarding shaving, or *shaving down*, as many competitive swimmers call it, swimmers have learned over the years that removing body hair will improve their times by 0.50 to 2 sec per 100 m. Experts disagree, however, as to the reason for this improvement. Some believe it is due to a reduction in frictional drag. Others believe that any improvements are due instead to psychological factors or improved feel for the water.

Sharp and Costill (1989) have presented strong evidence suggesting that shaving down does reduce frictional drag. They tested a group of swimmers by having them complete sub-maximal time trials at identical speeds. These time trials were paced in exactly the same way, both before and after shaving body hair, by using a pacing machine. After shaving down, the swimmers completed their paced swims with significantly lower blood lactate values and greater stroke lengths. Average blood lactate values for the group decreased from 8.48 mmols/L before shaving to 6.74 mmols/L after shaving for swims of exactly the same time and pace. Average stroke length increased from 2.07 m/stroke cycle before shaving to 2.31 m/stroke cycle after shaving. The control group did not improve on either measure. There were nine days intervening between the unshaved and shaved testing periods, so the conditioning level of the swimmers was not likely to have changed.

It was possible to ascribe the results these researchers reported to improved feel for the water. Consequently, Sharp and Costill had the subjects participate in another test, this one designed to show that improvements on the time trials were due to a reduction of frictional drag. Both the experimental and control groups completed identical swims before and after shaving down. In this case, however, the swims were tethered and the energy costs of the before and after trials were compared. The reason for the tethered swims was to eliminate the effect of frictional drag. The swimmers could not pull water along with them if they were not moving through the water. Thus, if the swimmers improved their performances on the tethered swims after shaving down, it would most likely be due to improved kinesthetic feel. And if their performances on the tethered tests did not improve after shaving down, that would be a good indication that the improvements they had made on the earlier time trials were probably due to reduced frictional drag. The energy cost for the before and after tethered swims was assessed by measuring and comparing oxygen consumption during several incremental stages of work.

The swimmers did not reduce their energy cost during the tethered swimming tests after shaving down. Apparently, shaving down did not improve their feel for the water. Otherwise, the swimmers would have stroked more efficiently and the energy cost would have been lower on the tethered swims after removing their body hair. The authors therefore concluded that a reduction of frictional drag, as a result of shaving down, seemed the logical cause for the lower blood lactate concentrations and the increases in the average distance per stroke.

There are other methods, in addition to shaving, that swimmers can use to reduce frictional drag. Wearing swimsuits made of low-friction fabrics is one of these. It seems that new low-friction materials are being developed every several months. Some fabrics are touted as having less frictional drag than human skin. It remains to be proven whether or not these claims are true, because present methods for measuring the frictional drag of fabrics lack sufficient validity to provide an authoritative finding. Several studies have shown that passive drag is reduced when swimmers are towed through the water while wearing some of the new partial- and full-body swimsuits. Those comparisons were made with the passive drag of unshaved swimmers, however. To my knowledge, at the present time, there is no published evidence that passive drag is lower when the values of shaved swimmers are compared both with and without the bodysuits.

Low friction or not, swimsuits that fit snugly should reduce frictional drag through their effect on body shaping. On the plus side, these suits can streamline the body by reducing the size of bulges at the chest and hips. On the negative side, the additional thickness of the fabric could increase the circumference of body parts and, in doing so, increase form drag. Perhaps, when the methodology for measuring active drag has been perfected, we will be able to say conclusively whether certain fabrics and suit styles reduce frictional drag more than shaved skin. Until then, swimmers will have to make their judgments based on feel and performance. Any suit they choose should fit snugly, however. It should not have any pockets or loose areas that can catch water. Seams should be kept to a minimum and be no more obtrusive than necessary to hold the suit together, and the suit should not restrict limb or body movements in any way.

Wearing swim caps is another way to reduce frictional drag. As mentioned, caps can streamline the head and present a smoother surface to the water than does a head of waving hair. Caps, like suits, should be constructed from materials that have minimal friction, they should be seamless, and they should fit smoothly with very few wrinkles where water could get caught and buffeted about.

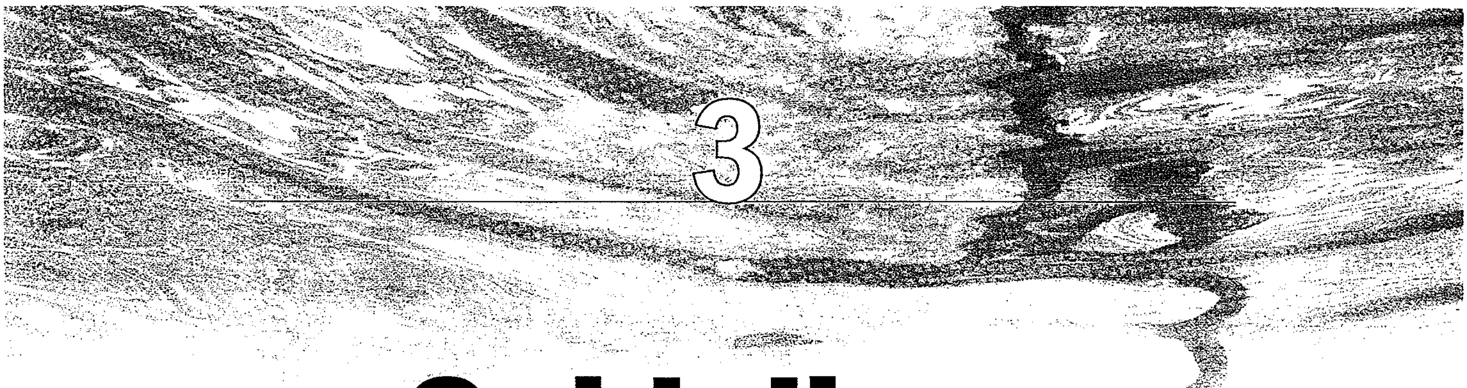
Recently, swimsuits and caps with roughened surfaces have been introduced. This is because a small amount of uniform roughening on a surface tends to cause the boundary layer to separate somewhat later, which results in less turbulence around the object. A roughened surface causes the formation of *bubble vortices,* areas where the boundary layer detaches and then reattaches over an object's surface. The formation of bubble vortices has the effect of delaying the complete separation of the boundary layer from an object.

The best example of the manner in which a roughened surface can be used to maintain an intact boundary layer for a longer period is the dimpled surface of a golf ball. The roughness of the surface causes the formation of bubble vortices and, in so doing, a later separation of the boundary layer around the ball. With the boundary layer separating later, the area of eddy currents behind the ball will be smaller and it will fill in faster. This, in turn, reduces the cavitation effect on the ball so that it will travel farther through the air. It may be possible that some roughening of the surface of swimsuits and caps could delay complete separation of the boundary layer and therefore reduce frictional drag. There is no way to be sure, however, because the methods for testing this effect are not as yet sophisticated enough to make a confident determination.

Reducing Resistive Drag by Pacing

The simple act of swimming faster will increase resistive drag, even when athletes are swimming very efficiently. When swimmers push the body forward against the water with greater velocity, the water will push backward with greater resistive force. For example, as indicated earlier, any small increase in velocity will cause resistive drag to increase by a factor of 4. Thus, swimmers encounter more resistive drag when they swim faster.

The effect of speed on resistive drag may seem academic, because it would be foolish for an athlete to swim slowly and lose races simply to reduce water resistance. There is, however, one application of this information that supports the wisdom of pacing races slowly in the beginning. An athlete who swims the first half of a race at a slower speed should expend less effort to overcome resistive drag. Consequently, that swimmer may be able to win the race by finishing faster, provided, of course, that they remain close enough to overtake their competitors and that those competitors are more fatigued from swimming faster early in the race. This observation, of course, is highly theoretical. Many factors, in addition to proper pacing, are involved in winning races. Nevertheless, saving energy by pacing properly should be a consideration when planning a race.



3

Guidelines for Increasing Propulsion and Reducing Resistance

New in this edition:

- A description of the arm sweeps and leg movements based on drag-dominated propulsion
- A discussion of body roll and swimming propulsion
- A description of wave propulsion in the four competitive strokes
- A discussion of the body wave and reverse body wave
- Expanded guidelines for reducing resistive drag

The purposes of this chapter are threefold:

1. to describe how swimmers apply drag-dominated propulsive force,
2. to discuss specialized topics that have a bearing on swimming propulsion, and,
3. to suggest general guidelines for effective swimming in all of the competitive strokes.

Propulsion From the Arms

One of the most common misconceptions in the swimming community is that swimmers alternately flex and extend the arms during the propulsive phases of their underwater strokes. In fact, arm flexion changes very little when swimmers apply propulsive force. This misconception is our first topic of discussion.

Arm Flexion and Extension

Do swimmers really flex and extend the arms during the propulsive phases of their underwater strokes? In three of the four competitive strokes, the answer to this question is no. The only exception is the backstroke, in which swimmers do extend the arms during their underwater strokes. The amount of arm flexion and extension is actually quite minimal when swimmers are accelerating the body forward in the front crawl, butterfly, and breaststroke. So there will be no confusion about this point, swimmers do extend the arms during the various recovery movements in some strokes. These actions take place before or after, not during, the propulsive phases of the various underwater strokes.

The arms are flexed approximately 90° during the first propulsive phase of the four competitive armstrokes. The misconception is that swimmers begin those phases with the arms extended and then gradually flex them throughout the first half of their underwater strokes, with arm flexion attaining its maximum value of approximately 90° as the arms reach the midline of the body at mid-stroke. In actuality, the arms are flexed nearly 90° before they begin applying propulsive force. After that, changes in arm flexion are minimal throughout the remainder of their propulsive phases. Put another way, nearly all of the arm flexion that occurs during the various underwater armstrokes takes place during the first, non-propulsive phase as the hands and arms move toward the catch position. Arm flexion changes minimally after that.

The photos in figure 3.1 show the amount of arm flexion used by Francisco Sanchez, a world-class front-crawl swimmer, at three different points during his right underwater armstroke. The graph accompanying these photos shows the velocity of his center of mass during that stroke. The letters *a*, *b*, and *c*, which are marked at points along the graph, correspond to the stroke phase depicted in the photo marked with the same letter.

Francisco is shown at the catch position in photo *(a)*, and at mid-stroke in photo *(b)*. In photo *(c)*, he is midway through the final out-, back-, and upsweeps of his underwater armstroke. Notice that his right arm is already flexed nearly 90° at the catch, and that it remains flexed approximately the same amount at mid-stroke and also as he is completing the propulsive phase of his underwater armstroke. As the velocity graph shows, he does not begin to accelerate forward until his arm reaches the catch position, so the arm flexion clearly occurs before he begins to apply propulsive force. After the catch, his velocity increases throughout the insweep of his arm, decelerates briefly during the transition to the next sweep, and then accelerates again as he sweeps his arm out and up toward the surface. Obviously, therefore, he maintains his arm in a flexed position for the entire propulsive phase of his armstroke. In other words, he flexes his arm before he begins to apply propulsive force at the catch. There is very little change in the amount of arm flexion from the time he begins to apply propulsive force until he stops pushing backward against the water as his arm approaches the surface.

This same pattern of arm movement is used in the butterfly and breaststroke, and through the first half of the underwater stroke in the backstroke. In order to get the hands and arms facing backward so that they can begin to apply propulsive force sooner, swimmers flex the arms as they sweep them down from the surface or out to the side to the catch position. From that point on, until they are ready to recover the arms, they push back against the water without any appreciable change in the amount of arm flexion. The reasons they stroke in this way will be discussed later in this chapter.

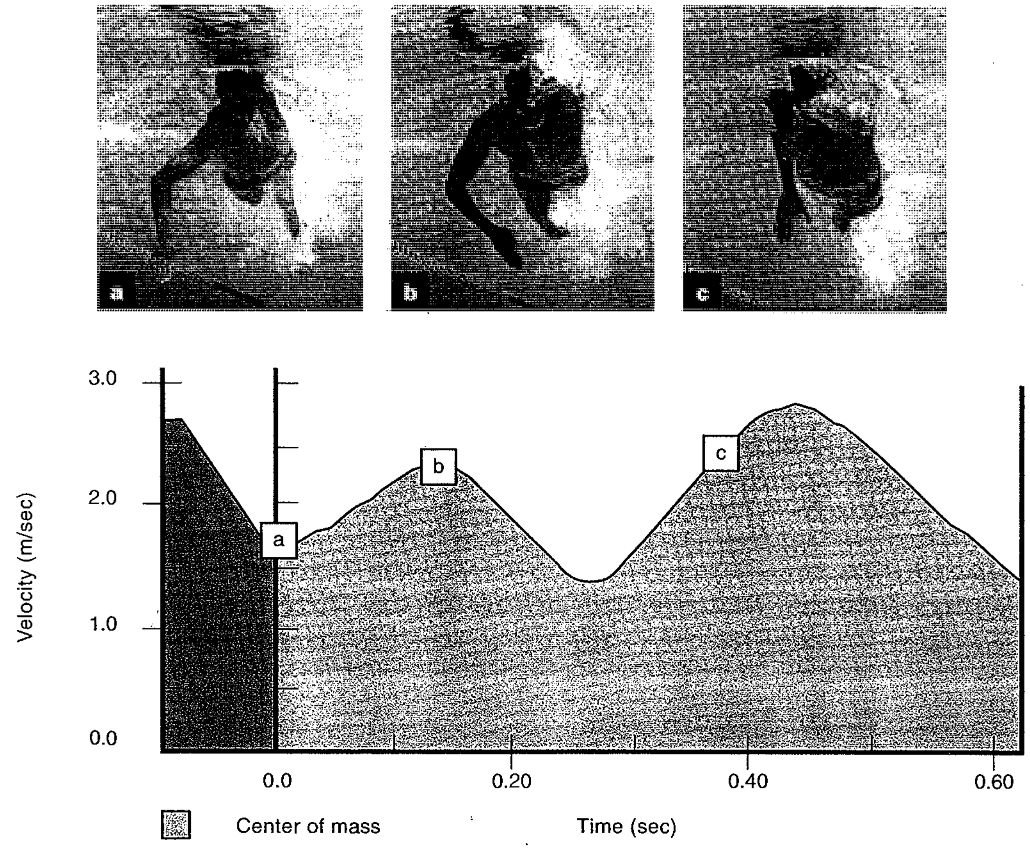


Figure 3.1 A front-crawl swimmer at the catch position (photo a), the end of the propulsive phase of the insweep (photo b), and in the middle of the propulsive phase of the upsweep (photo c). The graph depicts his forward velocity during the underwater stroke of his right arm. The a, b, and c points on the velocity graph correspond to each of the photographs.

Another of the most persistent misconceptions in competitive swimming is that athletes finish the propulsive phases of the front crawl and butterfly by pushing the hands backward until the arms are completely extended and near the surface of the water. World-class swimmers do not do this, nor should they. As mentioned, photo *(c)* in figure 3.1 shows Francisco completing the propulsive phase of his underwater armstroke with his arm still flexed approximately 90°. This motion is really an up and back movement of his arm. That is, he pushes water back with the palm of his hand and the underside of his forearm. Swimmers maintain the arms in a flexed position as they complete their underwater strokes principally because it allows them to use the forearms and hands to apply propulsive force. Extending the arms back during this phase would actually be counterproductive because the forearms would push up, rather than back, against the water during most of the movement.

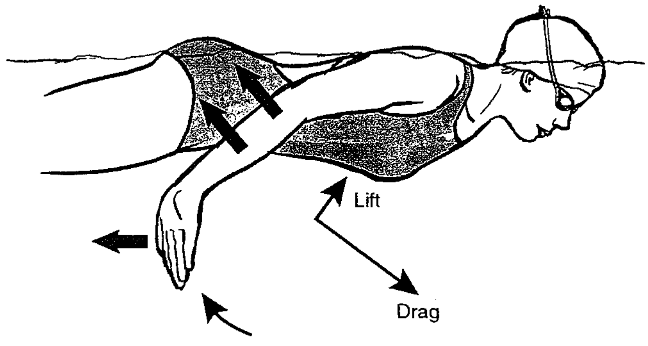


Figure 3.2 The propulsive effect of extending the arm during the upsweep. Notice that the swimmer is pushing up against the water with the underside of her forearm. This will cause a large downward drag force that will slow her forward speed.

The illustration in figure 3.2 shows what happens when swimmers extend the arms as they sweep them toward the surface. Although this swimmer can maintain a backward orientation with her hand, arm extension causes her to push up against the water, with the entire underside of her forearm, during most of the sweep. This will produce a large drag force that will pull her body down and retard her forward speed.

Where forward propulsion is concerned, it is far better for swimmers to keep the forearms facing back as they sweep the arms toward the surface. Contrary to popular opinion, this will not reduce stroke length or the amount of propulsive force applied. The distance swimmers travel with each stroke will actually be greater because they will be moving more water back with the forearms and hands than they could with the hands alone, and they will not be pushing the body down and stalling forward movement by pushing up against the water with the forearms. With regard to propulsive force, for the reason just cited, the amount they produce will actually be greater with a flexed arm. They will be applying propulsive force with the forearms as well as the hands. Stroke rate will not increase because their strokes will not be shorter, although their strokes may feel shorter because they are not extending the arm. It takes the same amount of time for swimmers to bring the hands to the surface whether they extend the arms or keep them flexed.

Forward velocity graphs like the one in figure 3.1 (see page 67), combined with videotapes that show arm position during the non-propulsive and propulsive armstroke phases, demonstrate clearly that swimmers flex the arms before they begin applying propulsive force. It is also clear that they maintain the arms in a flexed position until they have completed the propulsive phases of their armstrokes.

The Four Basic Arm Sweeps

Studying films and videos over a period of several decades has convinced me that there are really only four basic propulsive motions swimmers make with the arms. The rules governing a particular stroke sometimes cause these motions to appear different because the arms are moving in different directions, but the way they apply propulsive force with these motions is remarkably similar from one stroke to the next.

I referred to these motions as *sweeps* in the first two editions of this book. After concluding that swimming propulsion was drag dominated, I considered dropping the *sweep* terminology and returning to the terms *pull* and *push,* because those terms are deeply entrenched in the swimming literature. Neither set of terms, *sweeps* nor *pull* and *push,* really portray all of the complex physical aspects of swimming strokes, however. The terms *pull* and *push* certainly insinuate that swimmers are pushing back against the water, but they also evoke images of pulling and pushing the hands and arms horizontally backward through the water with little or no lateral motion. *Sweep* terminology, on the other hand, implies that swimmers are sculling the limbs through the water.

Four Basic Arm Sweeps Used by Competitive Swimmers

- **Outsweep:** The initial underwater sweep in the butterfly and breaststroke
- **Downsweep:** The initial underwater sweep used in the front crawl and backstroke
- **Insweep:** The second sweep used in all competitive strokes
- **Upsweep:** The final sweep of the front crawl and butterfly

Eventually, I decided to stay with *sweep* terminology. I believe it communicates the mechanisms of swimming propulsion best. It conceptualizes the true diagonal stroking patterns swimmers use. The four basic arm sweeps have been termed *outsweep, downsweep, insweep,* and *upsweep.*

Outsweep

The outsweep is the initial underwater movement in the breaststroke and butterfly, illustrated from an underneath view in figure 3.3. After the arms enter the water in the butterfly and after the arm recovery in the breaststroke, swimmers sweep the arms directly out to the sides until the hands are outside the shoulders, where the catch is made. They gradually flex the elbows as they sweep them outward in order to get the arms facing back and ready to apply propulsive force at the earliest possible moment.

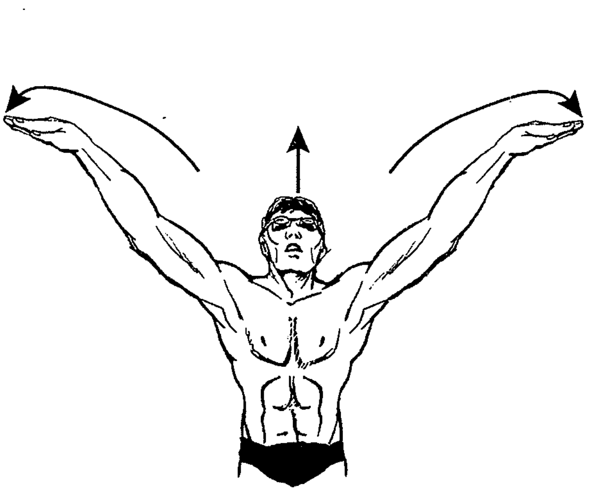


Figure 3.3 The outsweep, illustrated from an underneath view.

The arms should slide out gently and slowly until they almost stop moving when the catch is made. At the catch, the elbows should be flexed nearly 90° and the undersides of the hands, forearms, and upper arms should be facing primarily in a backward direction, ready to deliver propulsive force.

The outsweep is not a propulsive movement. Forward velocity graphs show that swimmers decelerate to some extent while they are positioning the arms to deliver propulsive force. While some deceleration is unavoidable during the outsweep, the amount of slowing can be lessened by sliding the hands and arms through the water with a fingertip lead. Swimmers should not press the palms or the undersides of the arms outward against the water. Nor should they press down on the water with the upper arms. These actions will only produce large outward or downward drag forces that will decelerate forward speed more than it is already slowing. Consequently, the outsweep should be made gently, slipping the hands and arms through the water until they reach the catch position.

You might wonder why butterfly and breaststroke swimmers slide the arms out, rather than down, to the catch position. It is probably because moving the arms out to the side does not decelerate forward speed as rapidly as would pressing the arms down against the water. Pressing downward exerts an upward braking force on the body. Pressing outward simply creates an inward force from one arm, the effect of which is cancelled by another inward force from the other arm. Backstrokers and freestylers can sweep the hands downward to the catch without decelerating unnecessarily because they can roll the body from side to side. Butterflyers and breaststrokers must stay in a prone position as they make the catch, thus they are more likely to push down against the water.

Downsweep

The downsweep is used by front-crawl and back crawl swimmers to position the arms to deliver propulsive force. In this respect, it serves the same purpose as the outsweep. The drawings in figure 3.4 illustrate the downsweep as it is used by *(a)* front-crawl swimmers and *(b)* backstroke swimmers. The downsweep, like the outsweep, is not a propulsive movement. Swimmers will decelerate during the downsweep, but the amount of deceleration should be kept to the minimum required to position the arm properly.

The downsweep begins with the arm extended forward underwater. The arm is then moved gently down, forward, and out to the side until the undersides of the hand,

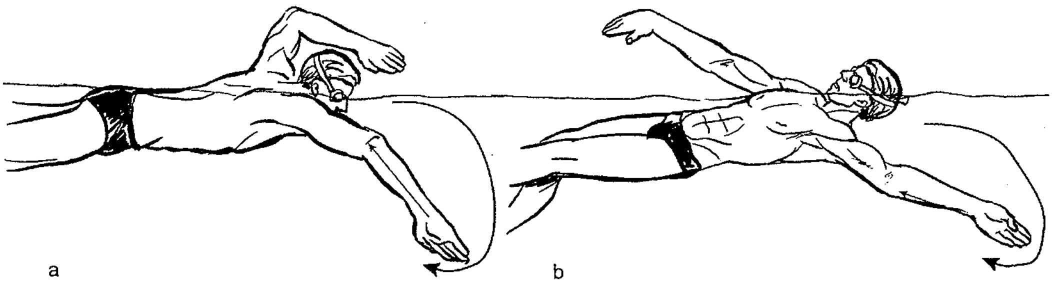


Figure 3.4 *(a)* Front crawl swimmer at the catch after completing the downsweep. *(b)* Backstroke swimmer at the same point.

forearm, and upper arm are facing back. At that point, the catch occurs and propulsive force begins. The arm almost stops moving at the catch in order to accelerate once the propulsive phase of the armstroke begins.

The fingertips should lead during the downsweep to reduce resistive drag. The elbow should be flexed gradually on the way down in order to shorten the arm's radius of rotation so that swimmers can get the arm and hand facing back earlier. The upper arm should remain almost parallel with the surface during the downsweep. It will travel downward somewhat as the swimmer rolls toward the arm that is sweeping down, but the upper arm should not be pushed down. Pushing down will create a counterforce that pushes swimmers up while decelerating forward speed. Swimmers should also not push down against the water with the palms or the undersides of the forearms as they sweep them down to the catch position. These actions will also produce a large upward drag, which will push the body up and retard forward speed even more than it is already slowing. The downsweep ends when the arm is flexed approximately 90° with the palm, and the undersides of the forearm and upper arm are facing primarily backward where they can apply propulsive force.

Front-crawl swimmers should sweep the forearms and hands primarily downward with just enough outward movement to position the upper arm in a backward direction at the earliest possible moment. Backstroke swimmers should sweep the hands and arms out to a greater extent because this allows them to achieve a good catch earlier. The depth of the downsweep is, in large part, caused by the amount of body roll that swimmers need to recover the other arm properly. A shallow catch will limit body roll, which may cause front-crawl swimmers to recover the other arm too wide. In the backstroke, a shallow catch with one arm will limit body roll and cause the other arm to drag through the water too much during recovery.

You might ask why front-crawl and backstroke swimmers sweep the arms outward during the downsweep rather than press them straight downward to the catch position. Moving the arms out to the side slightly produces at least three advantages:

1. The catch can be made earlier.
2. They can minimize the additional slowing effect that pushing the upper arms down through the water would have on their forward velocity.
3. They can use the underside of the upper arms to push back against the water once the catch is made.

Regarding the first two advantages, maintaining the upper arm nearly parallel with the surface and flexing the elbow during the downsweep allows swimmers to get the arms facing back earlier in the downsweep of the front crawl and backstroke. The drawings in figure 3.5 illustrate this point. The front-crawl swimmer in figure 3.5a is shown at the catch position from front and side views. This swimmer made the catch by moving her arm out and down while flexing her arm at the elbow. By moving it outward to the side during the downsweep, she was able to maintain her upper arm nearly parallel with the surface and avoid pressing downward with it. By contrast, the swimmer in figure 3.5b, also shown from front and side views, presses her arm straight down in order to make the catch near the midline of her body.

The swimmer in 3.5a is able to make the catch earlier than the swimmer in 3.5b, and she does not push down on the water to any great extent with her upper arm while doing so. Thus, as illustrated by the shorter length of the vertical arrow in *(a)* as compared to the corresponding arrow in *(b)*, the swimmer in 3.5a should decelerate less during the downsweep and she will be able to begin applying propulsive force sooner. The swimmer in figure 3.5b will produce some downward force with her upper arm, no matter how gently she sweeps it down, and that force will decelerate her forward velocity more than it is already decelerating during the downsweep.

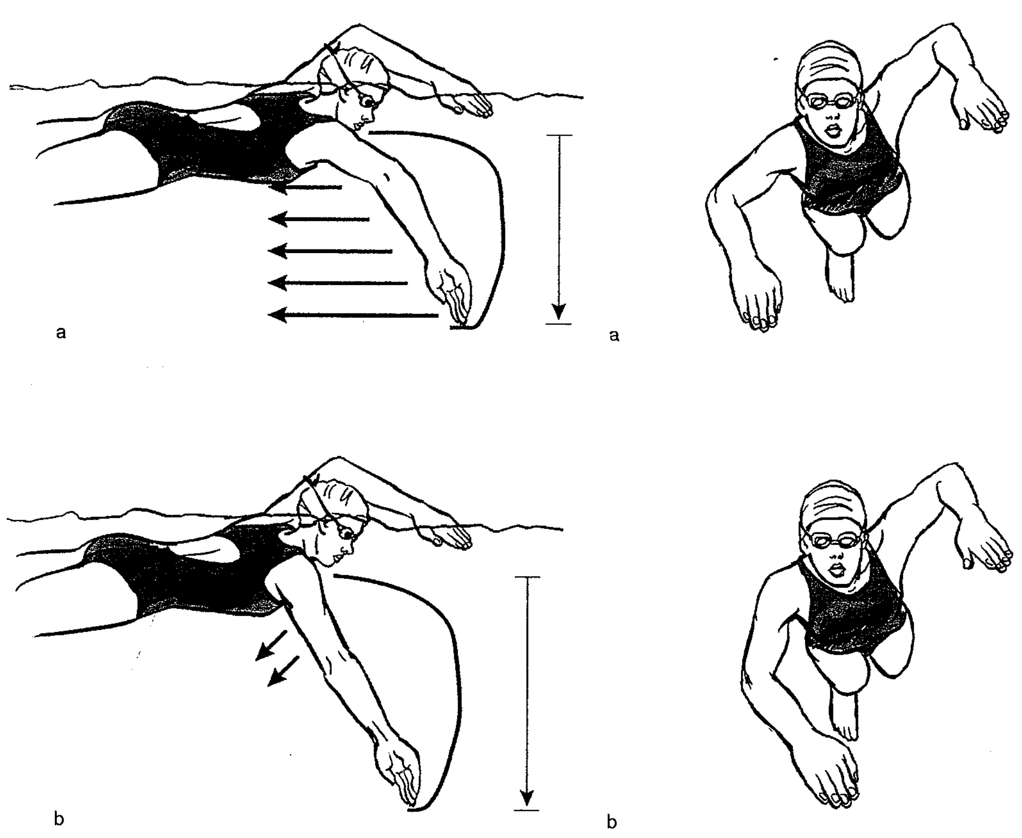


Figure 3.5 The effect of pressing the arm down during the downsweep. The front and side views in *(a)* show a swimmer who is making her catch by moving her arm down and out. The swimmer in *(b)* is making her catch by sweeping her hand down without moving it out to the side. As shown by the vertical arrows in the side views, the swimmer in *(a)* will be able to make her catch earlier.

The final advantage concerns positioning the upper arm to apply propulsive force. When front-crawl and backstroke swimmers slide the arms out slightly without pressing them down too much, as the swimmer in figure 3.5a is doing, they can orient the underside of the upper arms backward and parallel with the surface at the catch. Positioned in this way, the rear upper arms can be used, in addition to the forearms and hands, to push back against the water during the next stroke phase. The additional surface area should increase propulsive force during the insweep. Conversely, if they push the upper arms deeper into the water, as the swimmer in figure 3.5b is doing, they will not be able to push water back with them. Additionally, they will also have to push the arms up a longer distance during the final portion of their underwater strokes to get them to the surface of the water. This will push the torso down and slow forward speed.

Insweep

The insweep is the first propulsive phase of each competitive stroke. It follows the downsweep in the front crawl, and it follows the outsweep in the butterfly and breaststroke. There is a corresponding propulsive motion of the arms in the backstroke, but it is termed an *upsweep* because the swimmer is supine and the arm travels up more than in. Nevertheless, although the major direction of backstrokers' arms is different, in all other respects the way that propulsion is produced during the upsweep of the backstroke is identical to the insweep of other strokes.

The insweep was described incorrectly in previous editions of this book. I described it as a motion where the emphasis was on sculling the arm inward while not pushing back to any great extent. In actuality, swimmers use the undersides of the upper arms,

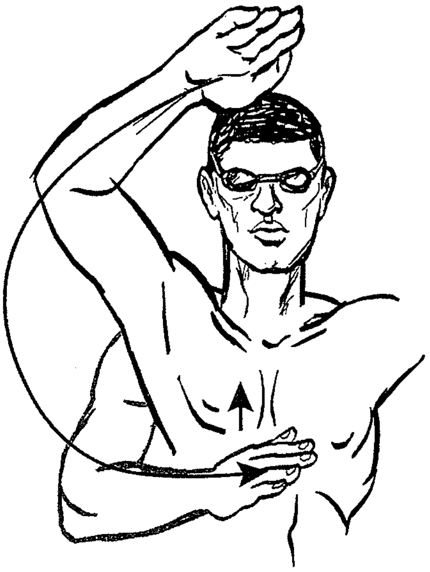


Figure 3.6 The insweep as used in the front crawl stroke.

forearms, and the palms of the hands like large paddles to push back against the water. The lateral motion of the arms during the insweep is a result of the direction the arm must travel to get from the catch to the next phase of the stroke while also applying propulsive force.

The first person to describe the insweep correctly was Charles Silvia, the legendary coach of Springfield College (1970). He referred to this movement as *upper arm adduction* because the arm was brought from an overhead position, out and back past the shoulder, and finally into the side in a large semicircular sweep. He believed, and rightly so, that this motion was very propulsive because swimmers were able to keep the hands and arms nearly perpendicular to the surface of the water for a longer period of time during the insweep. This, in turn, enabled them to make a better paddle of the hand and arm for a longer period of time. I, however, along with many others, renounced Silvia's teachings when lift propulsion became popular. This was unfortunate because his observations on stroke mechanics were very astute. The insweep is illustrated from an underneath view for a front-crawl swimmer in figure 3.6.

The insweep begins at the catch position following either the downsweep or outsweep, depending on the stroke. The hand and entire arm are pressed in a semicircular and lateral path out to the side, back, and then in until the upper arm approaches the ribs and the hand is brought under the body. The insweep ends at that point and the transition to the next stroke phase begins.

Limb speed should accelerate from the catch until the arms are traveling in under the body, at which time limb velocity decelerates while they make the transition to the next phase of the armstroke. The upper arms should move nearly parallel with the surface throughout the insweep, and the hands and forearms should remain perpendicular with the surface. Some swimmers may increase arm flexion slightly during the insweep for the purpose of making slight alterations in the paths of the arms and hands in order to accelerate water back more effectively. The arms should be flexed nearly 90° when the insweep begins so that any additional flexion will be minimal. Swimmers should not begin the insweep with extended arms and then flex them as they bring them back under the body. The amount of propulsive force produced will be considerably reduced if swimmers make the insweep in this manner.

Where forward propulsion is concerned, the first two-thirds is the most effective portion of the insweep. After that, the direction of the arms changes from primarily backward to primarily inward, and forward velocity decelerates. Regardless, swimmers should continue adducting the arms until the elbows are near the ribs during the insweep. This will place the hands and forearms under the midline of the body, where the next propulsive sweep, the upsweep, can be executed more effectively. They will be able to push the water back under the middle of the body to maximize propulsive force. Sweeping the arms in under the body probably also allows swimmers to prepare for the next propulsive phase by moving the limbs away from the water they accelerated back during the first two-thirds of the previous insweep and into other streams of water that have not yet been accelerated back.

I once believed that swimmers sculled the hands inward under the body because the palm of the hand changes the pitch or orientation from out to in during the insweep. I thought this indicated that they were rotating the palms and forearms during this phase. I now believe that the hand and forearm do not rotate at the elbow but instead stay in a static position during this sweep. Swimmers actually form large boomerang-shaped paddles with the undersides of the upper arms, forearms, and hands. Then they push these paddles back and in against the water until the upper arms are back near the ribs.

This is when the pitch of the palms and rear forearms quite naturally changes to outward and then to inward, not because of any conscious effort to rotate them in those directions but simply because the arms are traveling backward in an arc-shaped path that is back and out during the first half and back and in during the second half (see figure 3.6).

In other words, the palms and forearms simply face in the direction they are moving during the insweep. The rotation comes from the shoulder joint, not the elbow joint. Swimmers should simply keep the palms of the hands and the undersides of the forearms and upper arms aligned as though they were a single unit. The muscular force for rotating the arms should come from the back and shoulders. As I will explain in the next few paragraphs, this makes the insweep a very powerful propulsive motion.

Up to now, I've only mentioned one factor that makes shoulder adduction superior to sculling: Swimmers are able to utilize drag force to a greater extent, which in turn increases the propulsive force they can produce. Another factor, which should have an even greater effect on the production of propulsive force during the insweep, is that swimmers can use larger muscles and produce more force by adducting the arms backward at the shoulder instead of sculling them inward. The large muscles of the shoulders and trunk, the deltoids, the pectoralis major, and the latissimus dorsi, will be used to perform the work when the arms are adducted backward in a paddle-like manner. By contrast, they will not be able to produce nearly as much muscular force with sculling movements. The pectoralis major muscles of the chest and the frontal deltoids of the shoulders would still be involved in sculling, but swimmers use more force for inward rotation and less for pressing backward against the water because they rotate the arms inward more than they push them backward. At the same time, the posterior deltoids, and the large fan-like latissimus dorsi muscles that cover most of the area on the upper back will be used very little if the arms are not moving back. It should not be difficult to understand that minimizing the role of these two large muscle groups will dramatically reduce the propulsive force swimmers can produce during the insweep.

Another disadvantage of sculling, compared to shoulder adduction, is that sculling engages several small muscle groups in the forearms and upper arms to assist in hand and forearm rotation. Small muscle groups tend to fatigue more rapidly than larger ones. Consequently, swimmers who scull will probably fatigue earlier than those who do not. Of course, the arms do rotate inward during the insweep, even when swimmers use them like paddles. That rotation, however, will be accomplished by using the large muscles of the shoulders and back to adduct the entire arm. The small muscles in the upper arms and forearms will not be used to rotate the forearm and hand inward.

Upsweep

In the front crawl and butterfly strokes, the upsweep follows the insweep. There are actually two corresponding movements in the backstroke. One of these cannot be called an upsweep, however, because backstroke swimmers are in a supine rather than prone position, so the arms sweep downward rather than upward during this phase. The way they apply propulsive force is similar to the way it is applied in the upsweep described in this section, however. The upsweep for the front crawl stroke is illustrated from side *(a)* and underneath *(b)* views in figure 3.7. The

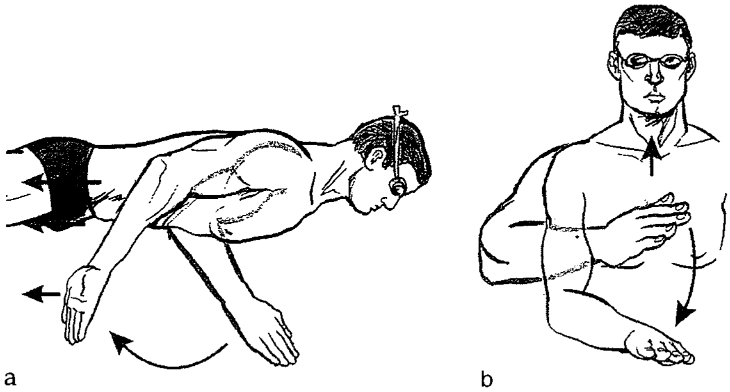


Figure 3.7 The upsweep as used in the front crawl stroke.

upsweep of the butterfly is similar, except, of course, both arms are stroking simultaneously.

The last part of the insweep should serve as a transition to the subsequent upsweep. The change occurs as the upper arm is coming in, toward the ribs, and the hands are passing under the midline of the body. At that point, the swimmer should change the direction of the hand and arm from in and up to out and up. This is accomplished by turning the hand and arm out quickly and pushing them out, up, and back toward the surface of the water. The swimmer continues pushing back against the water with the palm and rear forearm until the hand is to the side of the body and nearing the front thigh. At that point, the upsweep ends. The swimmer releases pressure on the water and collapses the palm inward to slip it out of the water into the arm recovery that follows. Arm and hand speed should accelerate markedly from the beginning to the end of the upsweep. The arms will generally reach their maximum velocity, often in excess of 6 m/sec, during this stroke phase.

The arm should remain flexed during the upsweep so that swimmers can push back against the water with the underside of the forearm and the palm of the hand. A small amount of arm extension may be needed, however, for swimmers to keep pressing back against the water as the arm travels out and up. Nevertheless, the amount of extension should not be excessive and the arm should still be flexed nearly 90° when the upsweep ends.

Front-crawl swimmers stop pushing against the water and recover the arm out of the water and over the surface when the upsweep has been completed. The arm should remain flexed during that recovery. To facilitate arm recovery, butterfly swimmers extend the arms upward and to the side as they (the arms) leave the water. For butterfly swimmers, the arms extend as the first part of arm recovery. Arm extension is not the final portion of the upsweep.

The description of the upsweep presented here is similar to the one provided in earlier editions of this book. At that time, however, the emphasis was on using the arm as a foil rather than a paddle. This may have caused a misconception that I want to clear up at this time. Where propulsion is concerned, the most important aspect of the upsweep is that swimmers push back against the water with the forearms and hands, even as they are sweeping them out and up. They should make every effort to maintain a backward orientation with the undersides of the forearms and the palms of the hands throughout this stroke phase. This will necessitate maintaining the arms in a flexed position throughout the upsweep.

Role of Hand and Arm Acceleration in Propulsion

Hand and arm acceleration became an important aspect of stroke mechanics with the research of Counsilman and Wasilak (1982). These two men investigated the relationship between limb velocity and swimming speed and reported that the best swimmers accelerated the hands from the beginning to the end of their underwater strokes. Later research by Schleihauf (1986) showed that this concept was accurate but oversimplified. Swimmers did not accelerate the hands smoothly from start to finish. Rather, hand speed accelerated in pulses, decreasing and then increasing with each major change of direction during underwater armstrokes. The slowest limb velocities were during the early portion of the various underwater armstrokes, however, and the fastest limb velocities usually occurred during the final propulsive portion of the underwater strokes, just as Counsilman and Wasilak had reported.

A typical hand velocity pattern for 50 m freestyle world record holder Tom Jager is shown in figure 3.8. The top graph shows his changing hand velocities throughout one underwater stroke cycle, and the bottom graph depicts the velocity of his center of mass. The swimmers in the middle of the graph show what stroke phase was being completed at each particular point on the graphs. The forward velocity of Jager's body and the nondirectional velocity of his hands are indicated on the vertical axis in m/sec. The time he took to complete each stroke phase is shown in 1/100 sec on the horizontal axis. I should make it clear that the hand velocities in figure 3.8 are three-dimensional. They represent the actual velocity of the hand without regard to direction. Swimmers' hand movements have backward, sideward, upward, and downward components, which are all combined to calculate the hand velocities presented here. The tip of Jager's middle finger was used as the reference point for hand velocity and he was swimming at 100 m speed. The tracings begin with the downsweep of his left armstroke.

The pattern of pulses in the velocity of his left hand went as follows. The speed of his left hand decreased after entry until the catch was made. His hand velocity accelerated, although not maximally, during the insweep as it traveled in under his body. This was followed by a short period of deceleration during the transition from insweep to upsweep, after which his left hand accelerated to its peak velocity as he swept it out and up toward the surface. The velocity of his left hand decelerated near the surface as he released pressure on the water and started his recovery.

A similar pattern of hand acceleration and deceleration took place during his right armstroke. Notice that those periods during the stroke cycle when hand velocities accelerated and decelerated correspond very closely to times when his forward velocity accelerated and decelerated during the stroke cycle.

The hand velocity pattern in figure 3.8 is typical of patterns used by swimmers in the remaining three competitive strokes. In all cases, the swimmers accelerate and decelerate the hands in pulses each time they change directions during the stroke, and those changes in hand velocity generally coincide with similar changes in the forward velocity of the center of mass. Counsilman and Wasilak (1982) reported maximum hand velocities in the range of 4.5 to 6 m/sec (14 to 20 ft/sec) in their study.

Apparently, swimmers do not accelerate the hands to maximum velocity until the final portion of their underwater armstrokes. Jager, for example, accelerates his hand speed to only 3 m/sec during the insweep under his body and then to 6 m/sec during the upsweep. This means that he intuitively chooses to use some optimum, rather than maximum, hand velocity at mid-stroke. Swimmers probably stroke this way to con-

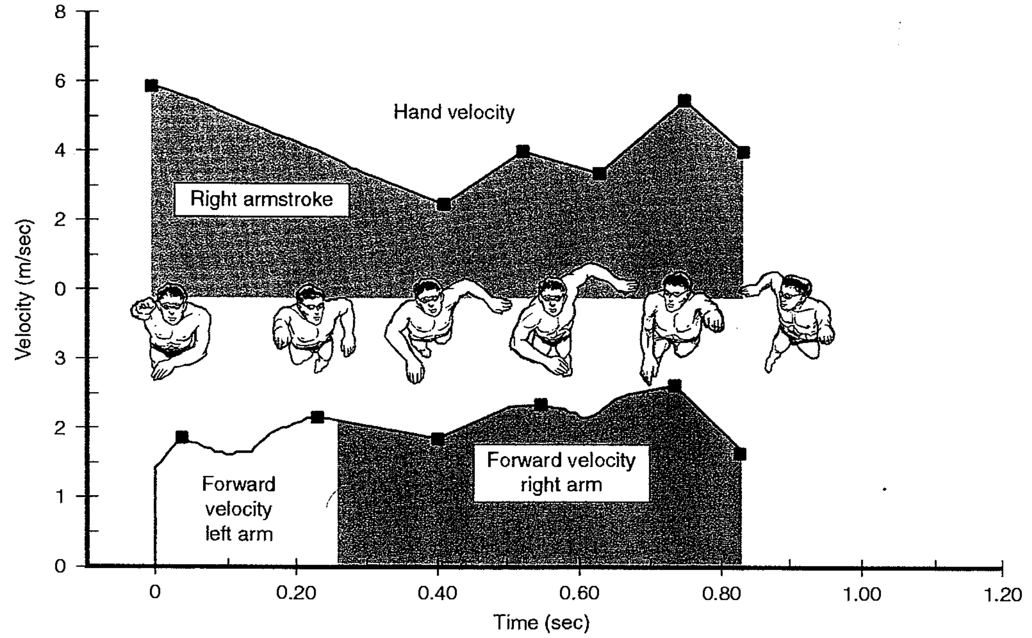


Figure 3.8 A typical hand velocity pattern for the front crawl stroke. The subject was Tom Jager.

serve energy. Perhaps, over the course of a race, it is not possible to maintain maximum hand speeds for the entirety of an underwater stroke.

As you would expect, swimmers accelerate the hands more in sprints than longer races. Also, females generally do not attain the same maximum hand velocities as males (Maglischo et al. 1986)

The Importance of the Catch to Fast Swimming

The *catch* is that point in the underwater armstroke where swimmers begin to accelerate the body forward with the arms. Forward velocity graphs show that, in all strokes, skilled competitive swimmers do not begin accelerating the body forward until they are approximately one-third of the way through their underwater armstrokes. The arms travel out or down approximately 40 to 50 cm before the catch is made. They have to travel this distance so that swimmers can get the undersides of the arms and hands facing back against the water before they start applying force. The graph in figure 3.9 shows the beginning of forward propulsion in the front crawl stroke. The swimmer is Kieren Perkins, world-record holder and 1992 and 1996 Olympic gold medalist in the 1500 m freestyle. Data collected during the finals of the 1500 m freestyle at the 1992 Summer Olympic Games, where his record of 14:43.48 was set, are displayed in 1/100 sec on the horizontal axis and forward velocity in m/sec on the vertical axis. The catch position is marked on the velocity graph and on a side view of his left armstroke pattern just above the graph.

The velocity graph begins when Perkins initiates the downsweep with his left arm. At that point, he has completed the propulsive phase of his right armstroke and his

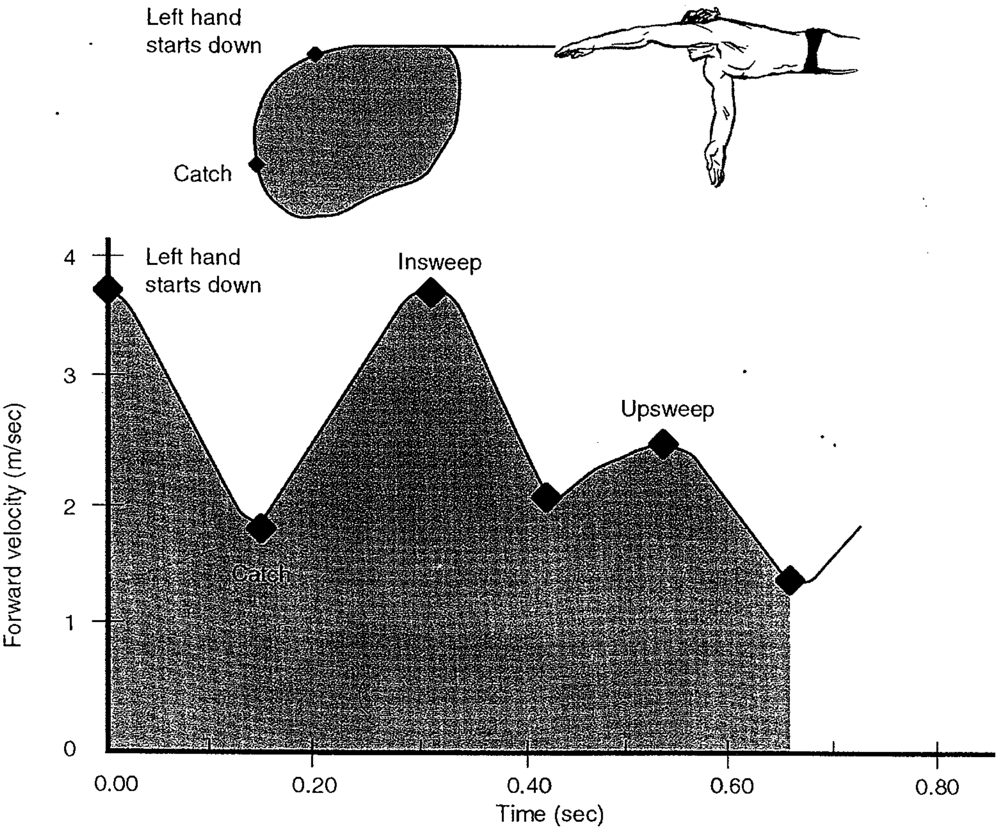


Figure 3.9 A forward velocity graph for Kieren Perkins. This graph shows the forward velocity of Perkins' center of mass during one underwater left armstroke.

Adapted from Cappaert 1993.

forward velocity is decelerating. Notice that his forward velocity continues to decelerate for approximately 0.20 sec after the downsweep begins. At that point, his hand has traveled nearly 50 cm downward and his arm and hand have achieved a backward orientation to the water. Then he begins to press his arm back as well as down and his body starts accelerating forward.

Swimmers make the catch similarly in the remaining three competitive strokes. They do not apply propulsive force until the hands are approximately one-third of the way through the underwater stroke cycle. Photos showing the catch position for each stroke will be included in subsequent chapters. The position of the arms at the catch has led coaches to frequently refer to them as *high elbow* catch positions.

The legendary swimming coach James "Doc" Counsilman was the first person to draw attention to the importance of the high elbow position at the catch. He did so in his excellent book, *The Science of Swimming* (1968). Swimmers should not attempt to apply propulsive arm force until the arms are in this high elbow position because, as mentioned previously, they cannot direct water back until the arms and hands are facing back.

Front-crawl swimmers should sweep the hands down and forward to the catch position. They should also be flexing the arm as it travels downward, until the elbow actually rides forward over the hand. Then, and only then, should they begin to push backward against the water. Backstrokers should slide the hand down, out, and forward while flexing the arm at the elbow until the elbow rides forward and catches up with the hand so that both hand and arm are facing back. Then they can begin pushing the arm back. Butterfly and breaststroke swimmers should slide the hands out to the side while simultaneously flexing the elbows until the elbows have caught up with and are above the hands, with hands and arms facing back, before they begin to apply propulsive force.

When racing, it is quite natural for swimmers to start applying force against the water as soon as they feel hand entry in the front crawl, backstroke, and butterfly; and immediately after the arms have been extended forward in the breaststroke. Nevertheless, they should not do so because the arms will be pressing down or out, not back, against the water at these times. It is no wonder, then, that the most common mistake in swimming is to apply force against the water before a high elbow position has been attained. This mistake is termed the *dropped elbow.* Figure 3.10, featuring a front-crawl swimmer with a dropped elbow, illustrates the reason the dropped elbow is such a serious stroke defect.

As described earlier, the arm must be in the water approximately 40–50 cm during the downsweeps of the front-crawl stroke before swimmers can get the undersides of the upper arms and forearms facing back. If front crawl swimmers try to apply force immediately, or soon after the downsweep begins, they will end up pushing downward on the water with the arms. This will push the body upward, creating a braking effect that reduces forward velocity more rapidly than it would otherwise be reduced during the downsweep.

Swimmers who drop the elbows do so because they try to apply propulsive force before the arms are oriented backward. This causes them to push down, out, or in against the water, causing counterforces that can disrupt their horizontal and lateral alignment and reduce their forward speed even more than it is normally reduced during the outsweeps and downsweeps of the various strokes. In the butterfly

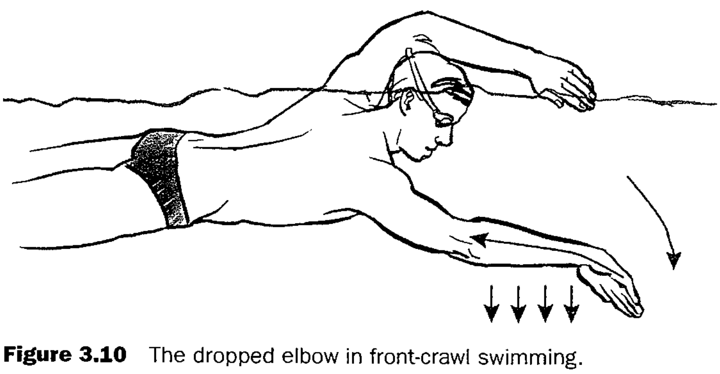


Figure 3.10 The dropped elbow in front-crawl swimming.

and breaststroke, a high elbow position is usually achieved by sweeping the hands and arms out, not down, because swimmers in these strokes cannot roll the body to the side when both arms are stroking simultaneously. If they drop the elbows, it will be because they cut the outward movement of the arms short and start pushing them down and in too soon. As they make the catch, backstrokers should slide the hands and arms out to the side more than front-crawl swimmers but less than butterfly and breaststroke swimmers. Because shoulder extension is limited after the arms are overhead, backstrokers find it easier to get the arms facing back by sliding them out almost as much as they slide them down.

From the previous discussion, it is obvious that the critical time when swimmers are likely to drop the elbows is during the downsweeps of the freestyle and backstroke and during the outsweeps of the butterfly and breaststroke. To correct this problem, they must be coached to wait until the arms are down far enough or out wide enough to achieve a backward orientation before they start applying force against the water. *The fastest swimmers have learned, through instruction or intuition, to wait until the arms are facing back before they start to sweep them inward.* Less-skilled swimmers try to apply force while the arms are still facing out or down.

Swimmers who drop the elbows are often fooled into thinking that they are pushing back against the water by the fact that they can flex the wrists and get the palms of the hands facing back quickly after they start moving the arms down or out to the side. What they forget is that the arms as well as the hands are traveling down or out, not back, during the downsweep or outsweep. Because of this, they will actually be directing water down or out instead of back with the broad undersides of the forearms and upper arms, even if the wrists are flexed with the palms facing backward. The dropped elbow can be avoided if swimmers wait until the entire arm is facing back before they start pushing against the water with each new stroke.

Many coaches believe that swimmers drop the elbows because they lack the muscular strength to keep them above the hands during underwater armstrokes. I doubt lack of strength causes dropped elbows, however. Skill, not strength, corrects the dropped elbow. No amount of strength will prevent swimmers from pushing down or out with the arms if they try to apply propulsive force before the arms are facing back. On the other hand, it does not take great strength to stroke correctly if swimmers are willing to wait until the arms are facing back against the water before they begin to push backward.

Arm and Hand Alignment at the Catch

Another important point to make about the catch is that swimmers must align the upper arms, forearms, and hands almost perpendicular to the surface before attempting to apply propulsive force. There should be no excessive wrist flexion. That is, the wrists should not face up or in when the arms are facing back. Nor should the wrists face out or down. Rather, the wrists should be facing in the same direction as the arms. By the same token, the arms should not face down or out when the hands are facing back.

All of these examples of misalignment will cause swimmers to drop the elbows and push down, up, or out with one portion of the limbs while trying to push backward with other parts of the body. When the catch is made, the entire arm and hand should be nearly perpendicular with the surface and aligned with one another.

Air Bubbles Around the Hand and Arm

Many coaches have commented that world-class swimmers appear to have fewer air bubbles around their limbs than slower swimmers do. That is because air bubbles indicate turbulence and a concomitant loss of propulsive force.

Air bubbles generally mean that swimmers did not make the catch properly. They trap air beneath the hands and arms as they enter the water. If swimmers begin to accelerate the limbs down or out immediately after entering, the water behind the arms will force that air from behind, around the front and sides of the limbs in a pattern of turbulence manifested in the form of a wildly rotating stream of air bubbles. In the front crawl, butterfly, and backstrokes, the hands travel down, in, and forward as they enter the water. Swimmers who drop the elbows will continue accelerating the arms in these directions after they enter and will also attempt to accelerate them immediately when they enter. These actions squeeze the air out from underneath the arms and hands, and a clear pattern of turbulence in the form of air bubbles is visible.

Skilled swimmers have fewer air bubbles around the hands and arms during the first portion of their underwater strokes because they do not try to apply force immediately during the downsweep or outsweep. They wait until they have reached the catch position before doing so. They actually slide the hands forward underwater for a short distance as they start each new stroke and then slow the arms as they move into the catch position. The forward stretch pushes the trapped air away from the arms so that no air bubbles are visible when they start sweeping down or out. Ceasing the rapid downward motion of the limbs and sliding the arms forward underwater has the effect of wiping the air away from the arms and hands. Consequently, there will be no air behind the limbs to create bubbles once the swimmers reach the catch position and begin pressing the arms backward through the water.

Air bubbles, in and of themselves, do not interfere with forward velocity. They do indicate stroking actions that will slow forward velocity, however. The presence of air bubbles signifies that swimmers have tried to apply force too early during the downsweep or outsweep of the various competitive strokes. Swimmers who produce a large number of air bubbles have, in effect, dropped the elbows. They have tried to apply force against the water before the arms were facing back.

That being said, some air bubbles can be seen around the hands and arms of even skilled swimmers between the entry and catch positions of the butterfly, backstroke, and front crawl. This is normal and does not necessarily indicate poor mechanics. If this turbulence is excessive, however, it is evident that the swimmers in question have dropped the elbows. They must slow the limbs and slide them forward for a short time after entry to correct the problem. Then, before they try to apply force to the water, they must slide them into a high elbow catch position.

The two butterfly swimmers in figure 3.11 show good and bad patterns of air bubble turbulence. The swimmer in figure 3.11a is catching correctly. He allowed his first kick to push his arms forward, wiping them free of trapped air shortly after they entered the

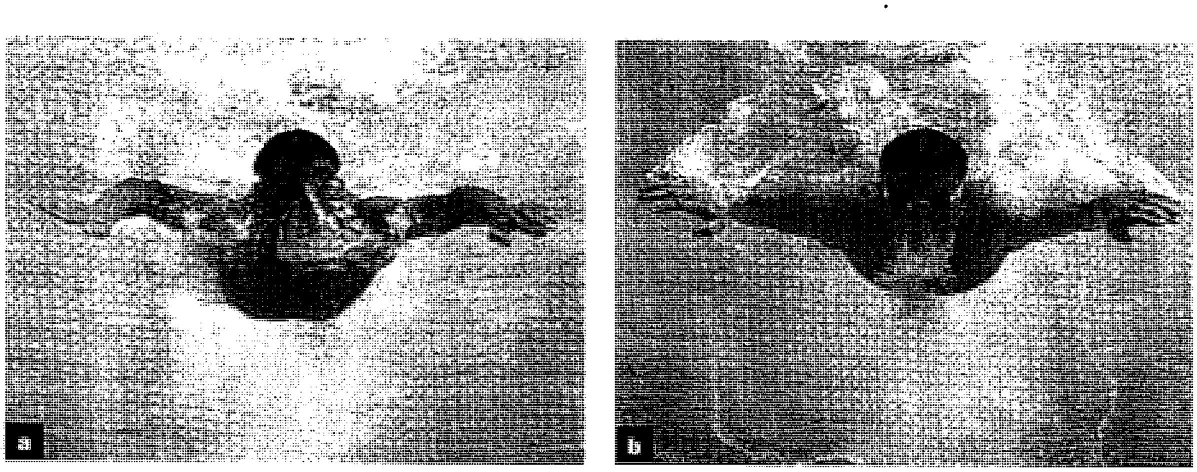


Figure 3.11 Illustration of air bubbles around the hands. The butterfly swimmer in *(a)* has very few air bubbles around his hand after entry, while the swimmer in *(b)* carries lots of air into the water, causing turbulence.

water. Consequently, there are very few air bubbles visible around his arms and hands during the outsweep. The swimmer in figure 3.11b began accelerating his arms down and out almost immediately after they entered the water. This caused the trapped air to burst out from underneath his arms in a large pattern of turbulent air bubbles.

Is Body Roll the Source of Propulsion?

In the last decade, there has been widespread acceptance of the belief that rolling the hips from side to side is the major catalyst for propulsion in the front crawl and backstroke (Prichard 1993). Several analogies have been cited from other sports to support this contention. Proponents of this technique point to the fact that land athletes initiate the striking, swinging, and throwing arm motions by first rotating the hips in the direction of the motion, producing a summation of forces, which begins in the legs, that gains force as it travels upward through the hips. These forces finally culminate with a whip-like movement of the arms that delivers tremendous power. Skills such as swinging a bat or racket, or throwing a ball, hammer, or discus are performed in this way.

These experts describe the application of force in swimming as one where rotation of the hips is transferred to the shoulders and arms, providing more force for the armstroke. In other words, proponents of this theory believe that the propulsive efforts of front-crawl and backstroke swimmers are initiated by hip rotation and that the arm follows the lead of the hips. This results in a gain of speed and power in a manner similar to the way body rotation causes a summation of forces in land activities.

This is a misinterpretation of the concept of force summation, however. What has been overlooked is that the relationship between arm movements and hip rotation in swimming is very different from that in land activities. For one thing, analogies that support the propulsive role of hip rotation take place on land, where the feet are planted against the ground so that the hips can rotate around this center of implantation without causing the body to fly off into space.

Swimmers, on the other hand, are freely suspended in the water, so there is no center of implantation from which they can generate force. Certainly, swimmers roll the hips from side to side in the front crawl and backstroke. I don't believe they do this to generate propulsive force, however. Rather, they do it to reduce resistive drag. As explained in the previous chapter, up and down movements of the arms exert forces on the legs and torso that cause them to move in the same directions as the arms. If swimmers let the body rotate in synch with the arm movements, the body will stay laterally aligned. If they resist the tendency to roll in the direction the arms are moving, however, forces from the armstroke will cause the body to twist from side to side.

There is also a fundamental difference in the way athletes summate forces during land activities and swimming. In land activities, the arms follow in the same direction the body is rotating to gather force from it. In swimming, however, the body and arm move toward one another during the insweep of the front crawl stroke and during the upsweep of the backstroke. The body actually rotates away from the stroking arm during the final propulsive phases of the backstroke armstroke. In this case, it is obvious that one hip is simply being pushed upward by the stroking arm while the other is being pulled downward by the recovering arm. There can really be no summation of forces due to body rotation during these motions. It is only during the final upsweep of the front crawl armstroke that the hips and arms are moving in the same directions, and both the amount and speed of hip rotation has been reduced significantly by that time.

For further proof that body rotation follows the movements of the arms and not vice versa, one need only view the underwater movements of a front crawl or backstroke swimmer frame by frame on videotape. The downward or upward movements of the arms always precede any change in the rotation of the hips. To paraphrase an old saying, the cart should not be placed before the horse. In competitive swimming, the hips are the cart and the armstroke is the horse.

Preventing Chronic Shoulder Pain With the High Elbow Catch

Achieving a high elbow position early in the downsweep or outsweep of the four competitive strokes is certainly an advantage because swimmers can begin accelerating the body forward sooner. Having said this, I should also mention that attempting to push back too early in the downsweep or outsweep is one of the most common causes of shoulder tendinitis in swimmers. This malady is so widespread among competitive swimmers that it is commonly known as *swimmer's shoulder.* At the very least, chronic tendinitis will reduce performance. At worst, it can cause swimmers to leave the sport prematurely. Many swimmers can prevent tendinitis or reduce its severity if they do not try to raise the elbows while pushing the arms back. They must wait until the elbows ride above the hands before they start to push back.

The most common cause of chronic shoulder pain is friction between the proximal head of the humerus (long bone of the upper arm) as it rubs across the soft tissues surrounding the shoulder joint: the supraspinatus tendon, the biceps tendon, and the corachroacromial ligament (Kennedy 1978). The locations of these structures are shown in figure 3.12.

Medial rotation, or inward rotation, is the joint action most likely to cause friction between the head of the humerus and the various ligaments and tendons that surround it, and this is the action swimmers perform when they attempt to get the elbows above the hands in the high elbow position. While it is important to attain a high elbow catch in all strokes, where preventing tendinitis is concerned, there is a right way and a wrong way to go about it.

The most severe friction takes place when swimmers try to push the elbows upward, above the hands, while at the same time pressing the arms backward. The head of the humerus is thrust forward in close proximity to the ligamentous structures of the shoulder joint, where it is more likely to come in contact with them as it rotates forward and downward. By contrast, friction will be less intense if swimmers wait until the elbows are above the hands before they attempt to push the hands backward. This way, the head of the humerus will not be thrust forward so vigorously against the ligaments of the shoulder when the catch is made.

You can feel this for yourself. Hold your arm in front of you at shoulder height with your elbow flexed. Then, try to put your arm in the high elbow position for the front crawl stroke by pushing your shoulder forward and your elbow upward, while at the same time pressing your hand down and back. You should feel a twisting strain in your shoulder joint as the head of the humerus moves forward and rotates downward across the various ligaments. Now, starting with your arm outstretched in the same position, move your shoulder forward and your elbow upward as your hand travels down, *but do not press your hand back.* The sensations of twisting and strain should be considerably reduced.

A similar experiment will produce the same result for motions that simulate the outsweeps of the butterfly and breaststroke. In this case, the wrong way is to press the hands back and out while trying to position the arms for a high elbow catch. The right way is to slide the hands out and down, but not back, until the elbows are above them. Many swimmers with a history of severe tendinitis go on to experience little or no shoulder pain after learning to catch before they start to push the hands back.

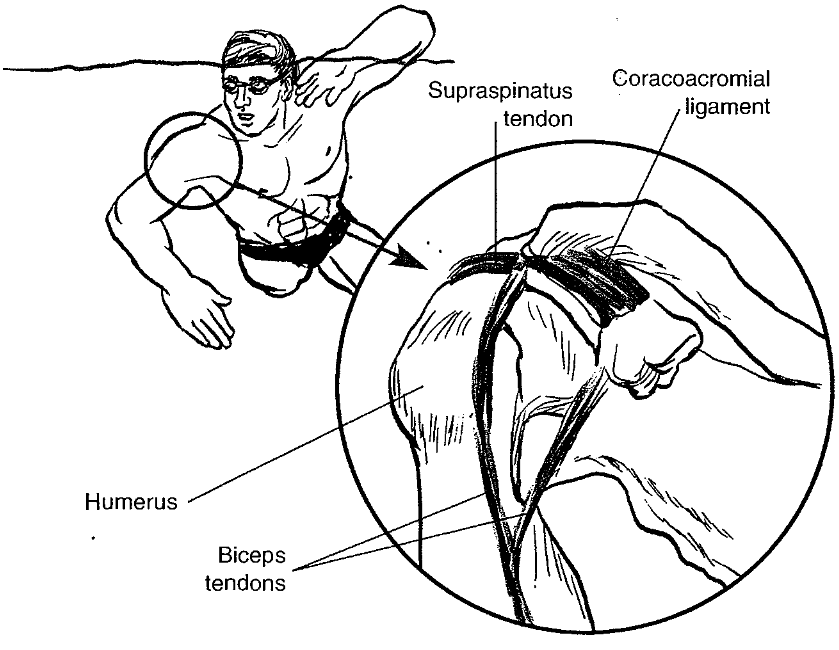


Figure 3.12 Bony and ligamentous structures of the shoulder joint.

Because the concept is recent, research on the relationship of hip rotation to propulsive force is sparse. Nevertheless, that research does not support the concept that hip rotation increases propulsive force. In the first study (Payton, Hay, and Mullineaux 1997), to simulate front-crawl swimming, researchers constructed a model of the trunk and arm. They concluded that body roll did increase the inward and outward velocities of the hand but not the backward velocities. This means that body roll might increase the production of lift forces during swimming but would have no effect on the production of drag forces. If you believe, as I do, that drag is the dominant propulsive force, then an increase in the amount or speed of hip rotation would do little to improve propulsive force.

In a second study concerning hip rotation and hand velocities in which swimmers were used as subjects, Payton, Bartlett, and Baltzopoulos (1998) reversed the earlier finding. They found that body roll actually reduced hand speed during the insweep of the underwater armstroke. Their conclusion: "The results do not support the view that swimmers can generate high hand speeds and large propulsive forces by body roll during the insweep."

Cappaert (1997) took a more practical approach to studying this issue. She compared hip rotation velocities and propulsive force during the armstroke for a group of swimmers. She was not able to find any significant relationship between pulling force during the front crawl and various aspects of hip rotation. Swimmers who initiated hip rotation earlier or reached maximum hip rotation speed earlier during their armstrokes did not produce any more propulsive force with their arms than the others. The subjects were 11 members of the U.S. resident swimming team. In another phase of this study, she trained swimmers to rotate their hips earlier and faster during their armstrokes to determine whether these actions would increase the propulsive force they could generate. The swimmers who received this special training did not increase the propulsive force of their armstrokes.

The only available research that does support hip rotation as a propulsive mechanism was reported by Prichard (1993). He reported that swimmers increased their propulsive force after performing drills to improve the amount and timing of hip rotation. These results should be viewed with suspicion, however. The graphs showed that the swimmers produced more propulsive force while swimming at the same speed. This is highly unlikely. If they were producing more propulsive force, they would cover the distance faster.

Another theory concerning the role hip rotation plays in swimming is that swimmers actually anchor the arms in the catch position and rotate the body around the arms to generate propulsive force. The reasoning behind this concept is equally faulty, however. An arm that is not moving cannot gain speed or force from hip rotation. Additionally, stroke patterns like the one in figure 3.10 (see page 77), provide proof that swimmers do not anchor the arms in the water. These patterns are drawn from the movements of swimmers' middle fingers with respect to a fixed point in the pool, and they clearly show that the hand does move a considerable distance through the water with each underwater stroke.

The point I am trying to make is an academic one. I believe that the arms and shoulders are the pistons that actually provide the force, and the body rotates both to improve the propulsive efforts of the limbs and to maintain good lateral alignment. In other words, the arms lead swimmers' stroking efforts and the hips follow—not the other way around.

Regardless, rolling the body from side to side is essential to efficient front-crawl and backstroke swimming, although not for the reasons usually espoused. Body roll does not add to propulsive force, except indirectly. Forward propulsion will suffer if swimmers do not roll the hips sufficiently and in proper sequence with the armstroke because, as mentioned earlier, lateral alignment will be disrupted and both the underwater and surface movements of the arms will be compromised.

I want to make one final point before leaving this section. My comments about the role of hip rotation were motivated by a desire to be accurate about the mechanisms of human swimming propulsion. I never intended to imply that body rotation is not important to fast swimming. I merely want to clarify why it is important. As indicated, hip rotation is an integral part of swimming the front crawl and backstroke effectively and should be taught to all swimmers in these strokes. Most do not roll enough, nor do they roll equally, to each side. Consequently, there is absolutely nothing wrong with overcorrecting for hip rotation, when it is called for. Drills that emphasize hip rotation will help swimmers stroke more efficiently and reduce resistive drag. Because of this, they will move through the water faster.

Drills for Teaching Arm Sweeps

It should be obvious by now that I no longer recommend using sculling drills as an aid for teaching the armstrokes of the four competitive strokes. In this section, I will describe two drills that can help swimmers learn to use paddle-like sweeps for propulsion. While these drills have some elements of the sculling drills I recommended in the previous edition of this book, the way swimmers move the arms against the water is vastly different.

The following drills should be performed as pulling sets with pull-buoys or tubes. Swimmers will learn how to use their arms for propulsion more quickly if they do not rely on their legs for this purpose.

EXAGGERATED BREASTSTROKE PULL

The purpose of this drill is to develop the insweep for the breaststroke, front crawl, and butterfly. The photos in figure 3.13 show the mechanics. Starting in a prone position with arms extended overhead (figure 3.13a), swimmers slide the hands slowly and gently out to the catch position (figure 3.13b). Notice that this swimmer's elbows are flexed and that his upper arms, forearms, and palms are facing backward when the catch is made. Swimmers should hesitate at the catch position for an instant to be certain they have the arms oriented properly backward.

Then they should adduct the arms rapidly and forcefully out, back, and in until the upper arms are against the ribs and the hands are underneath the body (figure 3.13c). After completing the propulsive phase of the pull, they should gently and smoothly recover the arms forward underwater and repeat the sequence until the prescribed distance has been covered. Swimmers can breathe as they would in the breaststroke, or they can use restricted breathing patterns if they prefer to watch the arms during some of the strokes.

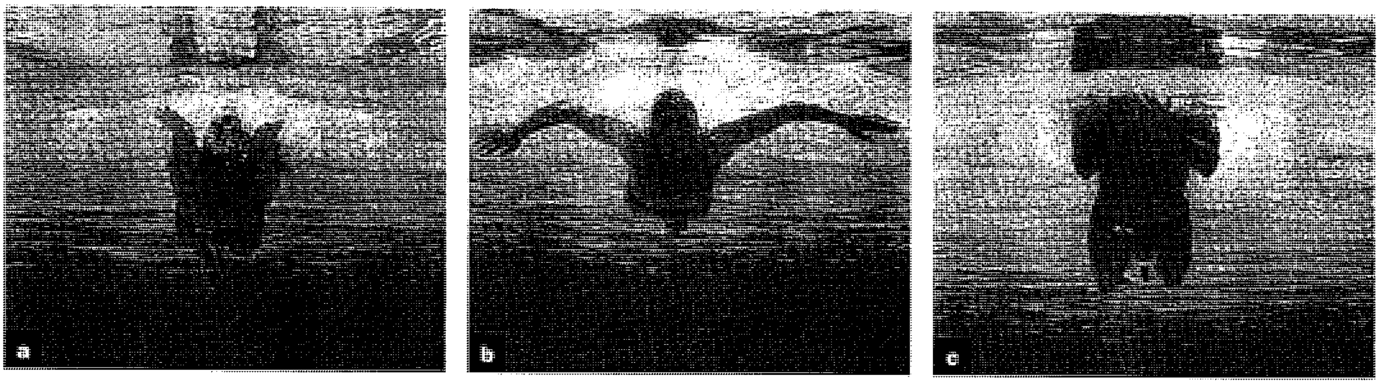


Figure 3.13 The exaggerated breaststroke drill. The swimmer is shown at the end of recovery in *(a)*, at the catch position in *(b)*, and at completion of the insweep in *(c)*.

UPSWEEP DRILL

As its name indicates, this drill is used to teach the upsweep in the front crawl and butterfly. The two photos in figure 3.14 show a swimmer at the beginning and end of the arm motions used in this drill.

Lying face down in the water, swimmers begin from the end position of the insweep: with the arms flexed approximately 90° and back near the ribs with the hands together under the body (figure 3.14a). From that point, they push back against the water with the palms and forearms of both arms simultaneously, sweeping them out and up toward the surface. Swimmers should do this without extending the arms to any significant extent. The upsweep ends when a backward orientation of the forearms can no longer be maintained. This will be as the hands approach the fronts of the thighs (figure 3.14b). At that point, they should stop pushing against the water, turn the palms in toward the thighs, and slide the hands forward, thumbs first, back to the starting position. Swimmers can breathe during this drill just as they would when swimming the butterfly.

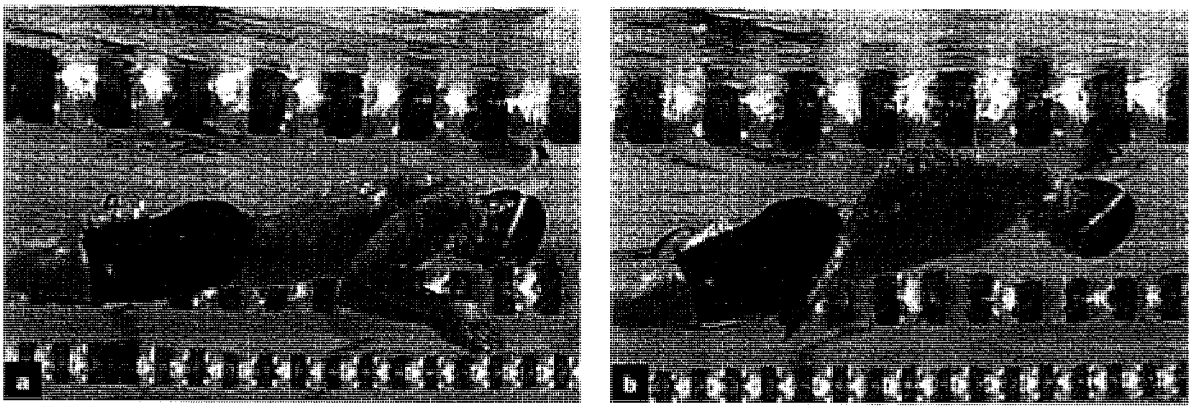


Figure 3.14 The upsweep drill. Photo *(a)* shows the starting position, from which the swimmer pushes back against the water with his palms and forearms, sweeping them out and up toward the surface to the ending position in photo *(b)*.

Propulsion From the Legs

From 1960 to 1980, experts did not believe that the legs added much to propulsion in three of the four competitive strokes. Except in the breaststroke, it was widely believed that maintenance of horizontal and lateral alignment was the primary function of the kick. Today, I think it is generally accepted that, while they certainly aid in maintaining alignment, the legs are also capable of contributing significantly to propulsive force in all of the competitive strokes. Propulsion from the kick comes at a high price, however, because compared to the armstroke, the legs require a much greater output of energy to deliver propulsive force. For this reason, distance freestyle swimmers often choose to save energy during the early portions of their races by reducing their kicking efforts. Swimmers in the 200 m freestyle, backstroke, and butterfly races also reduce their kicking efforts somewhat in the early parts of their races for the same reason. As was the case with the armstroke, there are four basic leg sweeps that swimmers use in the competitive strokes.

The Four Basic Leg Sweeps

The leg motions used by swimmers in the flutter kicks of the front crawl and backstroke and in the dolphin kick of the butterfly are very similar in the way they generate propulsive force. Swimmers use two basic leg movements, an *upbeat* and a *downbeat,* in each of these three strokes. The *downbeat* is the propulsive phase in the front crawl flutter and dolphin kicks. The *upbeat* is the propulsive phase of the backstroke flutter kick. In the breaststroke, the leg movements are best identified as an *outsweep* and an *insweep.* Let me describe how each of these four leg sweeps is performed in the following sections.

Four Basic Leg Sweeps Used by Competitive Swimmers

- **Downbeat:** The propulsive phase in the front crawl flutter and dolphin kicks
- **Upbeat:** The recovering portion of the front crawl flutter and dolphin kicks
- **Outsweep:** The first outward movement of the swimmer's legs in the breaststroke kick
- **Insweep:** The circular sweep of the legs in the breaststroke kick

Downbeat

Figure 3.15 shows how the downbeat of the dolphin kick can propel a swimmer forward. The small black arrow, indicating the direction of the sweep, shows that the feet sweep downward and slightly backward during the first half of the downbeat. The legs flex during the first half and then extend during the second half of the downbeat. The downbeat ends with the legs completely extended and with the feet just below the trunk. These propulsive mechanisms of the dolphin kick should be equally effective during the downbeat of the front crawl flutter kick.

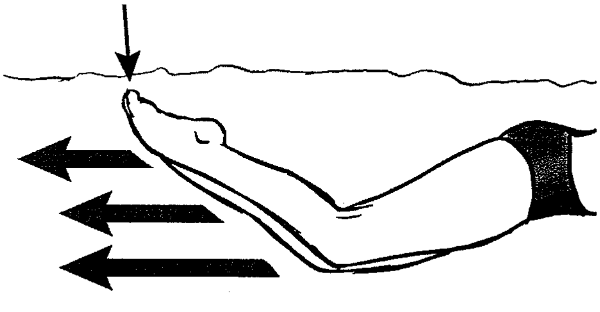


Figure 3.15 Propulsion during the dolphin kick.

The large arrows behind the swimmer's lower legs indicate how swimmers can push back against the water with the feet and lower legs while sweeping them down and back during the first half of the downbeat. The lower legs will lose backward pitch and direction as they near extension, however, so the main effect is a downward push against the water during the second half of the downbeat. This downward push is probably not propulsive in the front crawl flutter kick. Its primary purpose is probably to keep the hips at the surface of the water. The second half of the downbeat may be propulsive in the dolphin kick, however. It may produce a reverse body wave that propels swimmers forward. I explain this in more detail in chapter 5.

The feet will propel swimmers forward more effectively during the first half of the downbeat if they have an adequate range of plantar flexion. The drawing in figure 3.16a shows why the ability to extend the ankles (point the toes) over a long range should be an asset in flutter and dolphin kicking. The swimmer in this figure is able to maintain a backward orientation with his feet during a longer portion of the downbeat because his ability to extend his feet at the ankles is better than average. Consequently, he should be able to generate propulsive force for a longer portion of the downbeat.

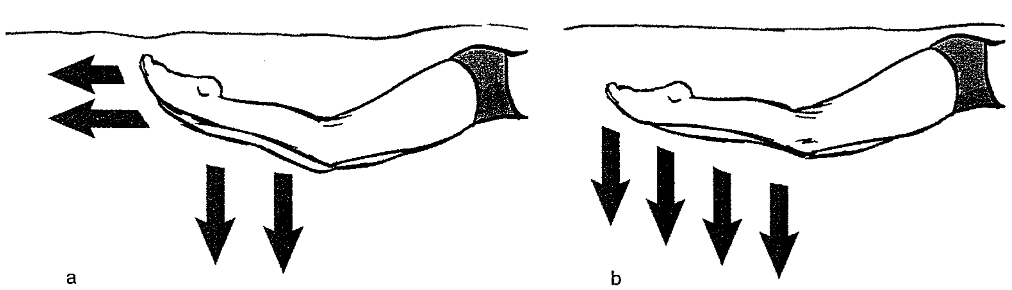


Figure 3.16 The importance of ankle extension to kicking.

By contrast, the swimmer in 3.16b has less ability to extend his feet at the ankles. Consequently, his feet lose backward orientation early during the downbeat. Because they are facing downward, his feet will not increase propulsion. They will, however, assist his legs in maintaining his hips at the surface of the water.

Upbeat

The upbeats of the front crawl flutter kick and the dolphin kick are probably not propulsive. The drawing in figure 3.17 illustrates why. It shows a butterfly swimmer completing the upbeat of the dolphin kick.

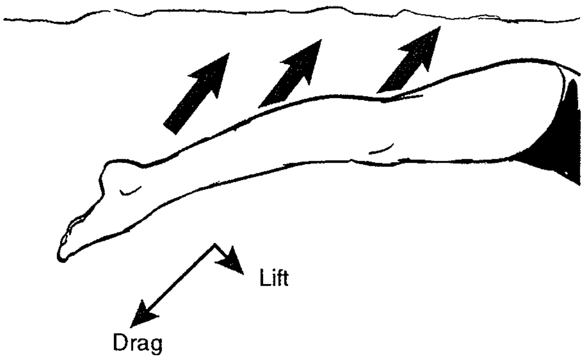


Figure 3.17 The upbeat of the dolphin kick.

Kick patterns drawn from films of world-class athletes swimming at competitive speeds show that their feet travel upward and forward during the upbeat in the butterfly and upward, forward, and laterally during the front crawl. Leg movements in these directions should actually inhibit rather than increase propulsive force because of the counterforces they produce in downward, backward, and lateral directions. The vector diagram in figure 3.17 shows that the upward and forward direction of the legs during the upbeat of the dolphin kick would produce a large downward and backward drag force. The small, if any, amount of lift force that might be produced by the legs would be directed downward and forward, and any combination of these two forces would be aimed in a direction that would tend to pull the body down.

Contrary to popular belief, the primary purpose of the upbeat in these two strokes is probably to position the legs to deliver propulsive force during the next downbeat. For this reason, the upbeat should be made gently so that the legs push up against the water with as little force as possible. The force of leg extension from the preceding downbeat should be used to rebound the legs up so that very little muscular force will be required to perform the upbeat. This action should be assisted by extension of the hip joints, but with only enough force to keep the legs traveling upward. The feet should hang loosely from the ankles in a natural position midway between extension and flexion so that they remain at a small angle of attack to the water relative to their upward and forward direction.

The water pressing down on the legs as they travel up will keep them in an extended position. Swimmers should not work against that water pressure by bending the legs as they sweep them upward. Bending the knees during the upbeat will only increase the forward movement of the legs, and the backward counterforce will retard propulsion even more.

Although non-propulsive, the upbeat probably serves three important purposes.

1. In the front crawl, it stabilizes the trunk, keeping it from being pushed out of horizontal and lateral alignment by opposing actions of the armstroke.
2. In both the front crawl and butterfly, it improves streamlining by bringing the legs upward and in line with the body during the most propulsive portions of the stroke cycles.
3. In both strokes, it brings the legs upward and into position for the next downbeat.

The upbeat is often taught incorrectly. Swimmers are taught to lift the legs to the surface, an action that really has a very detrimental effect on propulsion. The upbeat should be a very short upward movement of the legs. They should only travel upward from the lowest point of the preceding downbeat until they and the feet are in line with the body. The next downbeat should begin at that time by flexing the legs slightly at the hip joints and pressing downward with the thighs. When the downbeat begins, the upward pressure of the water below the legs will push the relaxed lower limbs upward, giving the appearance that the preceding upbeat is still underway. This is not the case, however. Flexion at the knee and the resulting upward movement of the lower legs is a passive motion caused by upward pressure of the water underneath the legs as the downbeat begins. Thus, although flexion of the lower leg will cause the feet to travel up to or slightly through the surface, the last portion of that upward movement is really part of the next downbeat.

The most common mistake poor kickers make is bending the knees during the upbeat. Very few kick down incorrectly. They use muscular effort to flex the legs at the knees during the upbeat, which increases the upward force of the legs and invariably leads swimmers to push the undersides of the lower legs forward against the water. This will push the hips downward into the water and decelerate forward speed.

Backstroke Flutter Kick. Because swimmers are on their backs, the upbeat of the backstroke flutter kick is the propulsive phase and the downbeat is probably non-propulsive. The downbeat should be executed with the leg straight, allowing water pressure below the leg to keep it extended as it travels downward. The upbeat should start as the leg passes below the body. At that time, the swimmer should start moving the leg upward by flexing it slightly at the hip. As the swimmer does this, water pressing downward from above will flex the lower leg in preparation for its final extension. It will appear that the swimmer is still kicking down while the lower leg is flexing at the knee, but the upbeat will actually be underway. The drawing in figure 3.18 shows how propulsion is probably produced during the upbeat of the backstroke flutter kick.

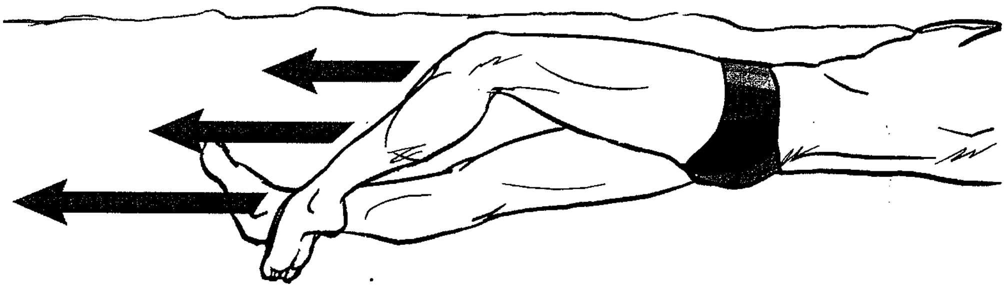


Figure 3.18 Propulsion during the upbeat of the backstroke flutter kick.

Once the upbeat is underway, swimmers will extend the lower leg upward and laterally with considerable speed and force. This leg extension begins with the knee flexed and the foot extended down and in (pigeon toed) and it ends with the leg extended just under the surface of the water. The lower leg and ankle will be facing back, and moving somewhat backward, during the first portion of the upbeat, allowing swimmers to push back against the water during that phase. Thus, the first portion of the upbeat is probably the propulsive phase. The final portion of the upbeat is probably not propulsive, however. The leg and foot will be pushing water upward and laterally. Consequently, that portion of the kick probably aids in maintaining lateral alignment by stabilizing the torso. As with the front crawl flutter and dolphin kicks, the ability to extend the ankles over a long range will increase the distance swimmers can push back against the water during the upbeat.

The downbeat of the backstroke flutter kick is probably not propulsive because the leg is traveling downward and forward, not backward, during this phase of the kick.

The downbeat should be made gently with minimal muscular effort, allowing the water pushing upward from beneath the leg to maintain it in an extended position until the next upbeat begins. The downbeat should end just as the leg and foot are passing downward below the trunk.

Outsweep

In the breaststroke kick, propulsion is probably produced by pushing back against the water with the soles of the feet as swimmers extend the legs. The feet do not push directly backward, however. Rather, they move in a circular path: out, back, and slightly downward. The drawing in figure 3.19 shows side and front view patterns of feet movement during the breaststroke kick.

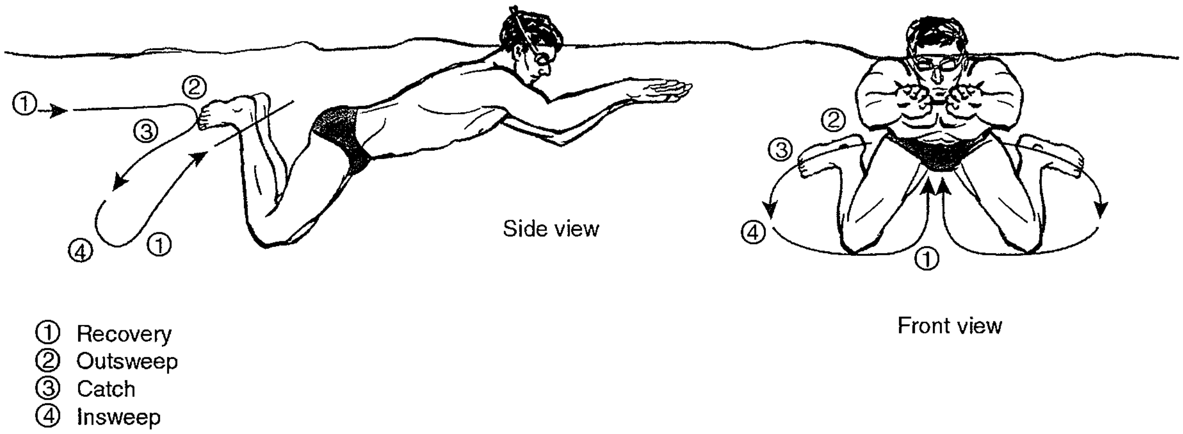


Figure 3.19 Side and front views of the breaststroke kick pattern.

Once recovered forward, the legs' first outward movement, termed the *outsweep*, is not propulsive. Its purpose is to place the feet in a catch position in which they can push back against the water. Humans have limited ability to flatten their feet. Therefore, breaststrokers must slide them outside the hips in order to get the soles facing back before they can begin to apply propulsive force. The outsweep begins at the end of the leg recovery and ends at the catch position, in this case, when the feet are oriented backward and begin to apply propulsive force by pushing back against the water. The catch takes place when the soles of the feet are facing back. Swimmers with good dorsiflexing ability (the ability to flatten the feet) will be able to attain a catch position with the feet earlier. Consequently, the propulsive phase of their kicks, the insweep, will be longer. To the contrary, swimmers with poor dorsiflexing ability will need to sweep the feet out and back longer before they are facing backward, and this will shorten the propulsive phase of their kicks.

Insweep

Once the catch position is reached, breaststrokers push back against the water with the soles of the feet as they execute a three-dimensional circular sweep in which the feet travel out, down, back, and in while they extend the legs at the knees.

Propulsion is probably dominated by drag during the insweep of the breaststroke kick, just as it is during the propulsive phases of the armstroke. Therefore, swimmers' primary emphasis should be on pushing back against the water with the soles of the feet during the circular sweep. As shown from the side view stroke pattern in figure 3.19, the swimmer's feet move somewhat downward in the early portion of the insweep. This is to get his feet in line with his body, where they can apply propulsive force more effectively.

The kick pattern in figure 3.19 makes it appear that the legs are pushing downward more than they truly are during the insweep of the breaststroke kick. This is because kick patterns are drawn from the movements of the big toes. The feet and toes start out above the hips when the insweep begins. During the insweep, however, the feet rotate downward so that the toes finish as the lowest body part at the end of this sweep. This downward toe rotation gives the false impression that the feet have traveled further downward than they actually did during the insweep.

Wave Propulsion

We have known for a while now that there is a third propulsive phase in the breaststroke that has nothing to do with propulsion from the arms or legs. In fact, it takes place during the time when the arms and legs are being recovered forward. The theory is that this propulsion is caused by the wave action of water filling in around swimmers as their velocity slows during the time they are recovering the limbs. Wave propulsion in the breaststroke is illustrated in figure 3.20.

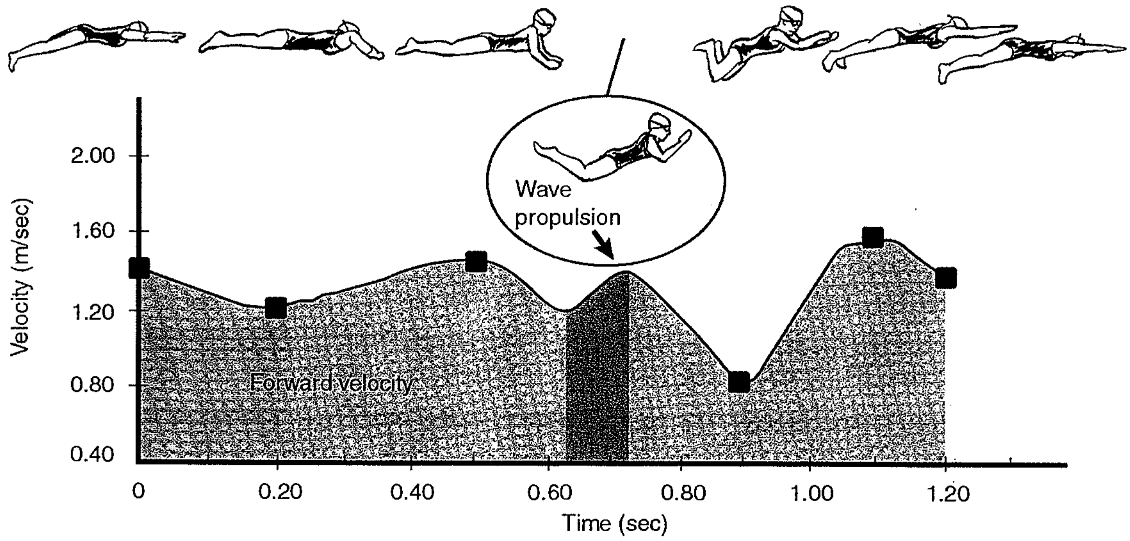


Figure 3.20 A center of mass velocity pattern for the third propulsive phase of the breaststroke during arm and leg recoveries.

Adapted from Mason, Tong, and Richards 1992.

Mason, Tong, and Richards (1992) have found a similar propulsive phase during the arm and leg recoveries of the butterfly that seems to also be caused by wave action. There is a slight period of deceleration that occurs just after swimmers complete the upsweep of the armstroke and the downbeat of the second kick. During this period, the wave action of the water causes them to accelerate forward during the first half of the arm recovery. I have also observed the effects of wave action in butterfly swimmers, both with center of mass and velocity meter measurements of forward velocity. An example of wave propulsion in the butterfly is shown in figure 3.21.

Wave propulsion appears to be caused by a wave of water that surges forward past swimmers just after they decelerate suddenly. Notice in figures 3.20 and 3.21 that the forward surge attributed to wave propulsion is always preceded by a short and very rapid period of deceleration after completion of the propulsive armstroke phases. Wave propulsion probably works in this way. When swimmers accelerate forward, they pull some water forward with them. Then, when they decelerate suddenly, some of that

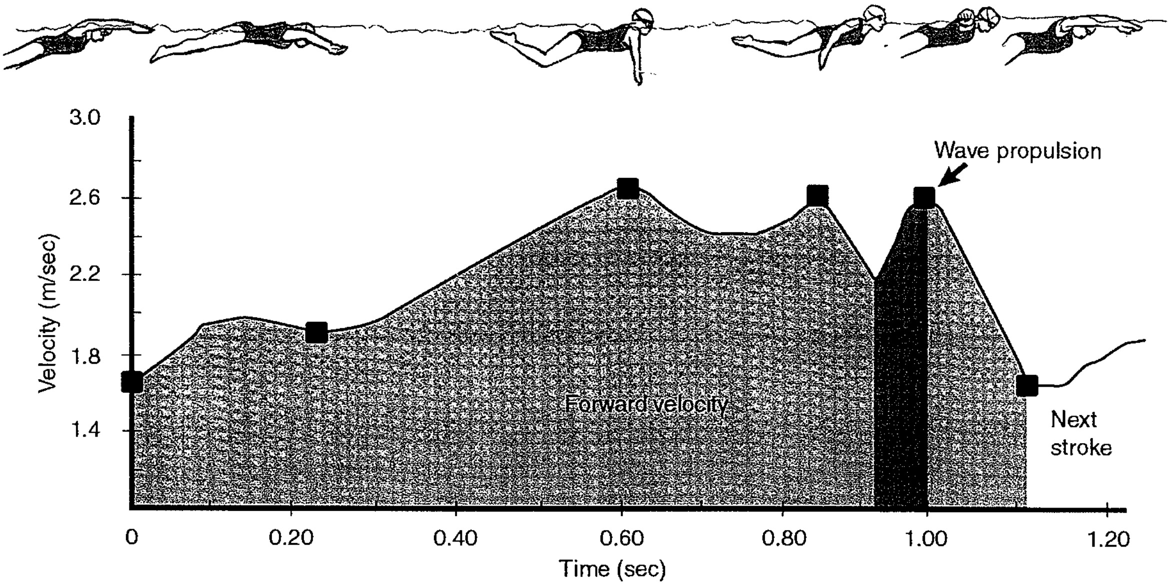


Figure 3.21 A butterfly velocity pattern showing wave propulsion during arm and leg recoveries.

water surges forward past them in a wave-like manner. This surge accelerates their bodies forward for a short time.

Wave propulsion is a classic example of transfer of momentum. Swimmers first transfer momentum to the water by pulling it forward. Then, when they decelerate, some of that momentum is transferred back from the water to the swimmers, accelerating them forward. Swimmers should utilize wave propulsion to the fullest extent possible because it is, in effect, cost-free propulsion. That is, swimmers do not have to exert any muscular effort to accelerate the body forward.

Swimmers can maximize the effects of wave propulsion by streamlining body position during the time it takes place. Poor streamlining will increase form and interference drag, which will in turn reduce the length and velocity of the forward surge provided by the waves. Good streamlining, on the other hand, will increase the speed and length of that propulsive surge. In figure 3.22, notice that the breaststroker's legs are sloping back at the start of his leg recovery. The fact that they are positioned this way will reduce form drag and should increase the amount of wave action propulsion he receives. Conversely, breaststrokers who push the legs downward and forward against the water during leg recovery will create a significant amount of pushing drag that will reduce, or perhaps eliminate, wave propulsion during this phase.

Butterfly swimmers must raise the legs in line with the body and maintain the hips at the surface during the arm recovery, otherwise an increase in form drag will reduce the amount of wave propulsion they receive. Any downward inclination, from head to feet, will increase form drag and reduce wave propulsion at this time.

Butterfly, and possibly front-crawl and backstroke, swimmers must cease pushing back against the water at the proper time during the finish of their underwater armstrokes if they expect to get a surge of forward propulsion from wave actions. If the arms continue pushing toward the surface when they are no longer oriented backward, forward speed will decelerate during the underwater armstroke and the water pressing against the body will have time to adjust to this reduction in speed before the arms start to recover forward. Consequently, the effects of wave propulsion will be blunted by the resistive drag created by pushing water upward with the arms at the end of the underwater armstroke, and the effect will have dissipated by the time the hands leave the water.

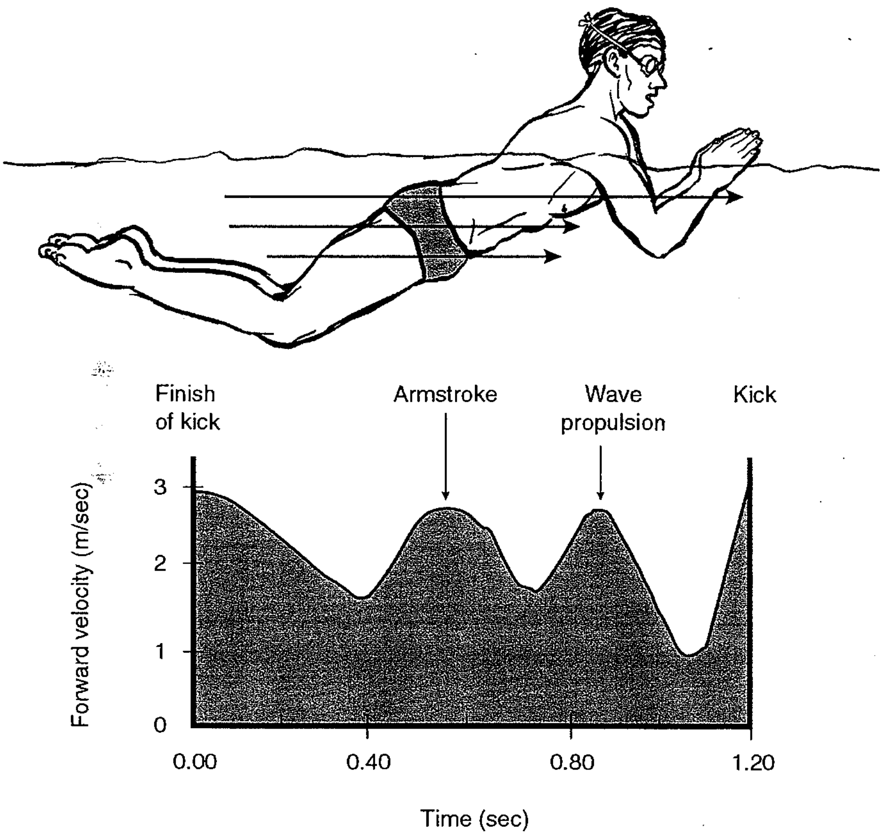


Figure 3.22 An example of wave propulsion in the breaststroke.

Body Wave

At one time, I believed that body undulation contributed to propulsion. Today, I'm not so sure. I no longer believe that swimmers who are moving forward through the water can displace water backward with sufficient force to accelerate the body forward. Still, there may be something about the effect of gravity pulling the body downward and forward after the hips have peaked that could maintain or increase propulsion for a short time. In this regard, Van Tilborgh, Willens, and Persyn (1988) have reported greater propulsive impulses for a dolphin-style breaststroker than for eight other subjects who did not use the dolphin style. Sanders (1996) also reported significant amounts of undulation among national-level breaststroke swimmers from New Zealand.

With regard to the butterfly, Sanders, Cappaert, and Devlin (1995) suggested that "energy accrued by raising the upper body was reused to aid propulsion or reduce drag" as the body descended into the water. According to these researchers, when butterfly swimmers raise the head and shoulders out of the water during the armstroke, they set up a situation in which subsequent downward movements of those body parts back into the water start a wave-like summation of forces that results in more force being produced by the downbeat of the dolphin kick. These researchers have described this form of propulsion as a *body wave*. The body wave should not be confused with wave propulsion. The former is caused by undulating movements of the body, while the latter involves propulsion that is due to the wave action of the water.

The swimmer in figure 3.23 initiates the body wave by dropping her head just before her hands enter the water. This is followed by downward movement of her shoulders, elevation of her hips, and finally, extension of her legs during the downbeat of the first dolphin kick. As indicated, the sequential nature of these undulating movements may

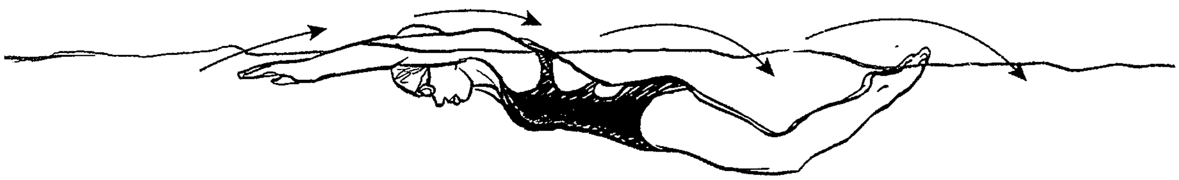


Figure 3.23 The body wave in swimming.

create a body wave or summation of forces that travel backward from head to feet, causing an additional amount of propulsive force during the downbeat of the first dolphin kick.

The body wave is a difficult concept to visualize, and even more difficult to accept. Nevertheless, it may be at work here. Observations of butterfly swimmers certainly show that the downward motion of the arms, head, and shoulders precede the upward undulation of the hips, which also precedes the major downward extension of the legs. Consequently, butterfly, and perhaps breaststroke, swimmers may actually use the sequential undulation of body parts to enhance their propulsion. It should not be overlooked that the effect of gravity may also play a role in enhancing propulsion, however. After butterfly and breaststroke swimmers have raised the head and shoulders out of the water to breathe, the effect of gravity may accelerate their reentry into the water. This, in turn, may pull the hips and thighs up and forward, accelerating or maintaining their forward velocity in the process.

Reverse Body Wave

I mentioned earlier in this chapter that the final downward portion of the dolphin kick downbeat may be a propulsive mechanism. I named this the *reverse body wave,* only because the term *body wave* had already been taken by Sanders and his colleagues. The reverse body wave may operate in the way illustrated in figure 3.24.

When butterfly swimmers kick down, the downward force from the legs will elevate the hips upward and forward over the water. As the hips pass over the peak of their upward undulation and start down, the downward force would normally have the effect of pushing the head and shoulders deeper into the water. If swimmers extend the arms forward and raise the head and trunk to a horizontal position, however, the downward force from the hips should push the body forward in the direction the hands and trunk are already moving. This, of course, is exactly what skilled butterfly swimmers do during this phase of the stroke. A key point in the timing of their strokes is to begin sliding the hands out and slightly up and to look up just as the hips pass over the peak of their upward undulation and start down. Breaststroke swimmers who use an undulating style also slide the hands and arms out and look up precisely as the hips pass over the peak of their undulation and start down.

The possible effect of gravity on propulsion at this time should also not be overlooked. After butterfly and breaststroke swimmers have raised the head and shoulders out of the water to breathe, the effect of gravity may accelerate the drop of those body parts back into the water. This, in turn, may pull the hips and thighs up and forward, accelerating them in the process.

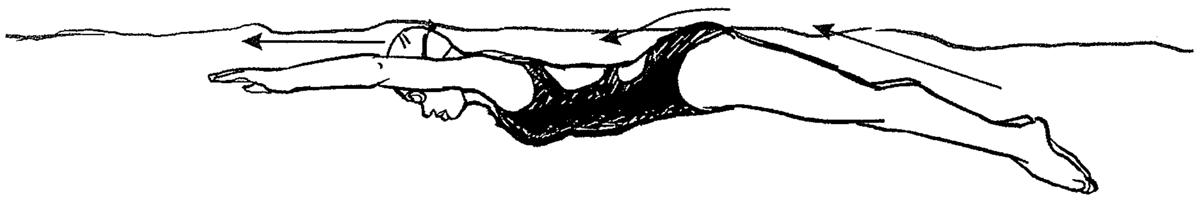


Figure 3.24 The reverse body wave.

Guidelines for Effective Swimming in all Four Competitive Strokes

Much of the material presented in this chapter has been theoretical and highly technical. To be useful to swimmers and coaches, it needs to be summarized and stated in simple terms that are applicable to competitive swimming. Below is a list of fundamental statements that apply to reducing water resistance and increasing propulsive force.

Fundamentals for Reducing Resistive Drag

- *Maintain lateral alignment in the front crawl and backstroke by rotating the body around its longitudinal axis in synchronization with the downward and upward movements of the arms.* The entire body must rotate, from head to toes, as an entire unit. Never try to maintain one part—the hips or legs, for example—in a flat position while the arms and shoulders are moving up and down.

- *To reduce form drag, keep the head in line with the trunk whenever possible.* The only time the head should be out of alignment is when it is lifted out of the water for a breath in the butterfly and breaststroke. The head should remain aligned with the trunk when it is rotated toward the side to breathe in the front crawl stroke.

- *Maintain horizontal alignment by swimming through the water, not over it.* Any efforts to elevate the head and shoulders above the water will only increase form and wave drag. The exceptions are the butterfly and breaststroke, in which swimmers should raise the head and shoulders out of the water to breathe. Even swimmers in these strokes should maintain a horizontal body position during the propulsive phases of the armstroke and kick, however, at least when it is possible to do so.

- *Body undulation is essential to propulsion in the butterfly and, to a lesser extent, in the breaststroke, but it should not be excessive.* Swimmers should raise the head and shoulders out of the water sufficiently to reduce resistive drag during breathing and, in the case of butterfly, to allow arm recovery without forward dragging. Undulation should take place at or just below the surface to a position above the surface where the breath is taken. Swimmers should not push the body underwater simply to increase range of undulation. Excessively pushing the body downward will only increase form drag.

- *All entry and recovery movements of the arms and legs should be "soft" and smooth to reduce pushing drag.* Where possible, keep the limbs within the cross sectional area of the body as they enter the water, and slide them forward through the water with the smallest and most tapered surfaces, the fingertips, facing forward.

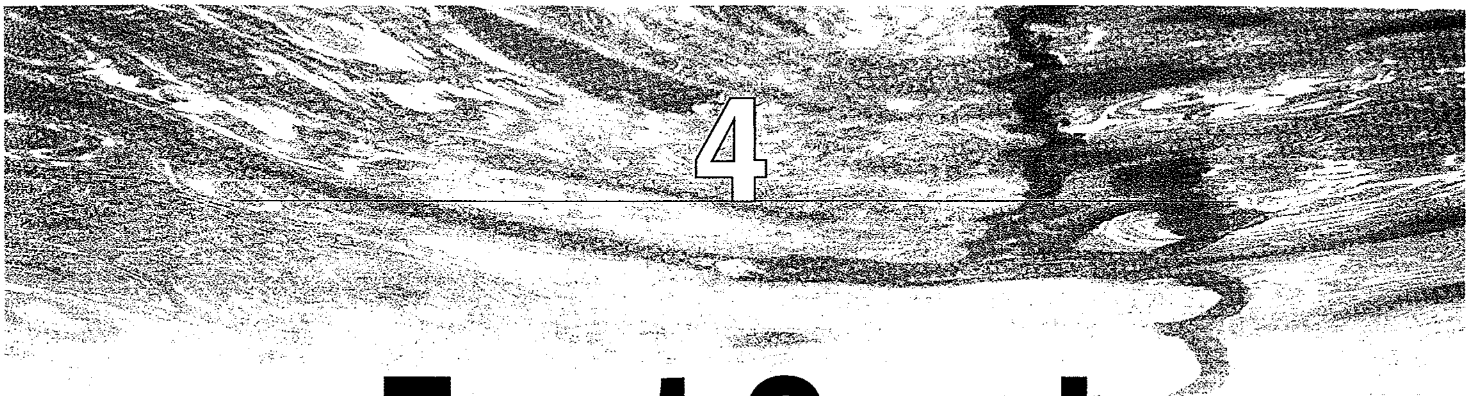
- *The first portions of all underwater armstrokes, the downsweep and outsweep, are not propulsive. Therefore, they should be executed softly and smoothly to keep pushing drag to a minimum.* Lead with the smallest and most tapered surfaces of the hands and arms, the fingertips, when sliding them down and out during the downsweeps and outsweeps of all four competitive strokes.

- *Don't kick any deeper, higher, or wider than necessary to produce an optimum amount of propulsive force.* Kicks that are excessively wide and deep will increase pushing drag and may disrupt horizontal and lateral alignment. Kicking upward excessively will push the body downward. Where possible, maintain an optimum leg spread that keeps the legs within the cross sectional area of the torso in both lateral and vertical directions.

- *Don't pull the legs into a flexed position in the flutter and dolphin kicks.* The legs should only travel upward to body level during the upbeat of the flutter and dolphin kicks (downbeat in the backstroke). The remainder of their upward motion should take place during the subsequent downbeat (upbeat in the backstroke). Leg flexion at this time may make it appear that the upbeat is still underway, but that flexion should occur as the thighs are actually pushing downward. At that time, the water underneath the relaxed lower legs will push the body upward into a flexed position until the legs start to extend at the knees. Use the minimum amount of muscular effort needed to flex the legs forward during leg recovery in the breaststroke.

Guidelines for Increasing Propulsive Force

- *Always wait until a high elbow catch position has been achieved before applying backward force against the water.* Inexperienced swimmers try to apply force when the arms are facing downward or against the water. They must learn to wait until they have positioned the undersides of the arms and the palms of the hands to push back against the water before applying force. The arms and hands should travel through approximately one-third of their underwater armstrokes before swimmers begin to push backward against the water.
- *The arms should be flexed approximately 90° when the catch is made, and they should not be extended or flexed further by any significant amount during the propulsive phases of the strokes that follow.* In other words, swimmers should form a boomerang-shaped paddle with the undersides of the arms and hands when they make the catch, and they should press backward against the water throughout the stroke without changing the shape of the arms appreciably. In this way, the work of forward propulsion is done by the large adducting and extending muscle groups of the shoulders and torso instead of the small muscle groups that tend to rotate the forearms and hands. The only exception to this rule occurs in the backstroke, in which the arms extend backward and below the thighs during the propulsive phase of their strokes.
- *Keep the palm of the hand and the underside of the forearm aligned as though they were one jointless unit during the propulsive phases of the various armstrokes.* The tendency to rotate the hand in and out in advance of the arm in the same direction and the tendency to overflex or hyperextend the hand at the wrist during the propulsive armstroke phase are two of the most common errors swimmers make. The hands do rotate during the various underwater armstrokes, but this is only because they are facing in the direction the arms are moving. This rotation is not initiated by rotating the palm and allowing the arm to follow. Swimmers should keep the palms of the hands aligned with the undersides of the forearms and allow the direction the arms are moving to dictate the pitch of the hands.
- *Always stroke in diagonally backward patterns during the propulsive phases of the underwater armstrokes.* Even though drag is probably the dominant propulsive force in swimming, pulling and pushing the arms straight back through the water will not provide the greatest distance per stroke, nor will it provide the fastest forward velocity. Effective swimming requires deviations from the straight backward application of force for all of the reasons described in this chapter and in chapter 1.
- *Hand speeds should accelerate in pulses with each major change in their direction, from the time they make the catch to the end of each underwater armstroke.* The hands accelerate in pulses during underwater armstrokes, slowing as they make the transition from one sweep to the next and then accelerating to the next point of transition. Nevertheless, hand velocity does accelerate from the start to the finish of their propulsive phases. Although they accelerate and decelerate in pulses, the hands should never reach maximum velocity until they are near the end of the propulsive phase of a particular underwater armstroke.
- *Propulsive efforts should cease as the hands approach the legs on their way to the surface.* Many swimmers make the mistake of pushing against the water until the hands reach the surface. Because the arms will be facing too far upward after they pass the legs, applying force at that time will not create any additional propulsion. Instead, it will push the body downward, decelerating forward speed in the process.



4

Front Crawl Stroke

New in this edition:

- A description of the front crawl armstroke based on drag-dominated propulsion
- A discussion of different catch styles and the advantages and disadvantages of each
- New drills for improving stroke technique

The front crawl stroke, or freestyle, has evolved into the fastest of the four competitive styles. One stroke cycle consists of a right and left armstroke and a varying number of kicks. For purposes of description, each armstroke has been divided into five distinct phases: (1) the entry and stretch, (2) the downsweep, (3) the catch, (4) the insweep, and (5) the upsweep and recovery. Where the relationship between armstrokes and leg kicks are concerned, swimmers use a variety of rhythms. The six-beat rhythm is most common. In it they execute six complete leg beats during each stroke cycle. A complete leg beat includes both an upbeat and a downbeat. Other common combinations of kicks per stroke cycle are the two-beat, two-beat crossover, four-beat, and four-beat crossover rhythms.

The various aspects of the front crawl stroke will be described in the following sections. I'll begin with a discussion of stroke patterns and center of mass velocity tracings, providing information on how each part of the stroke contributes to propulsion. The armstroke, flutter kick, and the timing between the arms and legs are described in the next section, followed by a description of body position and breathing techniques. The common mistakes athletes make when swimming this stroke is the topic of the next section, and the final two sections are concerned with drills for improving the front crawl stroke and the breathing patterns swimmers use in various races.

Stroke and Velocity Patterns

Stroke patterns have traditionally been constructed by plotting the movement of swimmers' middle fingers during their underwater stroking motions. They are also drawn from two points of view: relative to a fixed point in the pool and in relation to the swimmer's body.

Forward velocity patterns depict the changing forward velocity of a swimmer's center of mass during one complete stroke cycle. Hand velocity patterns, graphed according to the velocity of swimmers' middle fingers during their underwater armstrokes, illustrate the various changes in hand speed and their relationship to forward velocity during the underwater armstroke. These velocities are three-dimensional, in that they are algebraic summations of hand movements in all of the directions they travel during a particular phase of the armstroke. For example, a value for hand velocity during the latter phase of the insweep is a combination of swimmers' hand speeds in inward, upward, and backward directions.

Stroke Patterns

Side, front, and underneath views of front crawl stroke patterns are shown in figure 4.1. These particular stroke patterns are those of Tom Jager, world-record holder for the 50 m freestyle. They were drawn relative to a fixed point in the pool and are very similar to the patterns used by most world-class front-crawl swimmers. The various patterns clearly show the extent to which front-crawl swimmers use diagonal stroking motions for propulsion. The numbered dots on the stroke patterns designate the points where each phase of the underwater stroke begins and ends.

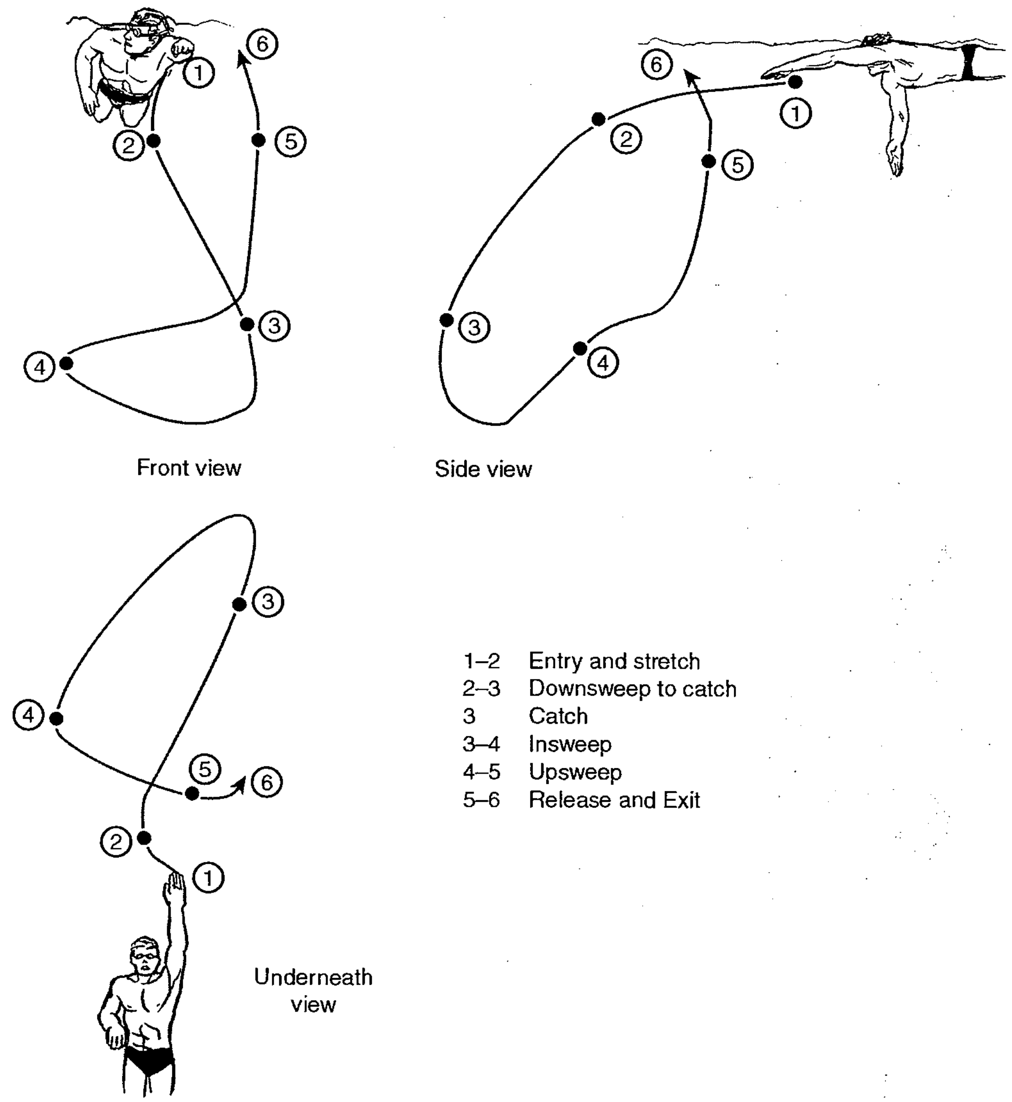
In figure 4.1, Jager's left hand enters the water when his right hand is under his body at mid-stroke. He slides the left arm forward, in a streamlined manner just under the surface, while he completes the propulsive phase of his right armstroke. This phase of the left armstroke has been termed the *entry and stretch.* It is non-propulsive and should be made with the utmost concern for reducing pushing drag so that right arm propulsion is not compromised. Notice that Jager's arm slides inward, toward the midline of his body, as well as forward. This provides better arm streamlining during the entry and stretch.

Jager begins sweeping his left hand downward at the instant the propulsive phase of the right armstroke ends. This phase has been termed the *downsweep*. The downsweep is also not propulsive. Its purpose is to move the arm deep enough in the water so that the undersides of the upper arm and forearm and the palm of the hand can be placed in a backward-facing position where they can apply propulsive force effectively. The point where that occurs is termed the *catch*.

As you can see, Jager's arm also travels forward and slightly outward during the downsweep. The forward movement allows him to reach farther forward before beginning to apply propulsive force, thus enhancing his distance per stroke. The slight outward motion allows him to position his upper arm backward at an earlier point in the downsweep so that propulsion can begin sooner.

Once the catch position has been attained, the stroke patterns show that Jager executes a complex circular sweep that brings his hand back and in under his body. This phase has been termed the *insweep*, and it is the first propulsive phase of the underwater armstroke. He starts pressing his arm back as the insweep begins, but it continues moving down and out for a short distance before changing direction to in and up. This rounding-off device helps him overcome inertia during the change of direction. The hand and arm continue moving back, in, and up until his hand is underneath his chest.

At this time, another transition, a *round-off*, takes place. Hand direction changes to out, back, and up in what I have termed the *upsweep*. The upsweep is the second pro-



1–2	Entry and stretch
2–3	Downsweep to catch
3	Catch
3–4	Insweep
4–5	Upsweep
5–6	Release and Exit

Figure 4.1 Typical stroke patterns for the front crawl stroke from front, side, and underneath views. These patterns were drawn from data provided by Tom Jager, world-record holder for the 50 m freestyle.

pulsive phase of the armstroke. It continues until the hand approaches the front of the thigh, where its direction then changes from back and up, to up and forward. No propulsion can be generated by a forward-moving hand. Consequently, swimmers release pressure on the water and slide the hand up, out, and over the water to the entry position for its next underwater armstroke.

Forward Velocity and Hand Velocity Graphs

Graphs of this type help us understand when swimmers apply propulsive force during their underwater armstrokes and what velocities we can expect from their propulsive efforts.

Forward Velocity Graph

A typical forward velocity graph is shown in figure 4.2. The swimmer is Francisco Sanchez, former NCAA champion in the 50 yd freestyle and three-time world short-course champion in the 50 and 100 m freestyles. He has a two-peak velocity pattern, which I believe is the most effective method swimmers can use.

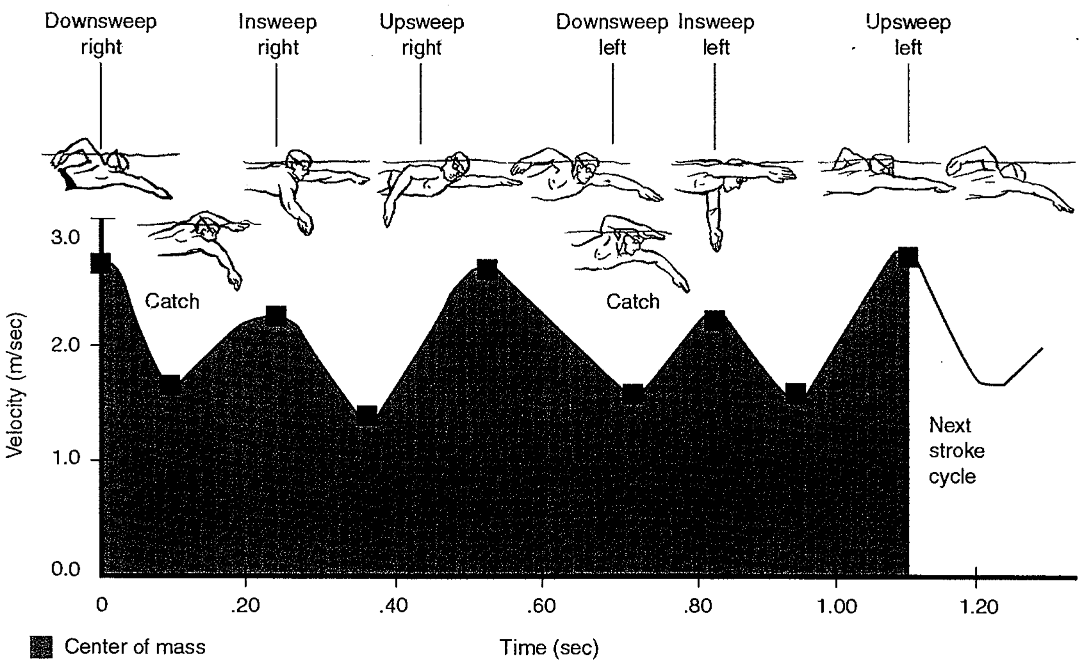


Figure 4.2 A forward velocity tracing for the front crawl stroke. The subject is Francisco Sanchez, world short course and NCAA champion in the 50 and 100 m freestyles.

The graph starts when he begins the recovery of his left arm and the downsweep of his right. His forward velocity declines approximately 1 m/sec during the downsweep of his right arm. This decline is unavoidable because he must position his arm for the catch before he can begin accelerating his body forward. Any attempt to begin the application of propulsive force earlier in the downsweep would only cause a greater loss of velocity. The reduction in velocity—approximately 1 m/sec, which takes place in 0.10 sec—is slightly greater than normal for world-class swimmers. Miyashita (1997) reported decreases in velocity of 0.5 to 0.8 m/sec for skilled front-crawl swimmers.

Sanchez begins accelerating his body forward with his right armstroke at the catch and continues to do so during most of the insweep that follows. Another, normal, decline in forward velocity occurs during the transition from the insweep to the upsweep as he changes the direction of his right arm from in to out. As indicated, this deceleration is also unavoidable if swimmers want to achieve a propulsive peak during the upsweep like the one shown in figure 4.2. Some swimmers use a straight-line application of force during the insweep and upsweep that results in one peak being produced by both sweeps. This *one-peak* propulsive style will be discussed in a later section.

Sanchez releases pressure on the water with his right arm when his body reaches its peak forward velocity during the upsweep. The left arm, which entered the water earlier, then begins its downsweep. The pattern for the left armstroke is very similar to that of the right armstroke, but there are a few important differences. The first of these is that velocity declines more and for a longer period of time during the downsweep of the left arm. The second is that the propulsive peaks during the insweep and upsweep are slightly lower and shorter in duration. Obviously, his left armstroke is not as effective as his right where propulsion is concerned. Asymmetry of this type is characteristic of every swimmer I have tested. The left arm is usually, but not always, the least-effective propelling agent.

Hand Velocity Graphs

The graphs in figure 4.3 show hand and forward velocity patterns for Carrie Steinseifer, cowinner of the gold medal for the 100 m freestyle at the Los Angeles Summer Olympics in 1984.

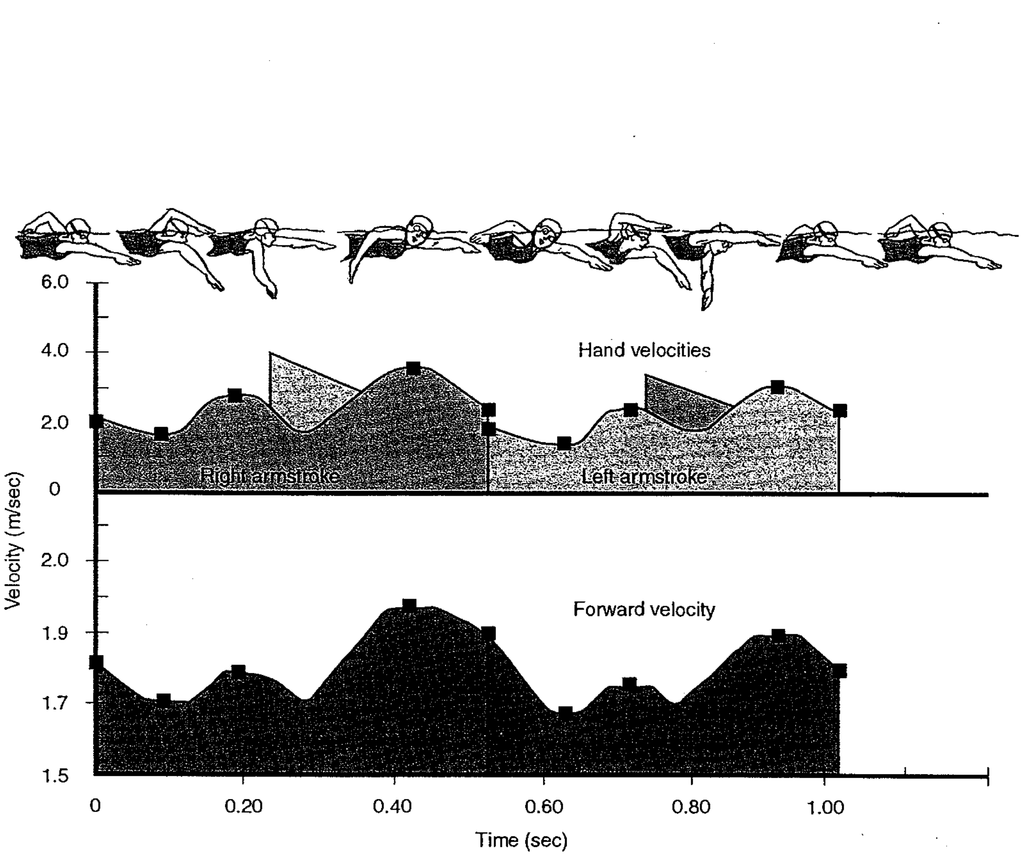


Figure 4.3 An example of body and hand velocity patterns for the front crawl stroke of Carrie Steinseifer, co-champion of the 100 m freestyle at the 1984 Olympic Games.

Her hand velocity varied from approximately 1.8 m/sec at its slowest point to nearly 4 m/sec at its highest. Notice that the increases and decreases in her hand velocity occur in pulses, which correspond to each of the major phases of her armstroke: the downsweep, insweep, upsweep, and recovery. The arm decelerates during each major change of direction from one stroke phase to the next and then accelerates throughout the succeeding phase until the transition to the next phase begins. You can also see that these increases and decreases in hand velocity mirror accelerations and decelerations of forward velocity.

In addition to those just mentioned, there are several other interesting aspects to these hand and forward velocity graphs. The first of these concerns the time interval between the entry of the hand into the water and the beginning of the downsweep. In figure 4.3, the hand velocity graphs for Steinseifer show an interval, 0.20 to 0.30 sec, from the time her hands enter the water until they begin the downsweep. This indicates that front crawl swimmers do not begin moving the arms into position for the catch immediately upon entry. Instead, they intuitively choose to streamline the arm in front until they have completed the propulsive phase of the preceding armstroke. Then they begin sweeping it downward to make the catch.

A second feature of the hand velocity graphs in figure 4.3 that reveals an important technical aspect concerns the loss of hand velocity during the downsweep of each armstroke. Steinseifer's hand velocities decline until they approximate her forward velocity during the downsweep of each arm. This means that her hand and arm are almost motionless when the catch is made. The hand and arm are really moving forward at the same speed as her body, which means that they are being pushed forward by the body. I cannot state too strongly that *swimmers must wait until they have established a good catch before they attempt to apply propulsive force with the arms.*

Another interesting facet is that she accelerates her hands only moderately during the insweep. Hand velocities reach approximately 3 m/sec during the insweep, but she is able to accelerate them to 4 m/sec during the upsweep. She may be gradating the acceleration of her arms purposefully so that they reach peak velocity during the upsweep. On the other hand, it may be that she is not able to accelerate her hands to the same insweep peak velocity that she reaches during the upsweep. The upper arm is used as part of the arm and hand paddle during the insweep, whereas only the forearm and palm are pressed back against the water during the upsweep. Perhaps the additional surface area provided by the upper arm reduces the peak velocity of the hand during the insweep.

Steinseifer's hand velocities just before leaving the water demonstrate an important technical point, one that runs counter to traditional teaching. Notice that her hand velocity decreases just after her body reaches its peak forward velocity during the upsweep. This deceleration of her hand velocity takes place while her hand is still in the water and provides convincing evidence that swimmers do not try to push back against the water until the hands reach the surface. If they did, hand velocities would continue to accelerate until the hands left the water.

A final revelation about stroke technique, evident from the forward velocity patterns in both figures 4.2 and 4.3, concerns the difference in propulsion generated by the right and left armstrokes. Both Sanchez and Steinseifer get more propulsion from their right armstrokes. During their respective downsweeps, the valleys for their left armstrokes are deeper and slightly longer than those of their right armstrokes. The propulsive peaks of their left armstrokes are also lower in magnitude and shorter in duration than those of the right.

The reason, or reasons, for these propulsive differences is not known. The most obvious explanation would be that they are due to differences in strength between the right and left arms. I doubt the validity of this explanation, however. I have put swimmers through various tests of arm strength, both on land and in water, and have then compared these with velocity graphs of their forward propulsion. Those tests did not demonstrate that the weaker arm was always the least propulsive of the two.

Another possible explanation has to do with breathing and body position. The less-propulsive arm is usually the one on the nonbreathing side. Perhaps swimmers must use some of the force produced by the arm on the nonbreathing side to realign the body after breathing. An even more plausible explanation is that they do not realign the body properly after breathing and, therefore, lose some propulsive force by compromising the technique of that arm. A great number of swimmers fail to roll the body back beyond the midline toward the nonbreathing side after breathing. Consequently, they have to pull the arm on the nonbreathing side across the body more to get it under the midline. Additionally, they have to swing it out wider during the upsweep to clear the hips as that arm leaves the water. Both of these actions may reduce the propulsive force from that armstroke.

In my opinion, failure to roll the body equally to both sides provides an explanation for the differences in propulsive effectiveness between the two armstrokes. It does not provide a complete explanation, however, because propulsive differences between the two arms have been found in the butterfly and breaststroke, in which body rotation is not used. This leads me to believe that lateral dominance may also be involved. In fact, it may be the principal factor that causes propulsive asymmetry between the right and left armstrokes. Swimmers probably develop a heightened kinesthetic sense in the arm they have used most since birth, the so-called dominant arm. As a result, they may be able to stroke more correctly with the dominant arm and thus gain more propulsion from it. Observations of swimmers' strokes have indicated to me that the dominant arm usually has fewer bubbles around it and appears to move through the various sweeps with greater precision, which suggests a more effective armstroke.

If lateral dominance is the principal reason for propulsive asymmetry between the right and left armstrokes, special drills that can increase the propulsive effectiveness of nondominant arms could improve performance considerably. I have three drill suggestions that may help swimmers improve the mechanics and endurance of their nondominant armstrokes.

1. Practice one-arm swimming with the nondominant arm.
2. Make a fist with the dominant arm and swim with an open hand on the nondominant arm so that it carries most of the load.
3. Concentrate on nearly equal rotation to the right and left. Swimmers should rotate toward the nonbreathing side enough to encourage strong insweep and upsweep with the arm on that side. Swimming with alternate breathing is a good drill for this purpose. This drill promotes equal body rotation to both sides and may encourage better use of the nondominant arm. Swimmers can return to one-side breathing once the nondominant arm has become a more effective propulsive agent.

One-Peak and Two-Peak Velocity Patterns

Research with members of the 1984 U.S. Olympic team showed that front-crawl swimmers tended to fall into two categories according to the way they applied propulsive force (Maglischo et al. 1986; Schleihauf et al. 1988). Some had two peaks of acceleration during each underwater armstroke while others had only one.

Two-Peak Pattern

Two-peak patterns were illustrated in figures 4.2 and 4.3 (see pages 98 and 99). The swimmers in these figures had two distinct peaks of forward velocity during each armstroke, one during the insweep and the other during the upsweep. Those peaks were separated by a period of deceleration in forward velocity that served as a transition from one stroke phase to the next. Swimmers who use a two-peak style typically sweep the hand into and often beyond the midlines of the body, which provides a longer insweep. They must then sweep the hand out from underneath the body, which provides a longer upsweep. These actions provide a longer pulse of propulsion during each stroke phase. Unfortunately, the price they pay for these two long propulsive sweeps is a transition period when forward velocity decelerates considerably.

One-Peak Pattern

A one-peak velocity pattern is illustrated in figure 4.4. In this pattern, one large peak of forward velocity takes place during the combined insweep and upsweep of each armstroke. Unlike the two-peak style, there is no deceleration period between the two sweeps.

Swimmers who use a one-peak style tend to use a stroke pattern that is less diagonal. They sweep the hands in less during the insweep and out less during the upsweep. The insweep and upsweep become almost one continuous motion, with only a small change of direction under the body. The advantage of this style is that these swimmers reduce the loss of velocity during the transition from insweep to upsweep. The disadvantage is that they shorten the length of the insweep, and in some cases the upsweep as well. Consequently, they do not achieve the same forward velocity during these phases.

You can usually tell whether swimmers are using a two-peak or one-peak velocity style by the amount they bring the hands in under the body. Obviously, two-peak swimmers will sweep the hands in under the body to a greater extent during the insweep.

You may be wondering whether one of these styles is better than the other. That is not an easy judgment to make because both styles have been used by world-record holders. Indeed, Matt Biondi was a two-peak swimmer and Rowdy Gaines used a one-peak style, yet both were world-record holders and Olympic champions in freestyle events during their careers. Ultimately, the most effective style for each swimmer will be the one that produces the greatest average velocity per armstroke. For some this may be a one-peak style, for others the two-peak method may be more effective.

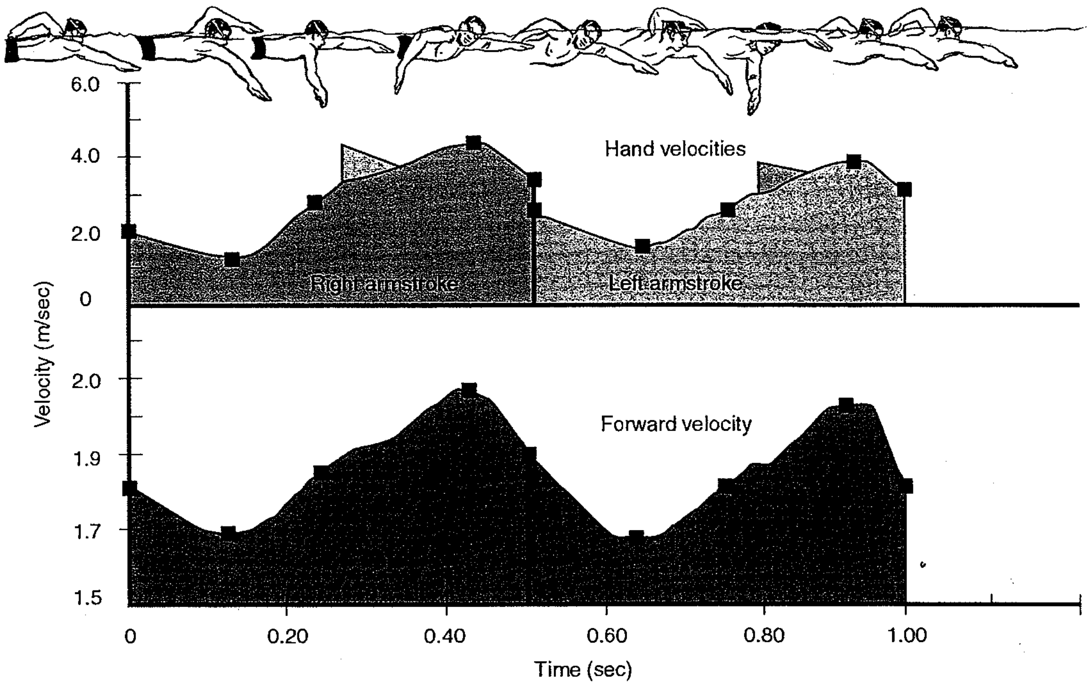


Figure 4.4 A one-peak forward velocity pattern for the front crawl stroke.

Although true, statements like this often leave us in a quandary as to which style should be taught to developing competitive swimmers. I believe we should teach the two-peak style because it has the potential to be more effective for the majority of swimmers. Two-peak swimmers are more likely to achieve a higher average velocity per armstroke because they can apply propulsive force over a longer time with less muscular effort. The increased diagonal position of the two-peak pulling pattern should provide the potential for a longer distance per stroke. In addition, two-peak swimmers should not need to accelerate hand and arm velocities as much to gain the same forward acceleration. One-peak swimmers gain propulsion by pushing one segment of water back with a constantly accelerating arm. Their stroke rates will be short and fast. Two-peak swimmers push back against one segment of water until it is accelerated, then move to another slower segment and accelerate it backward. Thus, two-peak swimmers should be able to achieve the same forward velocity with longer and slower armstrokes.

Why do some swimmers select a one-peak style? The obvious answer is that it may be best for their particular body type. I tend to reject arguments like this, however, because I believe the principles of effective propulsion apply to all, regardless of body type. In reality, the choice of a one-peak style may be dictated by several other factors, some of which do not necessarily dictate it as the best choice.

One of these factors is the kicking rhythm. There seems to be a tendency for swimmers with minimal kicking rhythms to use a one-peak style, perhaps because fewer kicks allow for a faster turnover rate. This is particularly true of females, who tend toward one-peak stroke styles and two-beat kicks. Swimmers who use a greater number of kicks per stroke cycle may tend toward a two-peak style because it provides more time for kicking.

Another possibility is that one-peak swimmers might have been taught according to the *push straight backward* theory. Consequently, many very talented swimmers may have developed a one-peak style early in their careers and were then not able to change that style without disturbing stroke fluidity and, thus, their speed. A third possibility may be that some swimmers intuitively sense the reduction of forward velocity during the transition from the insweep to upsweep and, believing it is not desirable, they try to eliminate it by reducing the diagonal movement of their arms during the insweep.

Short of cloning, we can probably never know if swimmers who use a one-peak style might have been faster using a two-peak style. As mentioned earlier, some swimmers may not be able to change a style that has been ingrained by years of competition and hundreds of miles of training without disturbing fluidity and reducing average stroke velocity. Therefore, my advice would be to teach young swimmers a two-peak style because it has the potential to be superior to the one-peak style. However, changing the strokes of older swimmers, particularly those who are successful, should be approached with caution.

Armstroke

For purposes of explanation, the armstroke has been divided into the following stroke pattern phases: the entry and stretch, the downsweep, the catch, the insweep, the upsweep, and the release and recovery. The photos in figures 4.5 and 4.6 show key points in the underwater armstroke from side and front views.

Entry and Stretch

One hand enters the water when the other is at mid-stroke. The entering arm should then be stretched directly forward in a streamlined manner (see figure 4.5 e-h). For better streamlining, the body should be rotated downward on the side of the entering arm during the stretch. This, of course, will result in the body rotating upward on the side of the stroking arm so that the stroking arm can sweep up past the hips and legs without traveling too far out during its upsweep. In this way, the stroking arm can push back against the water more effectively during the upsweep and, thus, be more propulsive.

The entering arm should slice into the water softly and smoothly to reduce pushing drag. The hand should enter the water forward of the head and between the middle of the head and the tip of the shoulder on the entry side. The arm should be flexed slightly and the palm should be facing slightly outward so that it can enter on edge. The fingertips should enter the water first. After entry, to create as little turbulence as possible, the arm should slide into the water through the same hole opened by the hand.

After entering the water, the arm should be extended forward and in, toward the middle of the body, just under the surface. The palm of the hand should be rotated down as the stretch nears completion and it should be stretched slightly forward and in so that it stays within the confines of the body, both from its lateral and vertical aspects. In this respect, the entering arm acts like the bow of a ship, allowing the oncoming streams of water to split around it so there will be less turbulence as the body passes through.

The length of the stretch will depend on the degree of overlap between the entering and stroking arms. If one arm enters the water when the other is starting its insweep, the stretch will be rather long. If the recovering arm enters the water near the end of the insweep of the stroking arm, however, the stretch will be made more quickly.

Some swimmers rotate the palm in and down during the stretch. Others rotate the palm until it is facing down at the end of the stretch. Still others keep the palm pitched slightly out as they stretch the arm forward. Rotating the palm down and in is probably the best method, providing the stretch is reasonably long. This is because sliding the arm toward the midline and rotating the palm in encourages better body rotation and streamlining. Nevertheless, any of the methods mentioned are satisfactory, provided

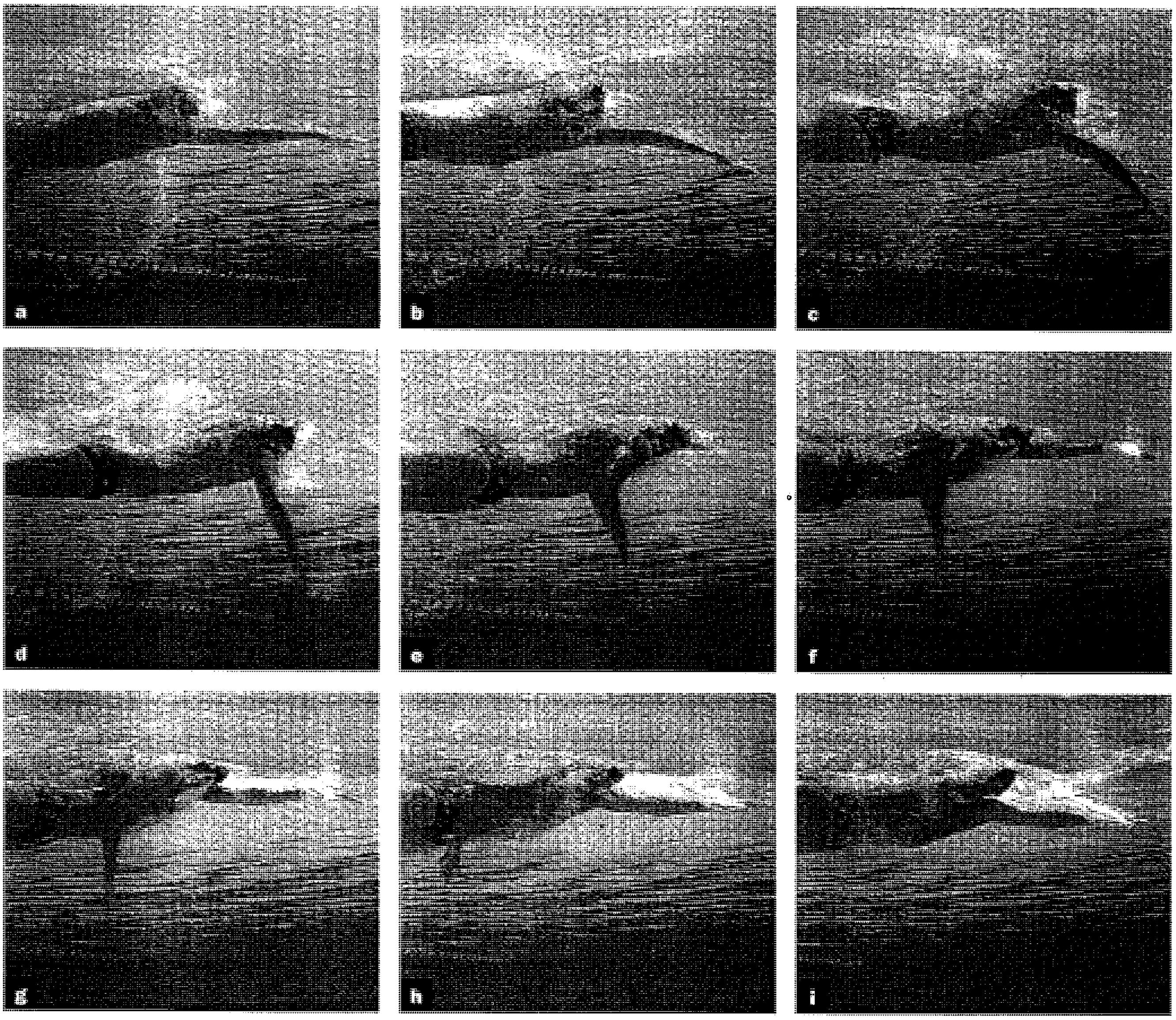


Figure 4.5 Side view underwater sequence of Francisco Sanchez swimming the front crawl stroke. Sanchez was an NCAA champion in the 50 yd freestyle and three-time short course world champion in the 50 and 100 m freestyles.

(*a*) End of upsweep with left arm. Start of downsweep with right arm.
(*b*) Downsweep with right arm. Recovery with left arm.
(*c*) Catch with right arm. Continuation of recovery with left arm.
(*d*) Mid-insweep with right arm. Continuation of recovery with left arm.
(*e*) End of insweep with right arm. Entry of left arm.
(*f*) Transition from insweep to upsweep with right arm. Stretch with left arm.
(*g*) Upsweep with right arm. Continuation of stretch with left arm.
(*h*) End of upsweep with right arm. Continuation of stretch with left arm.
(*i*) Recovery with right arm. Start of downsweep with left arm.

the body rotates sufficiently and the arm stays within the confines of the body as it stretches forward.

Hand velocity should decrease, from the entry and throughout the stretch, until the arm is simply being pushed forward by the forward-moving body near the end of the other arm's propulsive phase.

Downsweep

The major purpose of this sweep is to move the arm into position for the catch. This should be done as gently and rapidly as possible, using only the minimum force needed to move the hand and arm down into the catch position.

The downsweep should begin the instant swimmers release pressure on the water with the other arm. The downsweep is initiated by flexing the wrist to start the hand moving downward (see figure 4.5a-b). The arm is then swept down and forward in a curvilinear path. It is important that swimmers keep the hand and arm moving forward during the downsweep. Any attempt to push back on the water will result in a classic dropped elbow reaction, which will cause them to push down on the water with unnecessary force and their forward velocity will be reduced even more rapidly than it is already declining.

The arm should be flexed as it travels down. Flexion continues until the swimmer's elbow rides up, above the hand, and the hand, forearm, and upper arm are all aligned and facing backward in the classic high elbow catch position.

Although the upper arm moves slightly outward during the downsweep, swimmers would be wise to ignore this aspect of the movement. The outward motion of the hand and arm tend to occur naturally as a result of elbow flexion. It has been my experience that swimmers who focus on sliding the arm out generally overdo this facet of the downsweep and push water out too much.

The upper arm should not be pressed down any more than necessary during the downsweep. Ideally, it should remain parallel with the surface and move out, toward the side, as the arm is flexing at the elbow. But most swimmers find it necessary to press the upper arm down somewhat to reduce the intensity of humeral rotation in the shoulder joint, which can cause friction with the various ligaments and tendons and, thus, tendinitis. My best advice is to slide the upper arm down only enough to reduce friction in the shoulder. This will keep the downward force of the upper arm to a minimum while preventing shoulder pain.

Hand and arm velocities will accelerate slightly at the start of the downsweep, but they should decrease again once the downsweep is underway and until the hand is barely moving when the catch is made.

During the downsweep, the body will continue rotating downward on the stroking side and upward on the recovering side. The other arm will leave the water and travel through the first half of its above-water recovery while the downsweep is being made.

Catch

The catch position for the right armstroke is shown from front and side views in figures 4.5c and 4.6d respectively. The catch for the left armstroke is shown in figure 4.6l. The arm should be flexed approximately 90° at the elbow when the catch is made. The hand will be fairly deep, approximately 50 to 70 cm (20 to 28 in), at the catch (Schleihauf et al. 1988; Deschodt, Rouard, and Monteil 1996). The arm and hand will be outside the shoulder and facing back and slightly out. At the catch, the swimmer begins the first propulsive phase of the underwater armstroke, the insweep, by pressing the arm back as well as down.

As mentioned, the palm of the hand and the undersides of the forearm and upper arm will be facing back and slightly out at the catch. Once again, however, this pitch of the hand and arm is a natural result of arm flexion during the downsweep and should not be focused on.

There appear to be three distinct styles swimmers use when making the downsweep and catch. These styles are shown in figures 4.7a and b and in figure 4.8. Both of the catch positions in figure 4.7 are satisfactory. The one in figure 4.8 is not recommended, however.

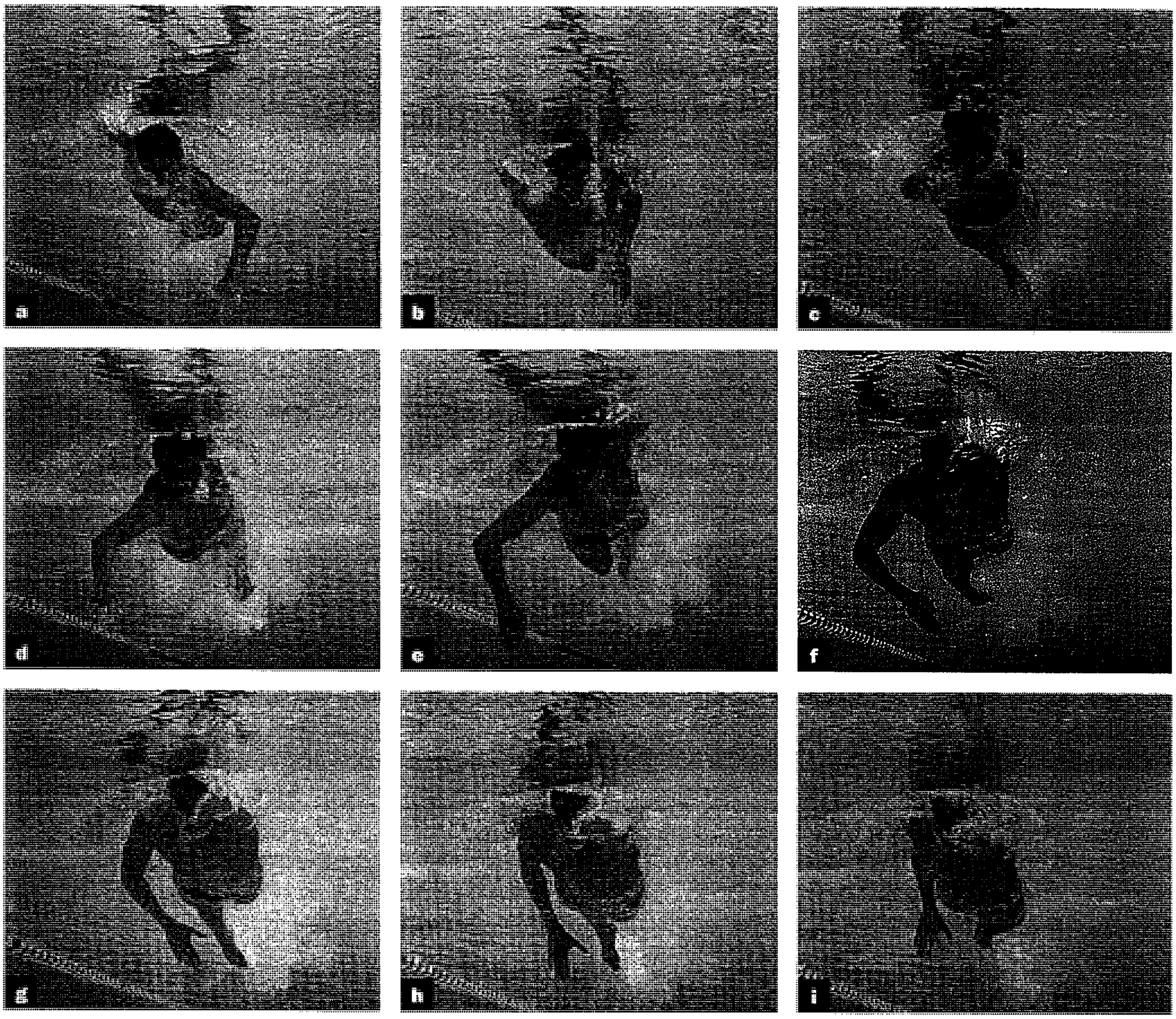


Figure 4.6 Front view underwater sequence of Francisco Sanchez swimming the front crawl stroke.

(*a*) Entry of right arm. Insweep with left arm.
(*b*) Stretch with right arm. Upsweep with left arm.
(*c*) Start of downsweep with right arm. Release and recovery with left arm.
(*d*) Catch with right arm. Recovery with left arm.
(*e*) Mid-insweep with right arm. Entry of left arm.
(*f*) End of insweep with right arm. Stretch with left arm.
(*g*) Transition from insweep to upsweep with right arm. Continuation of stretch with left arm.
(*h*) Mid-upsweep with right arm. Continuation of stretch with left arm.
(*i*) End of upsweep with right arm. Beginning of downsweep with left arm.

The catch position of the most common style is shown in figure 4.7a. This swimmer does not sweep his arm down very much. Instead, he moves his arm out to the side, and flexes his elbow quickly so that the catch can be made quickly. When the catch is made, his upper arm is out to the side, with the forearm and hand below it, and also considerably outside the shoulder. In the catch position for the second style, shown in figure 4.7b, the swimmer rolls toward the side more and, therefore, sweeps her arm

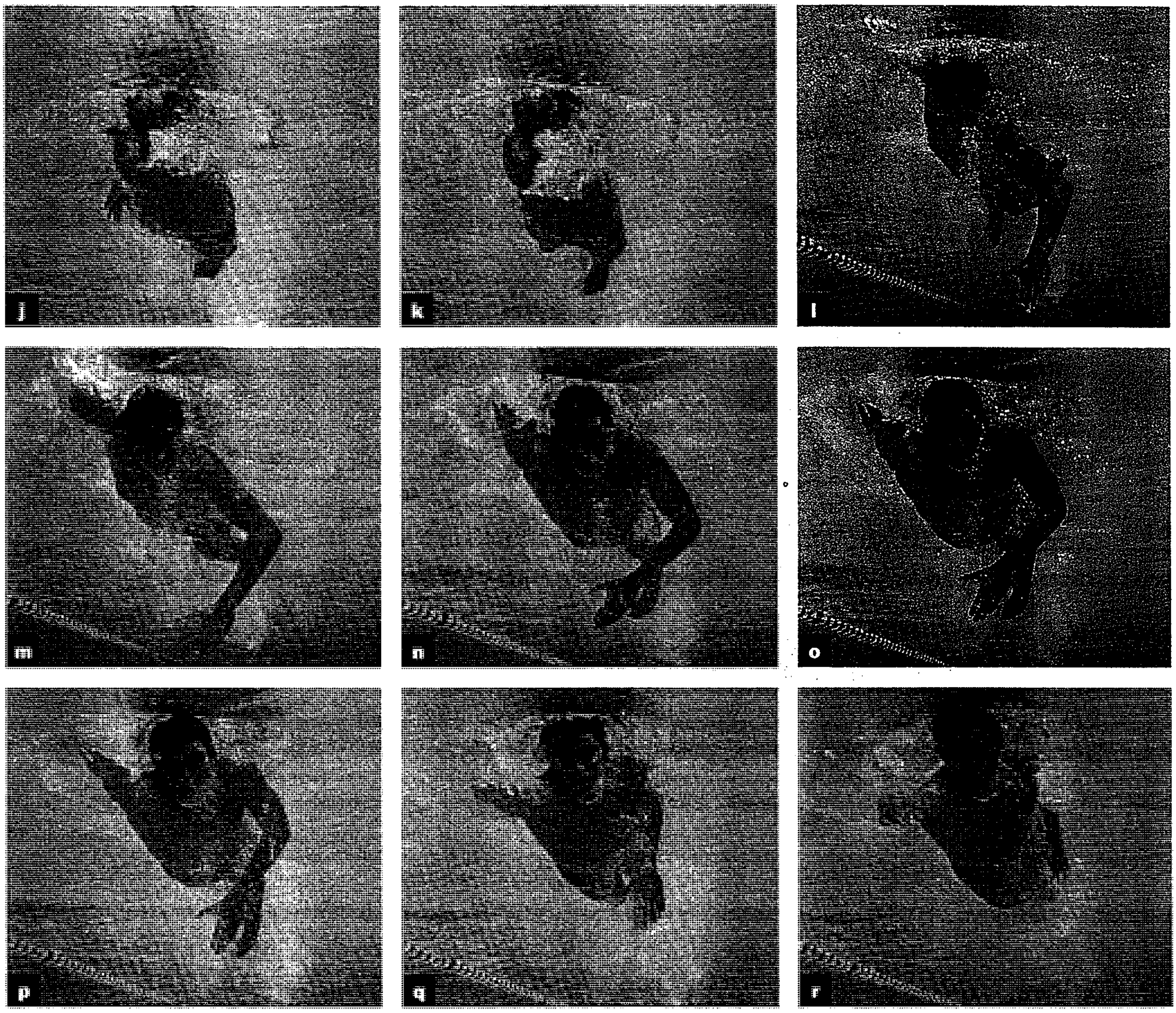


Figure 4.6 *(continued)*

(j) Release with right arm. Start of downsweep with left arm.
(k) Downsweep with left arm. Recovery with right arm.
(l) Catch with left arm. Entry of right arm.
(m) Mid-insweep with left arm. Stretch with right arm.
(n) End of insweep with left arm. Continuation of stretch with right arm.
(o) Transition from insweep to upsweep with left arm. Continuation of stretch with right arm.
(p) Upsweep with left arm. Continuation of stretch with right arm.
(q) End of upsweep with left arm. Start of downsweep with right arm.
(r) Release with left arm. Continuation of downsweep with right arm.

deeper. But she still moves it out to the side, resulting in the catch being made with her elbow somewhat lower in the water and with her hand only slightly outside her shoulder.

Because both styles are common among many world-class swimmers, it is impossible to recommend one over the other. I can speculate on the advantages and disadvantages of each, however. One significant advantage of the style illustrated by figure 4.7a is that

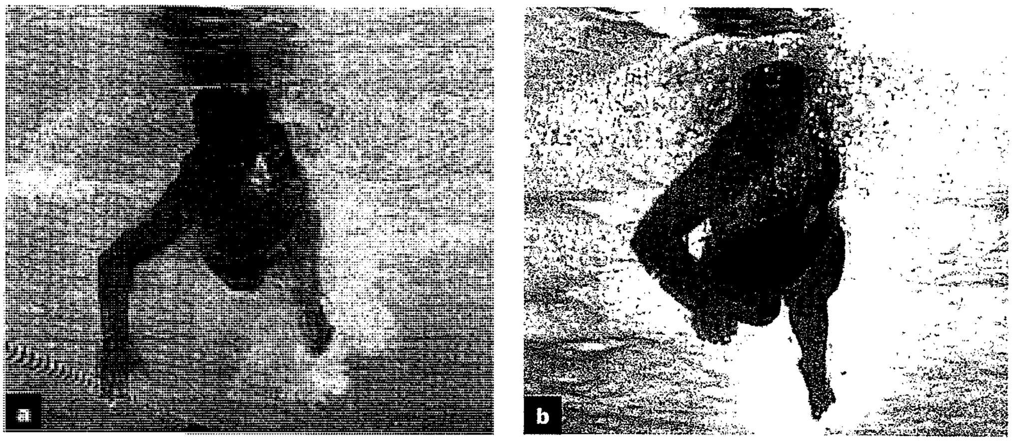


Figure 4.7 Two styles for the catch. The photo in *(a)* shows a high catch position, characterized by a very high elbow with the arm outside the shoulder. The photo in *(b)* shows another popular catch position, in which the arm travels down more and out less so that the hand is only slightly outside the shoulder when the catch is made.

the catch can be made quickly. Consequently, the period of deceleration between the end of the propulsive phase of the previous armstroke and the beginning of the propulsive phase of the present armstroke can be shortened. A second advantage is that pushing drag will be lessened because the upper arm will not be pushed as far down through the water. The third advantage has to do with the fact that the upper arm is positioned to press almost directly back against the water, where it can provide additional propulsive force during the insweep.

The major disadvantage of this style—and it is a serious disadvantage—is that the head of the humerus is thrust forward to a greater extent when the catch is made quickly and high. Thus, those swimmers with a tendency toward tendinitis are more likely to experience painful friction between the head of the humerus and the tendons of the shoulder joint. The second possible disadvantage is that the initial propulsive phase of the insweep will take place well outside the confines of the body.

One big advantage of a longer and deeper downsweep, as pictured in figure 4.7b, is that it is not as likely to cause tendinitis. Moving the upper arm down somewhat deeper will allow swimmers to achieve a high elbow without thrusting the head of the humerus forward as much. A second advantage is that almost the entirety of the insweep will be made within the confines of the body, where the application of propulsive force should cause greater forward acceleration.

The disadvantages of this style are the opposite of the advantages of the high catch. The downsweep will be longer, providing more time for a deceleration of forward velocity. It is also probable that pushing drag will be increased somewhat because the upper arm will be pressed deeper into the water. In addition, the upper arm will have to travel farther upward later in the stroke if it is pressed deeper to make the catch. Therefore, some of the propulsive force from the upper arm may be lost because it will be pressing up more.

The catch position shown in figure 4.8 is different from the previous two in some important ways. Notice that the swimmer's arm is very deep in the water and that it is almost fully extended.

Figure 4.8 The photo shows an improper technique for making the catch. The swimmer's arm is too deep and too straight when it reaches the catch position, which will increase resistive drag and reduce propulsion during the insweep that follows.

Although used by many swimmers, this catch position cannot be recommended for several reasons. First of all, the swimmer would have pushed his upper arm and forearm a considerable distance downward before they achieve a backward-facing position. The downward force, no matter how gentle, will only push his body up and cause an additional deceleration in his forward velocity. Because his arm is so deep, he will push it up excessively during the insweep, increasing pushing drag and reducing the production of propulsive force in the process. Finally, when the catch is made with a nearly straight arm, the swimmer will tend to flex his arm excessively during the insweep, sculling more than pushing, and this will reduce the propulsive force he can produce.

Insweep

The insweep is pictured from a side view for a swimmer's right armstroke in figure 4.5d and e (page 104). It is pictured for the right armstroke from a front view in figure 4.6e and f and for the left armstroke in figure 4.6m and n (pages 106 and 107).

The insweep begins at the catch. Once the underside of the entire arm and the palm of the hand are facing back in the classic high elbow position, the swimmer executes a semicircular back sweep that continues until his hand is underneath his chest. The undersides of the upper arm and forearm and the palm of the hand should form a large, boomerang-shaped paddle that is used to push back against the water during the insweep. To apply the greatest amount of propulsive force, swimmers should use the large muscles of the back and shoulders to press back against the water with this paddle.

The transition from the downsweep to the insweep is made smoothly by continuing the downward and somewhat outward movement of the hand that takes place during the downsweep *while* changing the arm's direction from forward to back. Once the arm is moving back, and if forward inertia has been overcome, it should also be brought back, up, and in, under the chest, to complete the insweep. The insweep ends when the upper arm is back, nearly against the ribs, and the hand is underneath the chest and near the midline of the body.

The pitch of the arm will change from out to in during the insweep. This does not happen because swimmers are sculling the hand in, however. It is simply because the direction of the upper arm changes from out and back to in and back during this sweep. The semicircular back- and insweep of the arm should be an adducting motion that takes place in the shoulder joint. The forearm and palm should not be rotated inward at the elbow joint during this adducting motion. They should remain rigidly aligned, just as they were at the catch, and there should be no twisting at the elbow and no rotation or supination of the palm. The adducting motion at the shoulder joint will quite naturally change the pitch of the arm and hand from out to in at precisely the proper time during the insweep. Sculling motions will only cause a dropped elbow and a loss of propulsion.

The arm should not be flexing to any great extent during the insweep. That is, the catch should not be made with an extended or nearly extended arm, which is then gradually flexed during the insweep. Flexing the arm during the insweep will only result in a dropped elbow and loss of propulsive force.

As indicated, the arm should be flexed nearly 90° at the elbow during the downsweep. It should then remain almost equally flexed during the entirety of the insweep. In some cases, the amount of flexion may increase slightly during the second half of the sweep to better position the hand and forearm for the upsweep that follows. Any increase in the amount of elbow flexion should be minimal, however.

Hand speed should accelerate moderately from start to finish of the insweep. Hand velocities usually accelerate from approximately 1.5 m/sec to between 2.5 and 3 m/sec at the end of the insweep (Maglischo et al. 1986; Schleihauf et al. 1984).

The first part of the insweep is probably the most propulsive phase. Propulsive force tends to decline during the latter portion, principally used to place the arm under the body's midline, where the first part of the succeeding upsweep can be executed more effectively. The velocity patterns in figure 4.2 and 4.3 (see pages 98 and 99) show an increase in forward velocity during the first part of the insweep. This is followed by a loss of velocity during the latter portion, where the transition between insweep and upsweep occurs. The two drawings in figure 4.9 show how, I believe, propulsive force is produced during the insweep. Propulsion during the first half is illustrated in figure 4.9a, and figure 4.9b shows how propulsion is generated during the second half of the insweep.

Some swimmers sweep the hand inward, to the midline of the body, and others sweep it well beyond the midline. Still others do not bring the hand under the body very much at all. These three insweep styles are illustrated in figure 4.10. The swimmer in figure 4.10a uses a short insweep. The swimmer in figure 4.10b sweeps her hand in to the midline, and the swimmer in figure 4.10c is using a long insweep with his hand traveling well beyond the midline of his body.

The insweep style used by different swimmers probably depends on early teaching and, perhaps, the position of the arm relative to the body when the catch is made. Some swimmers probably feel their forward velocity decelerating and begin the upsweep prematurely to counteract it. As a result, using a style similar to the one illustrated in figure 4.10a, they push the arm backward in a nearly straight line and it does not travel under the body as much. Swimmers who use this method usually have one-peak velocity patterns.

Many highly successful swimmers, particularly females, use this method. Nevertheless, I would not recommend it over the style shown in figure 4.10b, for two reasons. First, swimmers who use this method will need to accelerate the same segment of water back during the insweep and upsweep. Second, the first portion of the succeeding up-

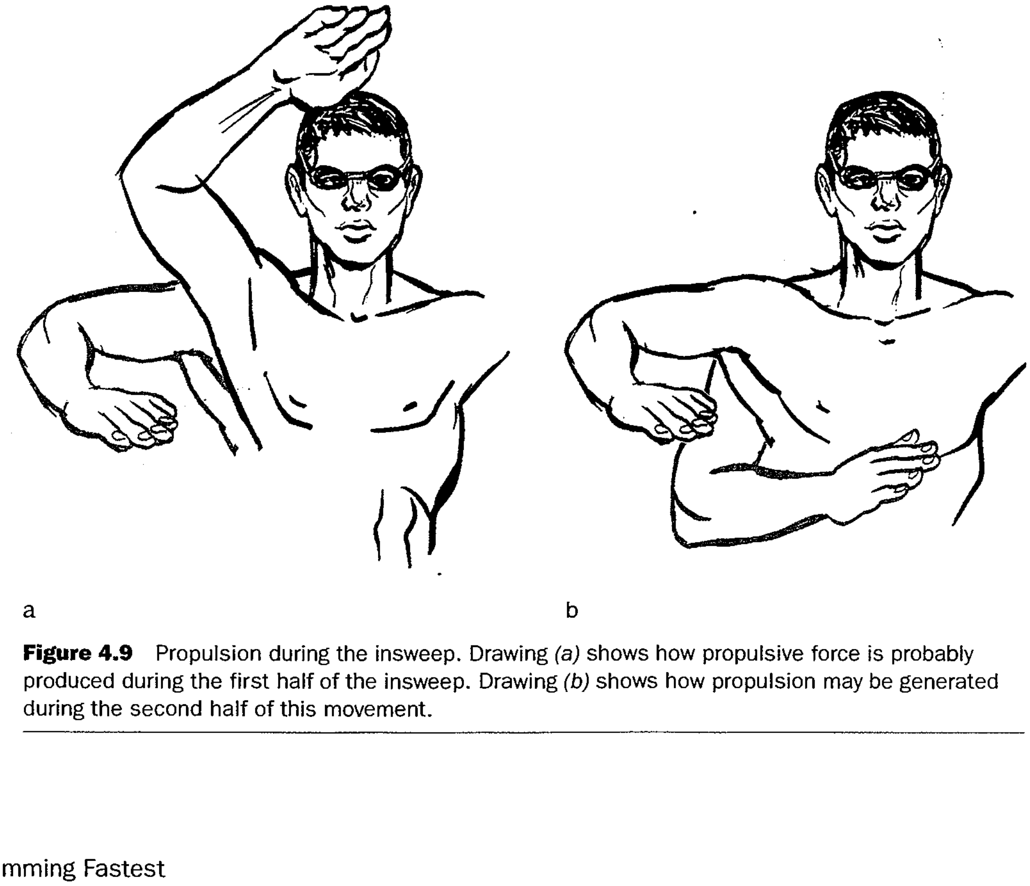


Figure 4.9 Propulsion during the insweep. Drawing *(a)* shows how propulsive force is probably produced during the first half of the insweep. Drawing *(b)* shows how propulsion may be generated during the second half of this movement.

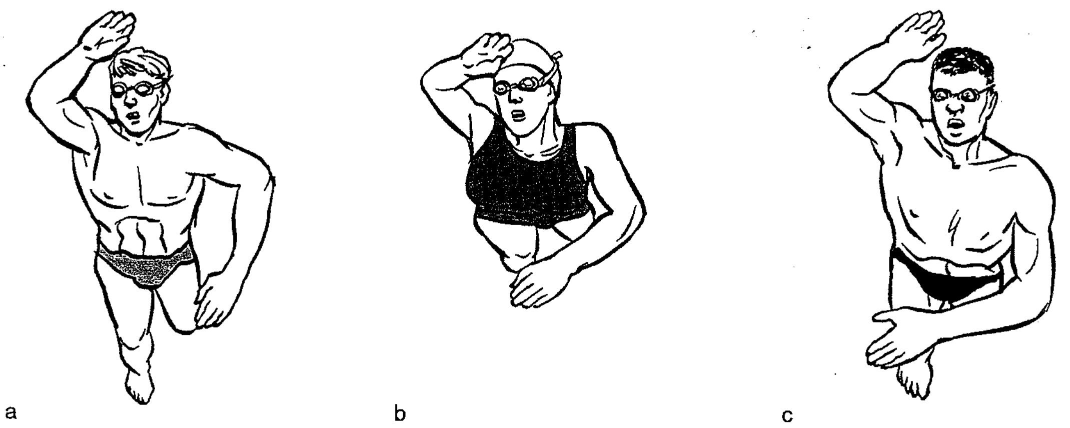


Figure 4.10 Three insweep styles: *(a)* short insweep, *(b)* sweep to midline, and *(c)* long insweep.

sweep will be made away from the midline of the body instead of under it, where the application of force should create greater forward propulsion during the final part of the insweep. I believe it is wiser for swimmers to continue sweeping the hand inward until it is at least under the midline of the body, as shown in figure 4.10b. By doing so, they will be more likely to find a new segment of slower water to push back against during the upsweep and much of that push can be made under the body where it will be more effective.

The crossover insweep style shown in figure 4.10c is usually used by swimmers who have been taught to catch at the midline and push the hand straight back under the body. They, characteristically, sweep the arm down quite deep before making the catch. The catch is usually made with the arm nearly extended and they intuitively learn to flex the arm to gain propulsion as they press it back and up during the insweep. The result is that the hand travels from a position near the midline across to, and sometimes past, the opposite hip during this sweep.

Swimmers who use this style generally sacrifice some propulsion because they use poor technique during the insweep. Some of that lost propulsion is usually regained during the upsweep, however, because that sweep becomes much longer.

The majority of swimmers use some form of crossover when they execute the insweep with the arm on the nonbreathing side. This is because they tend to roll more toward the breathing side, causing the arm on the opposite side to go deeper and further inward, toward the midline, during the downsweep. Because they make the catch with the hand inside the shoulder line and the body rolled considerably to the side, the hand quite naturally crosses the midline during the insweep.

Some swimmers also use the insweep to help rotate the body back from the breathing side. Consequently, to add in this process, they sweep the hand in a longer distance. This is not necessarily a bad thing if it better aligns the body for the upsweep. Having said this, however, I recommend that swimmers who use a crossover style make certain that they flex the arm during the downsweep and then adduct the arm back toward the ribs during the insweep, just as I described earlier. This, as compared to a sculling motion where the arm is flexed during the insweep, will improve insweep propulsion.

Upsweep

A side view of the transition from insweep to upsweep is shown for the right armstroke in figure 4.5f (page 104). A front view of this transition is shown for the right armstroke in figure 4.6g and for the left armstroke in 4.6o (see pages 106 and 107). A side view of the upsweep itself is pictured for the right armstroke in figure 4.5g and h. It is pictured from a front view in figure 4.6h and i, and for the left armstroke in figure 4.6p and q.

The upsweep is the second and final propulsive sweep of the front crawl stroke. It is the most propulsive phase of the armstroke. Most swimmers reach peak forward velocity for each armstroke near the end of the upsweep.

The upsweep begins as the previous insweep is completed and is a backward, outward, and upward sweep of the hand and arm from underneath the body toward the surface of the water. That sweep continues until the hand approaches the thigh and begins moving forward into the next phase of the armstroke, the recovery. The drawings in figure 4.11 show how, I believe, propulsion is generated during the upsweep.

The transition from insweep to upsweep begins as the hand passes close under the midline of the body. At that time, arm motion is rounded off in a circular manner from back, *in*, and up to back, *out*, and up. This transition is initiated by rotating the palm and forearm out quickly as the swimmer pushes back. The palm of the hand and the underside of the forearm are used as a paddle to push back against the water during the upsweep.

There is a misconception that the arm extends rapidly during the upsweep. This notion is a remnant of propulsive drag theory, which claimed that the hand was pushing back, not sweeping up. In fact, the amount of extension at the elbow is minimal during this portion of the armstroke so that swimmers can maintain a backward orientation with the forearm until the upsweep is completed. The arm may extend slightly during the upsweep to maintain pressure against the backward-moving water, but it should never extend so much that the forearm is pushing up, rather than back, against the water.

Propulsion from the upsweep ends when the hand approaches the front of the thigh, just below the bottom of the swimmer's swimsuit. The elbow will have broken through the surface at that time and the arm will begin moving forward into the recovery. Swimmers do not keep pushing the hand backward until it reaches the surface. To do so, they would have to extend the arm. This would cause them to push water upward with the underside of the forearm, which in turn would push the hips down and decelerate their forward speed even more rapidly than it normally decelerates during arm recovery.

Swimmers who push up in this way are fooled into thinking they are pushing the water back, because by hyperextending the hand at the wrist, they can maintain a back-


a
b

Figure 4.11 The upsweep of the front crawl stroke. The upsweep is shown from a side view in *(a)* and from an underneath view in *(b)*.

ward orientation with the palm until it reaches the surface. They cannot maintain a backward orientation with the forearm, however, and the retarding effect produced by pushing upward with the forearm negates any additional propulsion they can produce with the hand as it approaches the surface.

Hand speed should slow during the transition from the insweep to the upsweep, then it accelerates rapidly throughout the remainder of the sweep. For most swimmers, the hand reaches its greatest velocity during this phase of the armstroke; between 3 and 6 m/sec (10 to 20 ft/sec) depending on the distance of the race (Schleihauf et al. 1988; Maglischo et al. 1986; Counsilman and Wasilak 1982).

Release and Recovery

The side view of a swimmer's right arm release can be seen in figure 4.5i (page 104). Front views are shown in figure 4.6, with the right arm release in figure 4.6j and the left arm release in figure 4.6r (page 107).

The arm recovery actually begins before the hand leaves the water. Swimmers should stop pushing back against the water as the hand approaches the thigh and begins moving forward. At the release, the palm should be turned inward so that the hand can travel to the surface of the water on its edge. The pushing drag that results from the upward and forward hand movement will be reduced by presenting the smallest possible surface area to the water.

The purpose of the recovery is to place the arm in position for another underwater stroke. While this is an important function, it is non-propulsive, so the goals of the recovery should be

1. to get the arm over the water with the least disruption of lateral alignment, and
2. to provide a short period of reduced effort for the arm, shoulder, and trunk muscles.

For these reasons, swimmers should relax the arm as much as possible during the recovery, using only enough effort to get it back into the water in front of them. This does not require swimmers to swing the arm over the water with great speed or effort, merely moderate speed, minimal effort, and proper positioning. Consequently, arm velocity will decrease somewhat as the hand travels toward the surface after releasing pressure on the water. Swimmers should not make a conscious effort to reduce or increase this velocity, however. They should simply allow the momentum of the upsweep to carry the arm up and out of the water. Arm recovery is pictured in figure 4.12. The above-water photos show how the arms exit and enter the water and are recovered over it. They also show the proper technique for taking a breath. Descriptions of each phase follow.

The shoulder should come out of the water first, followed by the upper arm and the elbow. The forearm and hand are last to leave the water. When they do, they will be traveling up and out. Swimmers should continue to swing the arm over the water in a semicircular manner until it passes the head, at which time they begin extending it forward for the entry.

The body should be rolled approximately 45° toward the recovery side through the first half of the recovery so that the arm can be carried over the water with a high elbow. The elbow should be the highest part of the arm from the time it leaves the water during the recovery until it enters the water again in front of the shoulder. To accomplish this, the arm should be flexed at the elbow so that the forearm and hand can be carried almost directly below and only slightly outside it. Recovering in this manner will reduce the amount of outward arm motion during the recovery, and that will reduce the tendency for the swinging arm to pull the hips out of alignment. An excessive outward swing of the arm would have just that effect, causing swimmers to wiggle down the pool.

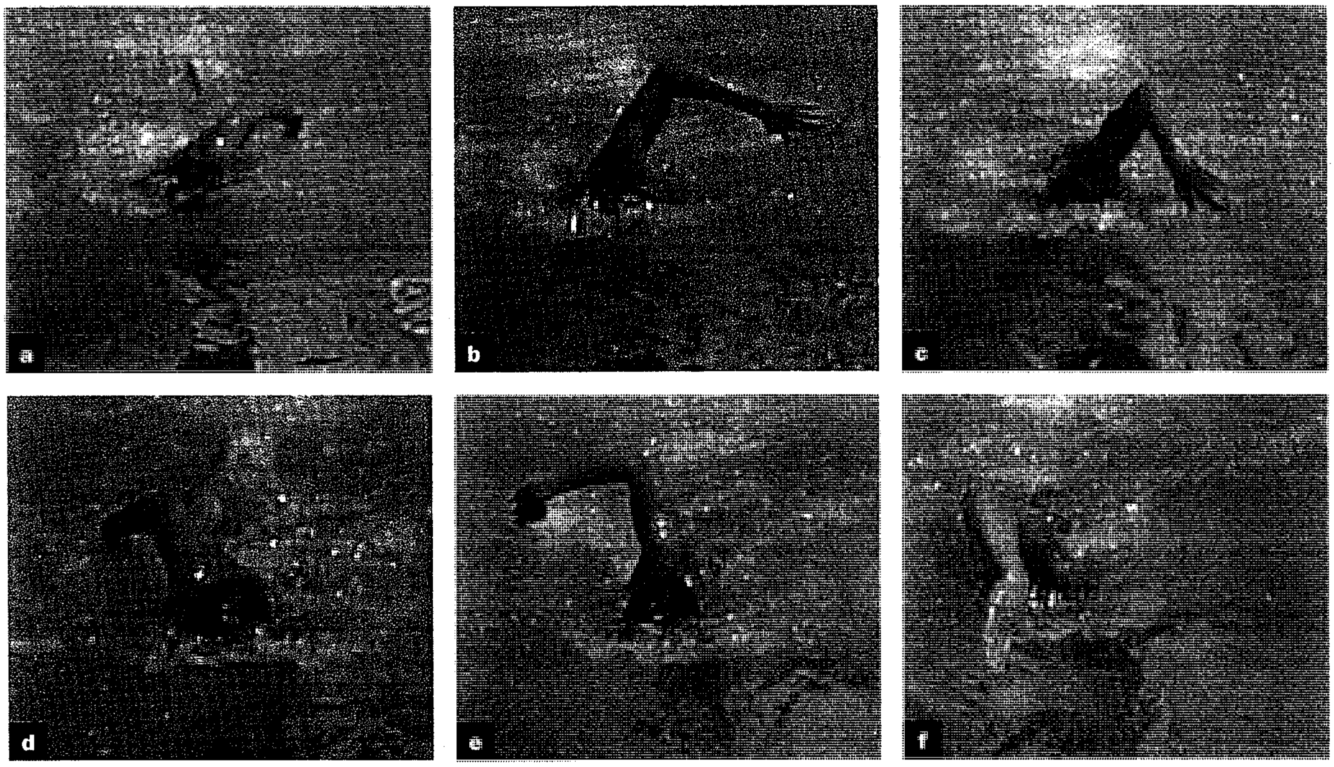


Figure 4.12 Above-water photos of Craig Hutchison, Canadian Olympian, showing his arm recovery and breathing technique.

(a) Exit with left arm (notice it is flexed).
(b) Mid-recovery with left arm.
(c) Reach for entry with left arm.
(d) Exit with right hand (notice the arm is flexed).
(e) Mid-recovery with right arm.
(f) Entry of right hand (notice it is on its side).

Some swimmers will flex the arm even more at the elbow as it travels over the water to keep it from swinging too wide. Others will simply maintain the degree of arm flexion they had when the arm left the water, throughout the recovery. Of course, swimmers in this latter group will already have the arm flexed considerably when it leaves the water.

Swimmers should begin reaching forward for the entry when the arm passes the head during recovery. At that time, they should be completing the insweep with the other arm and rotating the body back toward the opposite side. Although reaching forward, the fingertips should slice into the water while the arm is still somewhat flexed so that the hand is the first part of the arm to enter. Extending the arm over the water before it enters will result in the arm and hand smashing into the water at the same time, which will increase pushing drag. Once the hand enters the water, swimmers should extend the arm forward in the manner described for the entry and stretch earlier in this chapter.

Straight-Arm Recovery

Recently, Inge de Brujin of the Netherlands and Michael Klim of Australia have set world records in the sprint freestyle events using a straight-arm recovery, despite the fact that most experts advise against using this technique for the following reasons. First, as I have already explained, swimmers will decelerate during the final part of the upsweep if they extend the arm forcefully against the water during the final portion of the upsweep. Second, swimmers who extend the arm as it leaves the water are also more likely to rotate the body less toward the recovering side and are therefore more likely to fling the arm out to the side during the first half of the recovery. Third, swinging the arm around to the side tends to pull the hips out of alignment, causing them to wiggle down the pool.

With all of these possibilities for disrupting lateral alignment, why have some swimmers been so successful with a straight-arm recovery? Perhaps because it better fits the rhythm of their strokes. Both de Brujin and Klim are also world-record holders in the butterfly, in which swimmers use a wide, lateral recovery. These swimmers are adept at releasing the water at the proper time so that their arms do not push up against the water as they extend. Both swimmers are also accustomed to sweeping their arms further outward during the outsweep to overcome inertia as they change directions from sweeping their arms back and up during the upsweep to sweeping them up, out, and forward during the recovery. These swimmers may simply be more comfortable sweeping their arms out and around during the upsweep and recovery of the front crawl stroke.

It should also be mentioned that front-crawl swimmers who use a straight-arm recovery tend to recover their arms slightly higher than they would in the butterfly. This is because they recover their arms overhead more with a smaller lateral swing by rolling on their sides. Consequently, the negative effect on lateral alignment can be reduced.

Despite the success of these swimmers, I would not recommend using a straight-arm recovery except in cases where swimmers simply cannot execute a traditional high elbow recovery with ease and efficiency.

Timing of the Arms

The two armstrokes have a precise relationship to one another that is very important to fast swimming in the front crawl. It is important because the alternating movements of the arms must be coordinated with body roll, and vice versa, to facilitate the application of propulsive force and to maintain the body in a streamlined position during each stroke cycle.

Where timing of the two armstrokes and body roll are concerned, there is probably no other area of competitive swimming where the fallacy of the old adage "practice makes perfect" is more apparent. There are a huge number of swimmers, some of them very successful, who do not maintain a proper relationship between the roll of the body and the movements of the arms. Their faulty techniques are usually caused by breathing late, returning the head to the water too slowly after breathing, or failing to roll the body enough toward the nonbreathing side after breathing. These mistakes in timing are probably learned when swimmers are young and just beginning to swim. At that time, they can think of nothing but getting a breath and, thus, develop some bad habits that stay with them even after they become proficient.

The most important coordinating event between the two armstrokes and body roll occurs when the arm in front enters the water and the other arm is completing its insweep. The combination of one arm coming in and up, toward the midline of the body, while the other is traveling down and forward into the water should be accompanied by a rotation of the body toward the stroking arm. Rolling toward the stroking arm at this precise time allows the two sides of the body to move in the same directions as the arms and remain in good lateral alignment. The other positive aspect of rolling toward the stroking arm at this time is that the stroking arm is able to push back more directly against the water during the upsweep. With the body rolled toward the upsweep arm, the swimmer will not have to sweep it out as wide for the hand to clear the thigh on its way to the surface.

Another important feature of the timing between armstrokes is that the arm in front should not begin sweeping down until the other arm has completed its upsweep. This allows swimmers to keep the entering arm streamlined in front while the other arm is applying propulsive force. The entering arm thus creates less form and pushing drag than would be the case if it were pressing down below the vertical confines of the body. Consequently, it will interfere less with the propulsive efforts of the stroking arm.

When swimmers sprint, many of them go against what I have just recommended. They overlap the downsweep of the front arm with the upsweep of the rear arm so that they can begin applying propulsive force with the arm in front almost immediately as the other arm releases pressure on the water in back. This method probably reduces the average velocity per stroke cycle, distance per stroke, while increasing the energy cost. Nevertheless, the increase in turnover rate may result in faster times over a short distance. It is debatable whether sprinters should adjust their timing in this way, however. One notable swimmer who does not is Alexander Popov. He relies on an exceptional kick and great streamlining rather than a fast turnover when he sprints. Regardless, sprinters with weaker kicks may not be able to achieve fast times with this method. Despite the increase in energy, and reduction in distance per stroke, to produce fast times, they may need to use a faster turnover with a slight amount of overlap between the downsweep and upsweep.

Arm Rhythm

Arm rhythm is important to maintaining a constant stroke rate in the face of developing fatigue. When fatigued, swimmers often have difficulty getting the arms from the end of one stroke to the start of the next because they think of the arm rhythm incorrectly. They think of the underwater stroke as the fast and difficult part and the recovery as the slow and easy part. As a result, they often slow the arms too much as they are leaving the water. Actually, they should try to maintain arm speed from the catch, through the underwater armstroke and recovery, to the following entry with each arm. By doing so, they will tend to round off the stroke better as the arm leaves the water and they will keep it moving rapidly until it enters the water and is sliding forward in preparation for the next stroke. They should not exert the same strong muscular effort during the recovery that they use during the underwater armstroke, but they should maintain arm speed through the recovery.

Teaching the Armstroke

A front crawl stroke pattern drawn relative to the body is illustrated in figure 4.13. This pattern provides an excellent vehicle for teaching swimmers to use the various parts of the armstroke correctly. An underneath view has been used because it best portrays the nature of the stroke.

Based on this illustration, a set of instructions for teaching the underwater armstroke in the front crawl would go as follows. The hand and arm move in an S pattern under the body. They sweep down in the first third of the underwater armstroke (the first curve of the S) until a high elbow catch position is attained. They then sweep back and in during the middle third of the stroke (the second curve of the S) until the hand is under the chest and at the midline. In the final portion of the S pattern (the third curve of the S), the hand and arm sweep back, out, and up toward the surface. Pressure on the water is released and the recovery begins when the hand approaches the thigh.

The first curve of the S pattern is not propulsive and should be performed gently. Hand speed should then be accelerated gradually throughout the next two sweeps, reaching its fastest speed during the third curve of the S pattern. Swimmers should use the palm of the hand and the undersides of the forearm and upper arm like a paddle, to push back against the water, throughout the final two curves of the S pattern.

Figure 4.13 A stroke pattern for the front crawl drawn relative to the swimmer's moving body.

Teaching swimmers to trace this S pattern with the hands along the body will go a long way toward helping them use good stroking patterns when they swim the front crawl stroke.

Flutter Kick

The flutter kick consists of alternating diagonal sweeps of the legs with the downbeat of one taking place during the upbeat of the other. The primary directions of the kicks are up and down, thus the movements are called *upbeats* and *downbeats*. These beats also contain lateral components, however. The legs actually kick down and laterally, and up and laterally in the direction the body is rolling. The downward component of the kick is largely responsible for its propulsive force, while the upward component brings the leg back in position for another downbeat. The lateral portions of these leg beats probably help to stabilize and rotate the body so that swimmers remain in good lateral alignment as they roll from side to side.

As shown in the photos in figure 4.14, the leg travels up and forward during the upbeat. Thus, it is very doubtful that this portion of the kick is propulsive. Its purpose is most likely to return the leg into position for another downbeat. The leg travels down and slightly back during the downbeat because of the rapid extension that takes place at the knee. Therefore, this is undoubtedly the most propulsive phase, and may very well be the only propulsive phase, of the flutter kick.

Downbeat

The downbeat is a whip-like movement that begins with flexion at the hip, followed by extension at the knee. While it may seem that the downbeat begins after the swimmer's foot reaches its highest point, this is not the case. The downbeat actually begins when the leg is passing above the hips. At that point, the swimmer flexes the leg slightly at the knee and pushes down with the thigh at the hip. The swimmer is doing this with her left leg in figure 4.14a. Her lower leg, which should be relaxed, is pushed further into a flexed position by the pressure of the water underneath it, giving the impression that the upbeat is still underway. In reality, however, the upbeat has ended and the downbeat has begun.

This action of flexing at the hip and pressing down with the thigh while the lower leg continues traveling up overcomes the inertia of the previous upbeat, allowing the change of direction of the leg from up to down to take place with a minimum of muscular effort. As mentioned, the water pressure below the leg will also push the foot into an extended position, with the toes pointed up (plantar flexed) and the foot turned in (inverted) after the downbeat has started. This position can be seen clearly for the swimmer's left leg in figure 4.14b.

The water continues to push the lower leg into a flexed position until the swimmer's thigh is slightly below her body and her foot is near or slightly above the surface of the water. At that point, the swimmer extends her lower leg at the knee quickly and forcefully until it is completely straight and slightly below her body, as shown in figure 4.14c and d. The final motion of the downbeat is a push downward with the instep of her foot that returns her foot to a natural, or partially flexed, position with her toes almost directly below her heel. The downbeat is executed like a sine wave of muscular contraction. It begins with flexion at the hip joint, travels down the thigh to the knee where a rapid extension of the lower leg takes place, and from there down the leg to the foot, which is pushed down into a flexed position as the downbeat ends.

Upbeat

The beginning of the upbeat overlaps with the end of the preceding downbeat to overcome the leg's downward inertia and change its direction from down to up. This occurs

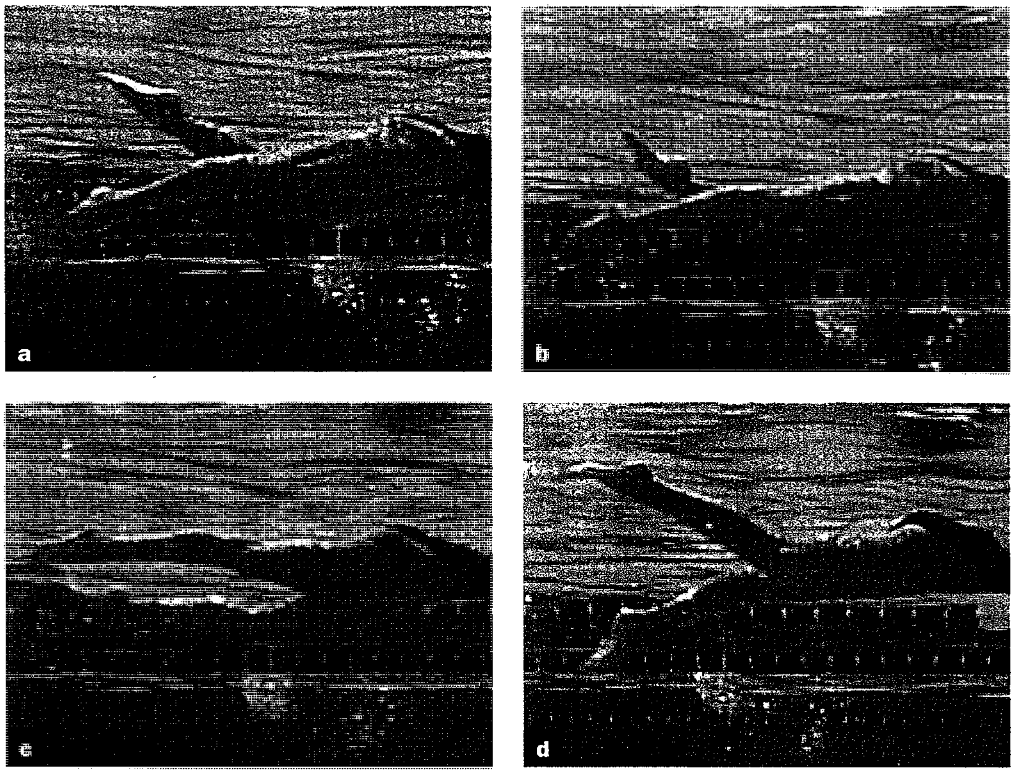


Figure 4.14 Sequence photos of the front crawl flutter kick.

(a) Start of downbeat with left leg. Start of upbeat with right leg.
(b) Start of leg extension with left leg. Continuation of upbeat with right leg.
(c) Continuation of downbeat with left leg. End of upbeat with right leg.
(d) End of downbeat with left leg. Start of downbeat with right leg.

in the following manner. When the swimmer extends the lower leg downward, it has a rebound effect that pushes the thigh upward, initiating the upbeat. The upward movement of the thigh also starts the lower leg moving upward once the downbeat has been completed. The leg will sweep up, forward, and laterally, opposite the direction the body is rotating. The swimmer in figure 4.14, a through d, is shown executing the upbeat with her right leg.

The inertial effect of the previous downbeat should allow the swimmer to use only a minimal amount of muscular effort to continue the upbeat once it is underway. As indicated in the previous section, the upbeat ends when the leg passes the body on its way up. That is when the leg flexes at the hip for the next downbeat.

The upbeat should be executed with a straight leg. The pressure of the water pushing down on the leg will keep it extended and the foot in a natural position, midway between flexion and extension, throughout this phase of the flutter kick. The lower leg and foot should be relaxed throughout the upbeat and remain so until the knee begins extending during the next downbeat.

The most common mistake that poor kickers make is to flex the lower leg at the knee during the upbeat. This causes the rear of the lower leg to push up and forward against the water, creating pushing drag that, at the least, reduces forward velocity and, in extreme cases, causes some swimmers to move backward when they are kicking on a board. The effect of this mistake is illustrated in figure 4.15. Figure 4.15a shows a swimmer who is kicking up correctly with his right leg in an extended position. The leg travels up and forward with a minimum of effort. In contrast, figure 4.15b shows a

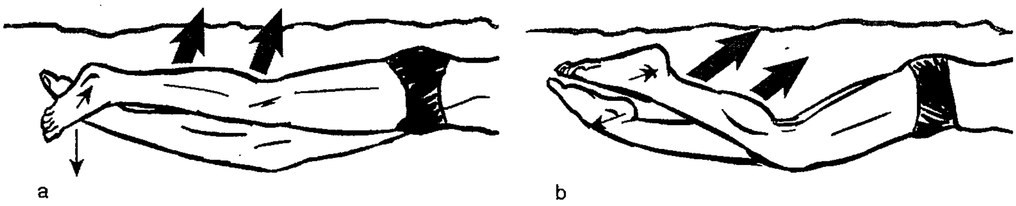


Figure 4.15 The effect of bending the leg during the upbeat. The swimmer in *(a)* is executing the upbeat correctly, with a straight leg. The swimmer in *(b)* is doing the upbeat incorrectly. He bends his leg and pushes water forward, producing a backward counterforce that will reduce his forward velocity.

swimmer who is flexing his knee during the upbeat. This causes him to push water forward with his right leg and this should reduce his forward velocity.

Kick Width

The flutter kick should neither be too shallow nor too deep. Body stabilization and propulsive force will be reduced if it is too shallow, and both form and pushing drag will be increased if it is too deep.

When the downbeat is completed, the foot should be just below the body line. Kicking deeper than this will not improve the propulsive or stabilizing effects of the kick. It will, however, increase the cross sectional surface area of the body presented to the water.

The optimal width of the legs at their widest spread is not known, but it is probably between 50 and 80 cm (20 and 30 in). Allen (1948) found that a kick width of approximately 30 cm (12 in) was superior to a narrower kick of 15 cm (6 in) for increasing propulsive force.

Diagonal Kicking

As indicated earlier, lateral motions of the legs probably assist in body rotation and stabilization during the flutter kick. This is because body rotation is facilitated and lateral alignment can be preserved if one leg kicks in the same direction that the body is rolling while the other kicks in the opposite direction. Thus, when swimmers roll the body to the right, one leg should kick diagonally downward and to the right while the other kicks diagonally upward and to the left. These diagonal leg movements reverse when the body is rotated toward the left side.

The usual practice of kicking with a board may be fine for improving leg endurance, but it inhibits diagonal kicking. Accordingly, most kicking drills should be done without a board so that the kick can be used in combination with body rotation. A drill for this purpose, side kicking, is described later in this chapter.

Should the Flutter Kick be Used for Propulsion?

The fact that the flutter kick can be used for both propulsion and stabilization was discussed in chapter 1. The question here is whether front-crawl swimmers should use it for propulsion or simply as a stabilizer. Adrian, Singh, and Karpovich (1966) have provided the most provocative information concerning this matter. They measured the oxygen consumption of 12 competitive swimmers while they were kicking only, pulling only, and swimming the full stroke. They reported that swimmers used nearly four times more oxygen when kicking only than they did when pulling only. The oxygen requirement was 24.5 L when they kicked at a speed of 3.5 ft/sec (57 sec per 50 yd) compared to a requirement of only 7 L when they pulled at the same speed. These results are supported by the work of other researchers as well (Astrand 1978; Charbonnier et al. 1975; Holmer 1974), all of whom found that kicking caused a considerable increase in the energy cost of swimming.

These data present a persuasive argument that middle distance and distance swimmers should reduce their kicking efforts to conserve energy during their races. The energy requirement of kicking is disproportionately large relative to the additional propulsion the legs can provide. Therefore, it seems advisable to reduce the effort from the legs to the the minimum required for support and stabilization during middle distance and distance races. In doing so, swimmers will delay fatigue so that they can swim a faster average pace the entire race. Sprinting is a different matter, however. It is more important to increase propulsive force than it is to conserve energy over short distances. Consequently, swimmers should kick vigorously in sprint races and during the final sprint in middle distance and distance races.

Timing of the Arms and Legs

Kicking rhythm refers to the number of leg strokes a swimmer takes during each complete stroke cycle. One complete leg stroke consists of an upbeat and downbeat. Thus, these two beats have traditionally been considered as one when the timing between arms and legs is described. Two armstrokes constitute one stroke cycle in the front crawl stroke.

World-class swimmers have used a variety of kicking rhythms successfully. The most popular rhythm is the six-beat kick, in which swimmers complete six leg beats during each stroke cycle. Other popular tempos are the two-beat rhythm and the four-beat rhythm.

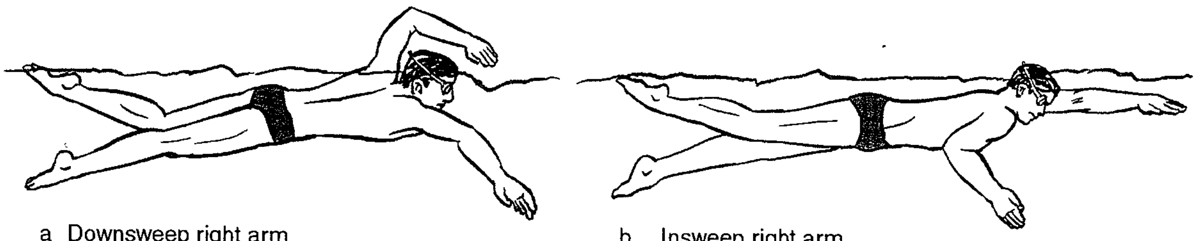
The six-beat rhythm is used by most sprint swimmers and a large number of middle distance swimmers, but by only a small number of distance swimmers. The two-beat rhythm has been used primarily, although not exclusively, by distance swimmers. Four-beat rhythms, used less frequently, are still popular among a significant number of swimmers. Eight- and 10-beat rhythms have also been tried over the years, but they were not successful and have been abandoned.

Six-Beat Kick

The six-beat rhythm, illustrated in figure 4.16, includes three leg beats per armstroke, or six beats per stroke cycle. This rhythm can best be described using the relationship between leg downbeats and the various arm sweeps during each stroke cycle. In this respect, one downbeat of each leg is coordinated with each of the three sweeps during one underwater armstroke. Focusing on the right armstroke, the downsweep of that arm is coordinated with the downbeat of the right leg (see figure 4.16a). The insweep of the right armstroke is accompanied by a downbeat of the left leg (see figure 4.16b), and there is another downbeat from the right leg during the upsweep of the right arm (see figure 4.16c). The timing is similar during the left armstroke, with the left leg kicking down during the downsweep of the left arm (see figure 4.16d), the right leg kicking down during the insweep of the left arm (see figure 4.16e), and the left leg kicking down again during the upsweep of the left arm (see figure 4.16f).

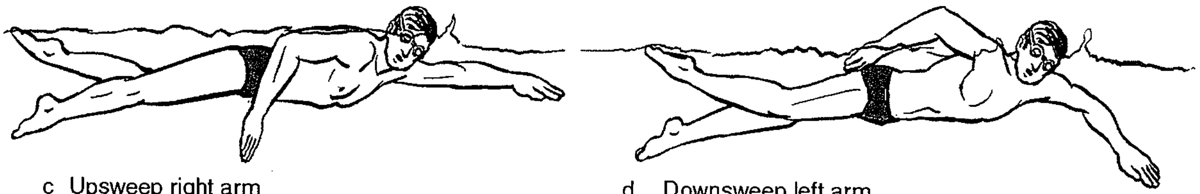
The coordination between arm sweeps and leg beats just described is so precise that the beginning and end of each downbeat of the legs coincides exactly with the beginning and end of the corresponding arm sweep. Large arm sweeps are accompanied by large kicks, but the kick will be smaller when its corresponding sweep is smaller. This probably explains why many six-beat swimmers have what appear to be major and minor kicks during each stroke cycle.

The six-beat rhythm is so natural that most swimmers perfect it through trial and error with little or no instruction. This timing undoubtedly contributes to the total propulsive force during each arm sweep. Most particularly, the downbeat of each leg that accompanies the downsweep of each arm probably plays an important role in reduc-



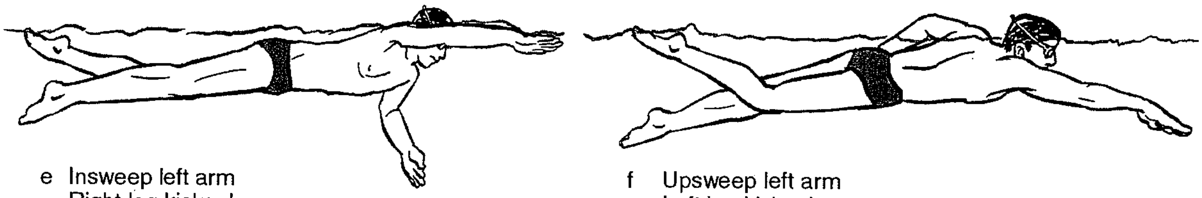
a Downsweep right arm
Right leg kicks down

b Insweep right arm
Left leg kicks down



c Upsweep right arm
Right leg kicks down

d Downsweep left arm
Left leg kicks down



e Insweep left arm
Right leg kicks down

f Upsweep left arm
Left leg kicks down

Figure 4.16 The six-beat kick in the front crawl stroke.

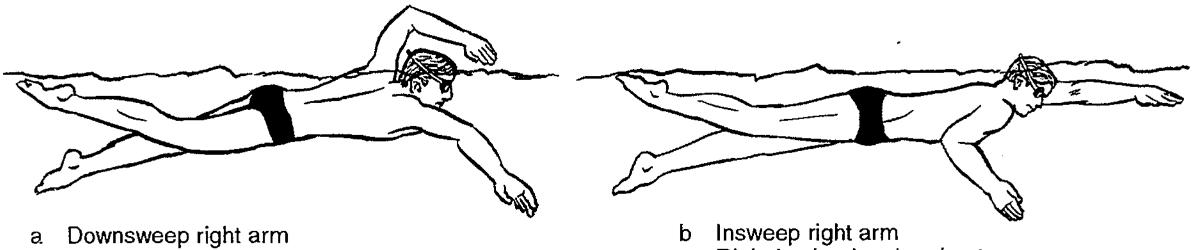
ing swimmers' rates of deceleration during that phase of the armstroke. In addition to the propulsive force they provide, the leg beats that accompany the insweep probably also assist in rotating the body toward the stroking arm. The downbeat that accompanies the upsweep of the armstroke probably contributes to the total propulsive force during that phase of the stroke, while also preventing the hips from being pulled down by the upward motion of the arm. Of course, the lateral components of first and third leg beats also assist body roll and, thus, maintenance of lateral alignment.

Straight Two-Beat Kick

There are two forms of the two-beat rhythm in use today: the straight two-beat kick, which will be described in this section, and the two-beat crossover kick discussed in the next. The timing for the straight two-beat kick is shown in figure 4.17. The swimmer executes two downbeats with his legs during each complete stroke cycle, or one downbeat per armstroke. Each downbeat of a particular leg takes place during both the insweep and upsweep of the corresponding armstroke. That is, the right leg kicks down during the right armstroke and vice versa (see figure 4.17, b and c for the right armstroke and figure 4.17, e and f for the left).

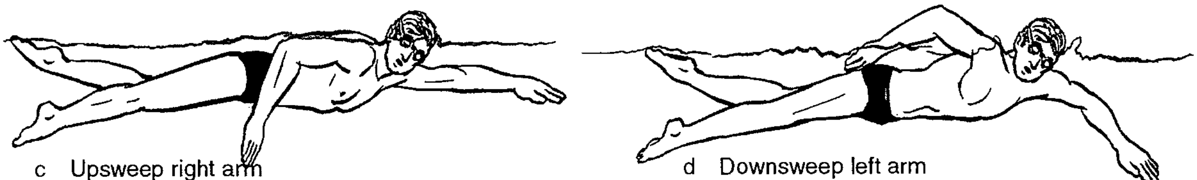
Of course, the other leg will be kicking up at the same time the downbeat of the opposite leg is taking place. The legs then hang in an open, or separated, position while the arm is recovered over the water and while it is sweeping down to the catch position. Thus, there is no help from the kick during this deceleration period of the armstroke.

The two-beat kick requires less energy than other rhythms, which may explain why it is preferred by many distance swimmers. Female swimmers, in particular, seem to gravitate toward this rhythm. This may be because they are generally more buoyant



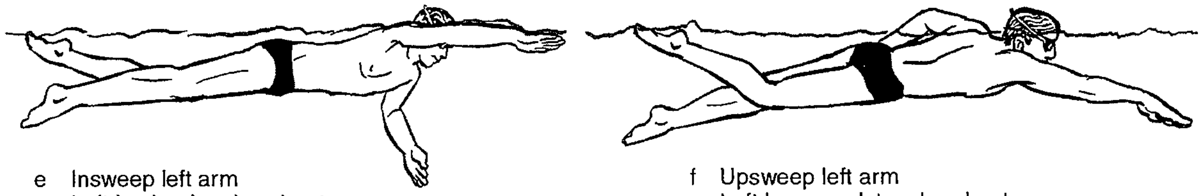
a Downsweep right arm
Legs pause

b Insweep right arm
Right leg begins downbeat



c Upsweep right arm
Right leg completes downbeat
End of first kick

d Downsweep left arm
Legs pause



e Insweep left arm
Left leg begins downbeat

f Upsweep left arm
Left leg completes downbeat
End of second kick

Figure 4.17 The straight two-beat kick in the front crawl stroke.

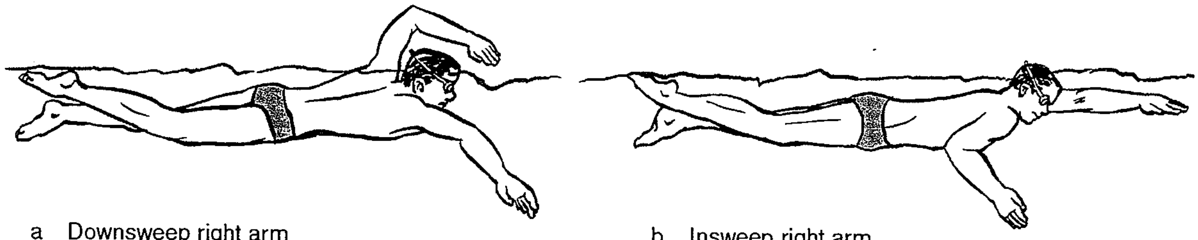
than their male counterparts and do not require a vigorous kicking rhythm to maintain their bodies in good lateral and horizontal alignment.

Swimmers who use a two-beat kick tend to modify the timing of the arms to compensate for the fact that they are not kicking during the downsweeps of the right and left arms. The first modification is a change in the stretch phase. Two-beat kickers tend to enter one arm later than the other and they shorten the downsweep to make a quick catch. Perhaps this is because with no kick to reduce their rate of deceleration, they need to reduce the time they spend in the downsweep. The second modification many two-beat swimmers make is to shorten the insweep of the armstroke. They probably do this because there is no kick from the opposite leg to counterbalance the insweep.

Two-Beat Crossover Kick

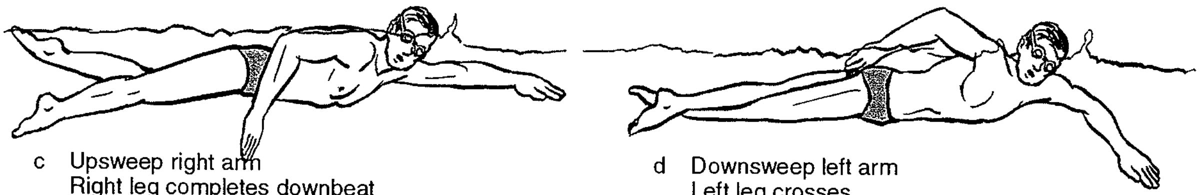
The two-beat crossover rhythm, illustrated in figure 4.18, is preferred by a significant number of male middle distance and distance swimmers. Referring to it as a *two-beat crossover kick* is really a misnomer because there are actually four leg beats per stroke cycle: two major downbeats and two minor crossover beats. The major downbeats take place during the insweep and upsweep of the corresponding armstroke in the identical sequence described for the two-beat kick. The partial crossover beats take place during the downsweep of each arm, as shown in figure 4.18, a and d.

The crossover beats are performed in the following manner. The legs do not hang during the downsweep of the armstroke, as they did in the straight two-beat rhythm. Instead, the bottom leg kicks up and in and the top leg kicks down and over, causing them to cross midway through their respective beats. Swimmers complete the



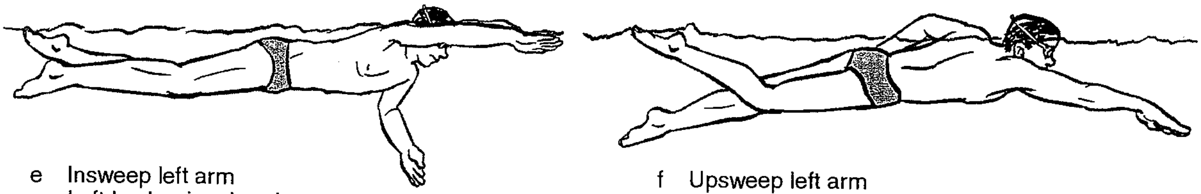
a Downsweep right arm
Right leg crosses
over left

b Insweep right arm
Right leg begins
downbeat



c Upsweep right arm
Right leg completes downbeat
End of first kick

d Downsweep left arm
Left leg crosses
over right



e Insweep left arm
Left leg begins downbeat

f Upsweep left arm
Left leg completes downbeat
End of second kick

Figure 4.18 The two-beat crossover kick in the front crawl stroke.

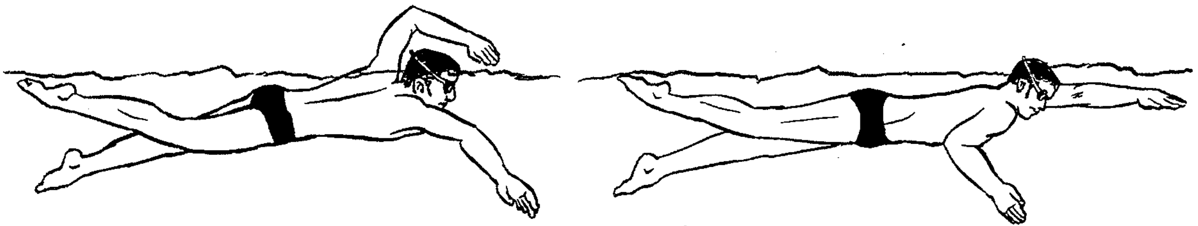
downsweep of the armstroke while the legs are crossing, then they uncross them in time to execute a major downbeat with the leg on the side of the stroking arm during its insweep and upsweep.

The leg that crosses over the other will always be the one on the same side as the stroking arm. In figure 4.18a, it is the right leg that crosses over the left while the right arm sweeps downward. The left leg crosses over the right during the downsweep of the left arm in figure 4.18d.

This rhythm appears to be a compromise between the energy-saving two-beat kick and the propulsive six-beat kick. Some swimmers, particularly less-buoyant males, have probably found intuitively that the two-beat kick is not vigorous enough to maintain their bodies in good horizontal and lateral alignment, while a six-beat rhythm may require more energy than they can sustain for the race distance. Consequently, they have gravitated toward the two-beat crossover kick, in which two small crossover beats maintain alignment and two large beats aid in propulsion. The two-beat crossover rhythm is also popular among swimmers who use wide lateral arm recoveries. Crossing the legs probably prevents the hips from being pulled in the direction of the sideward-swinging arm.

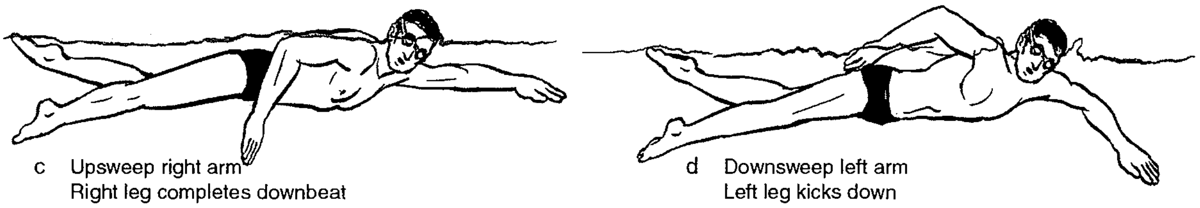
Straight Four-Beat Kick

There are also two four-beat kicking rhythms in use among competitive swimmers, a straight four-beat kick and a four-beat crossover kick. The illustrations in figure 4.19 show a swimmer using a straight four-beat kick. This rhythm is really a combination of the six-beat and two-beat styles described earlier. The swimmer uses a two-beat rhythm during one armstroke and a six-beat rhythm during the other armstroke.



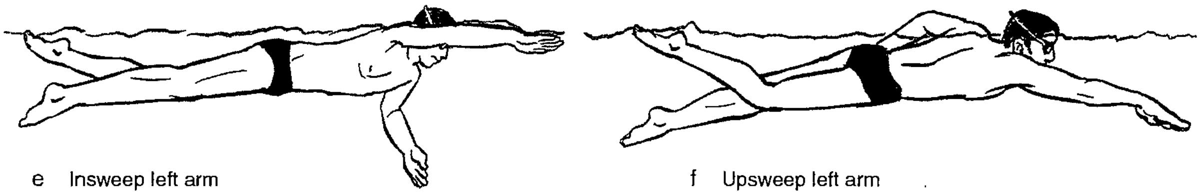
a Downsweep right arm
Legs pause

b Inswheep right arm
Right leg begins downbeat



c Upsweep right arm
Right leg completes downbeat
End of first kick

d Downsweep left arm
Left leg kicks down



e Insweep left arm
Right leg kicks down

f Upsweep left arm
Left leg kicks down
End of fourth leg beat

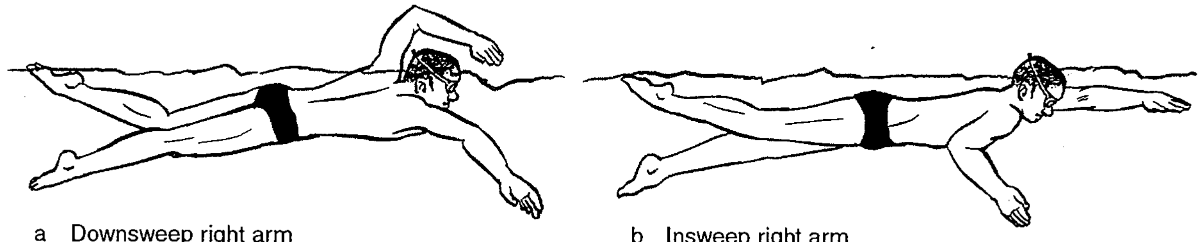
Figure 4.19 The straight four-beat kick in the front crawl stroke.

Notice that in figures 4.19, a through c, the swimmer executes only one downbeat with his right leg during his right armstroke. That downbeat takes place during the insweep and upsweep of that armstroke, just as it would with a two-beat rhythm. The swimmer kicks downward three times during the left armstroke, with each downbeat accompanying a sweep of the arms in the same sequence described for the six-beat kick.

The four-beat kick is, apparently, a compromise between the need to save energy by reducing the number of kicks per cycle, while at the same time maintaining horizontal alignment and, perhaps, gaining more propulsion than can be supplied by a two-beat or two-beat crossover rhythm. Most swimmers use the two-beat rhythm during the stroke on the breathing side. This may keep the kick from interfering with the breathing movements of the diaphragm.

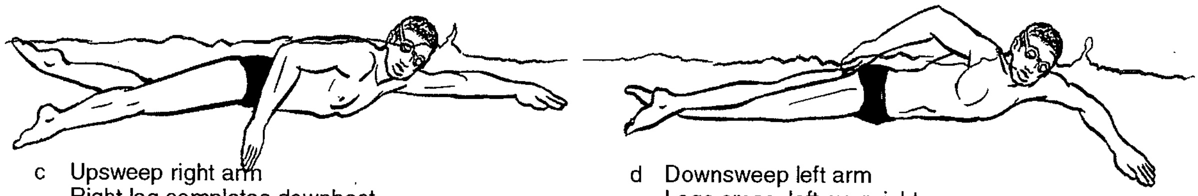
Four-Beat Crossover Kick

The four-beat crossover rhythm, illustrated in figure 4.20, is a combination of a two-beat crossover rhythm on one side and a six-beat rhythm on the other. The crossover beat comes during the downsweep of the arm on the side where only one major downbeat occurs (the left side in figure 4.20). The legs would normally hang during this phase if a straight four-beat kick were used. But swimmers who use the four-beat crossover rhythm cross the legs, top over bottom, during the downsweep of the armstroke on that side (figure 4.20d). Then they uncross the legs in time to kick down during the insweep and upsweep of that arm (figure 4.20, e and f). The legs kick down three times in a normal six-beat rhythm during the stroke of the other arm (the right arm in figure 4.20, a through c).



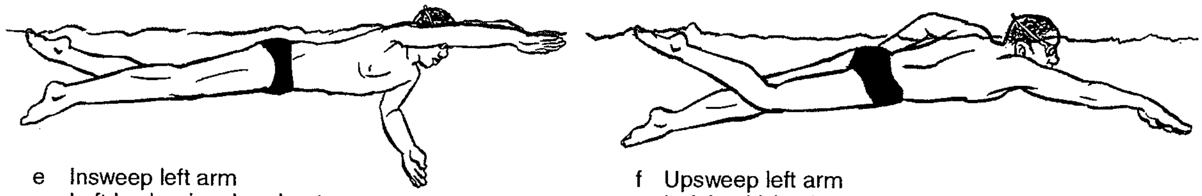
a Downsweep right arm
Right leg kicks down

b Insweep right arm
Left leg kicks down



c Upsweep right arm
Right leg completes downbeat
End of third leg beat

d Downsweep left arm
Legs cross, left over right



e Insweep left arm
Left leg begins downbeat

f Upsweep left arm
Left leg kicks down
End of fourth leg beat

Figure 4.20 The four-beat crossover kick in the front crawl stroke.

Most, but not all, four-beat crossover kickers use the two-beat rhythm during the armstroke on the nonbreathing side. As mentioned earlier, swimmers tend to rotate less to that side, causing them to recover that arm with a wider sweep. These swimmers may be using the crossover beat to counteract the disruptive effect of that wide recovery on their lateral alignment.

Which Kick Rhythm Is Best?

It is tempting to recommend the six-beat rhythm as the best possible timing between the arms and legs. The way the leg beats coincide with the propulsive sweeps of the arms is reminiscent of a well-oiled piece of machinery. Nevertheless, many world-class swimmers have been successful at all distances using other rhythms. Therefore, the six-beat kick cannot be recommended for everyone.

Perhaps factors such as body build, buoyancy, specific muscular weakness, specific joint flexibility, and various physiological capacities make it more efficient for some swimmers to use fewer kicks per stroke cycle. In this regard, Persyn, DeMaeyer, and Vervaecke (1975) at the Leuven Institute in Belgium have reported the following results from a study of 62 national-level Belgian and Dutch swimmers.

- Two-beat crossover kickers had longer legs.
- Six-beat kickers had larger vital capacities, greater inward rotating ability at their hips, larger hands, and greater triceps and shoulder extension strength.

- Six-beat kickers were able to kick faster for short distances.
- Six-beat kickers' legs tended to sink more easily.

On the basis of these results, it is possible that swimmers with long legs may gravitate toward two-beat or four-beat rhythms because a six-beat kick would cause them to swim with a turnover rate that is too slow. Perhaps, also, large, strong, flexible swimmers with fast kicks who are also not very buoyant may prefer a six-beat rhythm. Swimmers with a larger vital capacity may prefer to gain more propulsion from the six-beat kick because they can partially offset the added energy cost through greater oxygen consumption. Inward rotation of the hips probably makes the kick more effective, which would explain why swimmers who are above average in this ability prefer the more propulsive six-beat rhythm. By the same token, swimmers with larger hands and greater strength in the triceps and shoulders probably tend toward longer strokes where the six-beat rhythm fits best. It is easy to understand why swimmers with exceptional kicking speed would choose the six-beat rhythm: They can gain more propulsive force from their legs. Finally, swimmers with marginal buoyancy may require faster leg rhythms to keep their legs from sinking. These are all reasons that swimmers might find a particular rhythm more suited to their special abilities.

What about swimmers who make the wrong choice? There may be a number of good kickers who use two-beat and four-beat rhythms for reasons that have nothing to do with their physical characteristics and abilities. They may simply gravitate toward an energy-saving two-beat or four-beat rhythm because of training demands. The need to save energy during long training sessions may unknowingly encourage some swimmers to switch from a six-beat timing to one of the less costly rhythms. And, once a two-beat or four-beat pattern becomes ingrained, they end up using it in competition as well.

We can only speculate whether these swimmers might have been faster if they had stayed with a six-beat rhythm. After all, we have seen that some middle-distance and distance swimmers can save energy and still excel with a subdued six-beat kick. Controlled research is needed to determine whether two- and four-beat rhythms are more efficient for some swimmers or whether the six-beat kick is the superior style for all.

Body Position and Breathing

As explained in chapter 2, swimmers encounter less resistance when the body is streamlined horizontally and laterally. Breathing mechanics are important in this respect, because the most likely time for the body to come out of alignment is when the head is turned to take a breath.

Horizontal Alignment

Horizontal alignment is best evaluated from a side view, where the depth and inclination of the body are readily observable. Good horizontal alignment is illustrated by the drawing in figure 4.21.

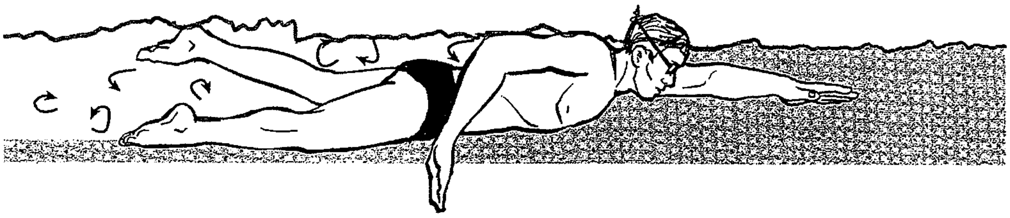


Figure 4.21 Good horizontal alignment in the front crawl stroke.

The swimmer in figure 4.21 is nearly horizontal from head to toes so that his body takes up the minimum space in the water. Aligning the body horizontally in this way causes fewer streams of water molecules to become turbulent as his body travels through them. It also allows the water to fill in behind the swimmer more quickly so that fewer eddy currents are formed. Thus, the differential between the high pressure in front of the swimmer and the low pressure behind him are minimized so that their retarding effect on forward velocity will be reduced.

The keys to good horizontal alignment are

- a natural head position in line with the trunk,
- a fairly straight back, and
- a narrow kick.

Unfortunately, there are still many who believe that swimmers need to get up on top of the water to swim fast. Today, however, we know that swimmers should try to remain in a horizontal position. Any attempt to swim over the water requires deeper kicks with more force to maintain the head and shoulders above the surface. At the same time, swimmers must push down vigorously with the arms during the downsweep to support this high body position. While it is true that swimmers do ride higher in the water when they sprint, it is not necessary to use any of these energy-wasting efforts to maintain that high position.

Sprinters' bodies tend to ride higher in the water simply because they are swimming fast. When athletes swim faster, the water being diverted underneath the body tends to push them into a natural hydroplaning position that does not require any additional effort to maintain. By the same token, they will not hydroplane when they swim slower simply because the upward pressure of the water passing underneath the body will be reduced. Swimmers should not attempt to hold the head unnaturally high, nor should they arch the back excessively, to achieve a high body position. They should allow the pressure of the water to do the work for them. Swimming with the head held high and an arched back will increase total drag 20% to 35% (Clarys 1979).

The face should be in the water with the waterline somewhere between the hairline and the middle of the head. The waterline will tend to be at or beyond the middle of the head in longer races and for less-buoyant swimmers. It will tend to be closer to the hairline in shorter races and for more buoyant swimmers.

Swimmers should roll, not lift, the head, to the side when they breathe because lifting the head will cause the hips and legs to drop deeper into the water. When they inhale, one side of the face should remain in the water. The swimmer in figure 4.12 (see page 114) has good head position when he is breathing and when his face is in the water.

The width of the kicks should be such that the feet just reach the surface on the upbeat of the kick and are only slightly below the body on the downbeat. That way, swimmers won't increase drag unnecessarily by increasing the vertical distance between the surface and the lowest part of the body.

Boomer (1996) recently advanced a theory on horizontal alignment that has become popularly known as *pressing the T.* The basic tenet of his theory is that pressing the center of buoyancy, located in the upper trunk, down into the water will make the legs ride higher in the water. There is certainly research and anecdotal support for this belief (Pendergast et al. 1977; Watkins and Gordon 1983). Nevertheless, I am not convinced that pressing the trunk down provides any advantage where maintaining the legs near the surface is concerned. In fact, it may interfere with the natural hydroplaning effect of the water pressure under the body. The pressure of that water should provide less-buoyant swimmers with all the support the legs need when they are swimming fast. For the present, my advice would be that swimmers should neither try to hydroplane by lifting the head and arching the back nor elevate the legs by pressing the chest and shoulders down into the water. They should simply align the body as horizontally as possible from head to toes and let the pressure of the water underneath determine how high they ride in the water.

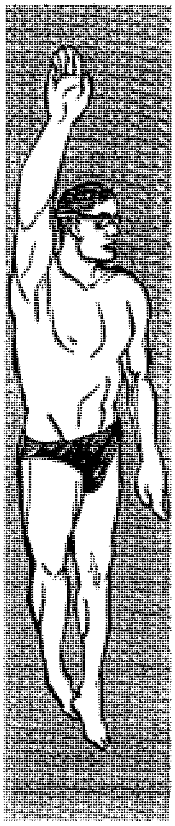


Figure 4.22 Good lateral alignment in the front crawl stroke.

Lateral Alignment

Lateral alignment in the front crawl can best be evaluated from above or underneath. The swimmer in figure 4.22, shown from underneath, has excellent lateral body alignment as he rotates his head to the left to breathe. His hips and legs stay within the confines of his shoulder lines because he rolls his entire body from head to feet as a single unit. Provided he continues to roll in this manner, his body should stay in good lateral alignment whether he is rolling to the right or to the left.

Rolling the body from side to side in rhythm with the horizontal and lateral movements of the arms is an important technique that helps front-crawl swimmers maintain good lateral alignment because the body tends to stay aligned when it follows the movements of the arms. Rolling is, and should be, a natural reaction to stroking movements. The body should follow the movements of the arms, rolling the shoulders, trunk, hips, and legs down on one side when the arm on that side is moving down, and up on the other side when that arm is traveling upward. Otherwise, as mentioned, the hips and legs will swing from side to side.

Although it is possible to roll too much, most swimmers roll too little. It is only when swimmers try to prevent the body from rolling that the horizontal and lateral movements of the arms pull the hips and legs out of alignment. The old adage, "swimming with a flat body position reduces drag," is false. The best front-crawl swimmers continually rotate their bodies from side to side during each stroke cycle. In fact, they spend more time on their sides than they spend in a flat position. Accomplished front-crawl swimmers will roll in the range of 40° to 45° toward the nonbreathing side (from a prone position) and they will roll approximately 50° to 60° from a prone position toward the breathing side (Levinson 1987). Sanchez is rolling properly in figure 4.6 (see pages 106 and 107).

The Stretch-Out Style

In recent years, the great success of Alexander Popov has resulted in a number of experts recommending his long *stretch-out style* as the ideal way to swim the front crawl stroke. This has resulted in some misrepresentations of his style, particularly among those experts who are recommending that swimmers use a partial *catch-up stroke.* The *stretch-out style* is a style in which one arm enters the water while the other is moving down for the catch. I want to warn against the adoption of this style by all swimmers.

Extending the arm fully out in front after it enters the water certainly improves streamlining while the other arm is completing its propulsive phase. But the stretch can be overdone if swimmers use a partial *catch-up style,* in which they wait until the rear arm has left the water and started its recovery before they begin to move the front arm down for the catch. Swimming in this way will extend the period of deceleration that occurs between the end of the propulsive phase with the rear arm to the beginning of the propulsive phase with the front arm.

Swimmers need a strong six-beat kick to use a partial catch-up style because they must depend on the kick for propulsion during the deceleration period between the propulsive phases of the two arms. Even then, it could be argued that they would decelerate less if the period between the end of propulsion with one arm and the beginning of propulsion with the other were shorter.

Gliding on the arm in front after the other arm has completed its propulsive phase is not recommended for any swimmer, but it should particularly be avoided by swimmers who have a weak six-beat kick and swimmers who use four-beat or two-beat kicking rhythms. Likewise, this gliding will not work for swimmers who have a weak upsweep. Reduced propulsion from the kick, or a weak upsweep, coupled with a glide will simply result in greater deceleration between the propulsive phases of the armstrokes. For this reason, an emphasis on long, stretched-out armstrokes with a slow stroke rate, while it may increase distance per stroke, could seriously reduce forward velocity for some swimmers.

To maintain a high swimming velocity, swimmers with weak six-beat kicks or broken rhythm kicks need to use a faster stroke rate than others. Assuming similar stroking proficiency, swimmers of average or less than average height will also need to use a faster turnover rate than taller competitors because they will be covering less distance with each armstroke. For these reasons, certain swimmers cannot afford to stretch the front arm out for a long time after it enters the water and before they start it down for the catch.

At the same time, they, just like all swimmers, should not start that arm down while the other arm is applying propulsive force. Instead, they should stretch the front arm out, just under the surface of the water, to improve streamlining only for as long as they are completing the propulsive phase of the underwater stroke with the other arm. And, they should begin moving the front arm downward, from its extended position toward the catch, at the precise moment when the rear arm releases its propulsive pressure on the water. As mentioned earlier, this will be when the rear arm approaches the thigh, not when it leaves the water. No swimmer should be advised to continue stretching the front arm after the rear arm's propulsive efforts have been completed simply because doing so will increase the distance the body travels forward during each armstroke.

I should mention two things before leaving this section. The first is that Popov does not glide too long. While his stroke is certainly long and he does extend his arm fully after it enters the water, underwater competition video reveals that he begins the downsweep with his front arm at precisely the moment he stops pushing back against the water with his rear arm.

The second is that what has become known as *front-quadrant swimming* is not necessarily incorrect. In this method for describing the timing between the two arms in the front crawl stroke, one full armstroke is likened to a circle containing four quadrants. The front two quadrants are the above-water and underwater portions of the armstroke that constitute the last half of the arm recovery and the first half of the underwater armstroke. The rear two quadrants are where the last half of the underwater armstroke and the first half of the arm recovery take place. It has been recommended that the timing between the arms should be such that the stroking arm is somewhere in the front underwater quadrant when the recovering arm is in the front above-water quadrant of the stroke circle. The timing between the two armstrokes is considered incorrect if the underwater arm is in the rear underwater quadrant when the recovering arm enters the front above-water quadrant.

This description is accurate in that it does indicate the correct range of positions for the two arms. As such, swimmers will have the proper relationship between the stroking and recovering arms so long as they do not delay the start of the downsweep of the arm in front until the recovering arm has entered the front above-water quadrant. Unfortunately, some have interpreted *front-quadrant swimming* to mean precisely that one arm should not start sweeping downward until the other is entering, or very near to entering, the water. This interpretation of front-quadrant swimming is not correct and will result in longer than desirable periods of deceleration between the propulsive phases of the two armstrokes.

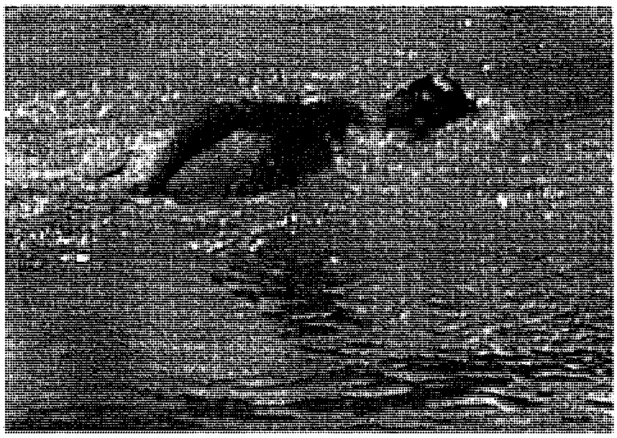


Figure 4.23 A side view photo of a swimmer breathing under the bow wave as he completes the upsweep with his arm. The swimmer is Craig Hutchison.

Breathing

Front-crawl swimmers, even those who are highly skilled, tend to make many mistakes when they turn the head to the side for a breath. They turn the head too late, lift it out of the water, and pull it back and away from the midline of the body. In reality, head movements should be coordinated with body rotation so that freestylers can take a breath without disrupting lateral alignment. The correct position is shown from the surface in figure 4.23.

Craig Hutchison, the swimmer shown in figure 4.23, rotates his face toward the surface as the arm on his breathing side sweeps up at the end of its underwater armstroke. His mouth does not appear to be above the surface when he breathes because he is breathing at the base of a bow wave that was created around his head. He takes his breath during the first half of the recovery and returns his face to the water during the second half. His body is rotated maximally to the breathing side during the upsweep. Thus, he need only rotate his head a short distance for his mouth to clear the water so that he can take a breath. There is no need to lift his head or pull it away from the midline of his body. The return of his face into the water is also coordinated with the roll of his body. That action takes place during the second half of his arm recovery when the arm on his breathing side is extending forward for the entry and his body is rotating back toward the nonbreathing side.

Except in sprint races, competitive swimmers should breathe once during each stroke cycle. In longer races, they need a steady supply of oxygen to delay fatigue. Swimmers should not hold their breath in these races. Instead, they should begin to exhale immediately after inhaling. However, they must time that exhalation so that another breath is not needed before they have completed one stroke cycle. The exhalation should be very slow at first, letting just enough air escape from the mouth and nose to reduce thoracic pressure. They should continue exhaling slowly until the mouth has returned near the surface for the next breath, at which time they should exhale the remaining air in a rapid burst, take another breath, and start the next breathing cycle. Inhalations should be larger than normal, but not excessive. Swimmers should not gasp for air. Exhalations should be complete but not forced. Little instruction in how to inhale and exhale is needed. Practice and the demands of the race will train most swimmers to breathe in the most economical manner.

Alternate Breathing

While the usual pattern is to breathe to only one side, and to the same side each time, some swimmers prefer breathing on both sides in a style called *alternate breathing*. With this method, they breathe twice during every three stroke cycles, breathing to the right on one stroke cycle, to the left on another, and not breathing during the middle stroke cycle. Another style of alternate breathing is to breathe twice to the left, complete a stroke cycle without a breath, and then breathe twice to the right. In this case, swimmers take four breaths during every five stroke cycles.

Alternate breathing has been used by many world-class swimmers, particularly females. Its use is controversial, however, having both strong proponents and opponents among elite coaches and swimmers. The following advantages have been cited for alternate breathing.

- The stroke will be more symmetrical. Alternate breathing encourages swimmers to roll the body equally to both sides, which increases body rotation and improves streamlining on the nonbreathing side. Increased body rotation should also improve the underwater mechanics for the armstroke on the nonbreathing side because swimmers will not have to use some of its force to rotate the body back from the breathing side.
- Alternate breathing may improve pulmonary diffusing capacity so that more oxygen will be extracted from the air swimmers inhale.
- Swimmers can watch competitors on both sides of them during races.

The most compelling argument against alternate breathing is that oxygen supply will be reduced. This may cause swimmers to fatigue earlier in races. This is obviously a very serious disadvantage that, potentially, could outweigh all of the advantages listed earlier, and for this reason I do not recommend that swimmers use alternate breathing in races. Having said this, I should also make it clear that there are exceptions to every rule. Certain athletes swim faster when they breathe alternately. These swimmers usually have a serious stroke defect that is corrected by alternate breathing, allowing them to cover the distance faster despite a reduced oxygen supply. Of course, it is preferable to correct the stroke without resorting to alternate breathing, but if the problem is serious and breathing alternately is the only method that rectifies it, these swimmers should use alternate breathing.

You can test the effectiveness of alternate breathing with a simple procedure I call *experimental swims.* Swimmers should complete several long experimental sets of repeats, totaling 2,000 to 4,000 m, at challenging speeds over a period of a few weeks. They should use alternate breathing on the even-numbered swims and conventional breathing on the odd-numbered swims within these sets, and they should pay close attention to the times for those repeats and the degree of effort required to produce those times. Swimmers who are consistently faster or feel they are swimming easier on the even-numbered swims should consider using alternate breathing in races. The others should stay with breathing to one side only.

Although I do not recommend alternate breathing in races, except in rare circumstances, this technique can be a very valuable teaching aid if used in training. I recommend that all swimmers learn alternate breathing in training during their formative years because it may encourage them to roll equally to both sides and swim more symmetrically when their strokes are evolving. They can then switch to conventional one-side breathing once their strokes are developed.

Common Stroke Mistakes

Some of the most common mistakes that swimmers make are described in this section to help readers diagnose and correct them.

Armstroke Mistakes

This section addresses mistakes in the armstroke and appropriate corrections. Making these adjustments is important for proper technique.

Recovery and Entry Mistakes

The most common mistakes that swimmers make during the arm recovery are to (1) use too much effort, (2) swing the arm over the water low and wide, (3) *overreach,* and (4) *underreach.* The most common mistake they make during the entry is to (5) push water forward.

1. Maintaining a relaxed recovery is not easy for swimmers to do when they want to swim fast. Their natural reaction is to recover the arms over the water quickly when they want to increase speed. What they fail to realize is that the recovering arm is traveling a shorter distance and through a less dense medium than the stroking arm. Consequently, the recovering arm will reach the entry position too early if its speed is accelerated and this will upset body rotation and stroking rhythm. In addition, thrusting the arm forward may pull the hips out of lateral alignment, particularly if the recovery is made with a wide swing to the side. Another problem with a fast recovery is that swimmers may shorten the upsweep of the stroking arm in order to begin the downsweep with the other arm. This, of course, will shorten what is the most propulsive phase of the armstroke.

Although swimmers move the arms faster during the sprint, the mechanism for doing so is to increase arm velocity throughout the entire armstroke. When this is done, the recovering arm will naturally travel over the water faster to maintain the proper relationship with the stroking arm. Even under these circumstances, however, the recovery should remain as inertial and relaxed as possible.

Swimmers should allow the momentum from the upsweep to carry the arm forward into recovery, and they should use the minimum effort necessary to keep the arm moving through the entry. In this respect, they should gradually release pressure on the water as the elbow breaks through the surface and overcomes its backward inertia by starting the arm forward by shrugging the shoulder as the hand continues up through the surface.

2. When swimmers recover the arms over the water low and wide, they usually pull the hips out of alignment in the opposite direction. These side-to-side movements cause the swimmer to take up much more space in the water. Additionally, the side-to-side movements will also cause the swimmer to push water forward with the hips and legs. All of these actions will increase form and pushing drag and dramatically reduce forward speed. Swimmers should keep the arm flexed and the elbow higher than the hand throughout the recovery, and they should recover the arm forward with as little outward swinging as possible.

3. The mistake of *overreaching* occurs when swimmers extend the arm too much before entering it into the water. The effect of this mistake is illustrated in figure 4.24. This swimmer has extended his arm forward until it is almost straight before entering it into the water. As a result, the broad underside of his arm drops onto the water, pressing a large segment of water down and forward and decelerating his forward speed.

Overreaching usually occurs because swimmers simply try to reach forward too soon during the recovery. They begin reaching forward for the entry before the arm passes the shoulder, and this early reach causes the elbow and upper arm to push down and forward through the water before the hand enters. Swimmers should be coached to maintain a high elbow throughout the recovery. They should not begin to extend the arm forward for the entry until after it has passed the head, and the hand should enter the water before the arm is completely extended.

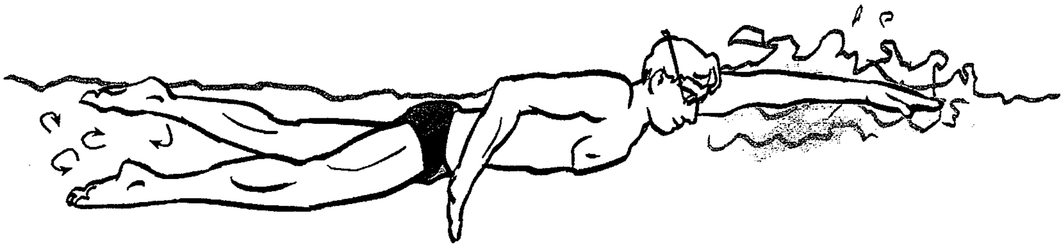


Figure 4.24 Overreaching during the entry.

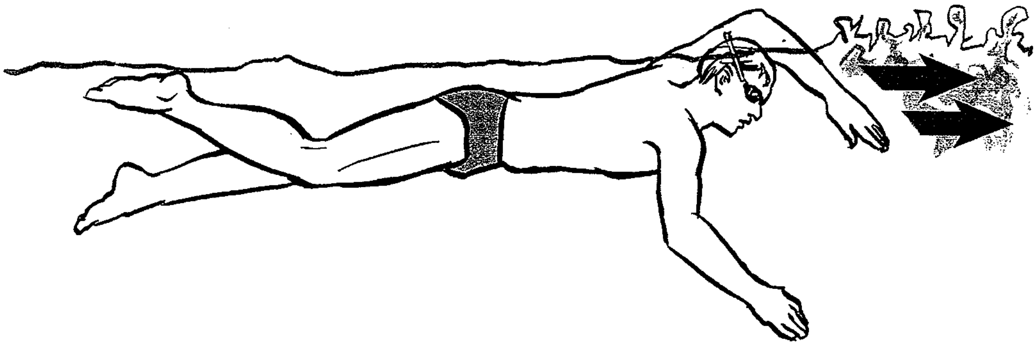


Figure 4.25 Underreaching during the entry.

4. *Underreaching* is the opposite mistake, illustrated in figure 4.25. This swimmer makes his entry too close to his head and then immediately drives his arm forward and down to the catch. When this happens, there is a tendency to push the upper side of the forearm and the back side of the hand forward underwater, which will increase pushing drag and decelerate forward speed.

This style of entry was popular at one time because coaches believed that it placed the arm in a high elbow position sooner after entry. We now realize that the entering arm should be stretched forward just under the surface of the water after it enters so that it can remain in alignment with the body until the rear arm has finished its propulsive phase.

5. Pushing drag may also be increased if the palm of the hand is not in line with the forearm as it enters the water. Some swimmers make the entry with the hand flexed at the wrist, causing them to push water forward with the back of the hand as they stretch it forward underwater.

It is possible to enter the hand into the water without pushing water forward when the palm is facing down. Indeed, some very successful swimmers do so. Nevertheless, swimmers are less likely to push water forward if the hands enter with the palms turned slightly outward. Consequently, most use this method. Where the entry is concerned, the best advice is to slide the hand into the water with the palm turned out and with little or no flexion at the wrist. Swimmers who prefer to enter with the palm flat should slide the fingertips into the water first and then enter with the hand through the hole made by the fingertips. The hand may be flexed at the wrist as it starts to enter the water, but it should be straightened in line with the wrist before it disappears beneath the surface. The back of the hand should not be pushed forward against the water.

Downsweep Mistakes

The most common mistakes during this phase of the armstroke are to (1) drop the elbow, (2) maintain the arm in an extended position, (3) slide the hand out to the side too much, and (4) slide the arm out to the side too little.

1. The dropped elbow described in chapter 3 and illustrated in figure 3.10 (see page 77) results from the attempt to begin pushing against the water before the arm is oriented backward. When swimmers try to apply propulsive force with the arm facing down, they succeed only in pushing water down and decelerating their forward speed. They must wait until the arm is facing back before they attempt to apply propulsive force.

2. It is commonly believed that the arm should remain extended during the downsweep and then be flexed during the insweep that follows. Sweeping the arm down in an extended position causes myriad problems, two of which I will mention here. First, the arm must travel down deeper to achieve a backward orientation when it is extended. This increases deceleration during the downsweep and causes the upper arm to push down against the water.

Second, the tendency to scull inward with the forearm and hand is increased during the insweep when the catch is made with an extended arm. The entire arm should be used like a boomerang-shaped paddle to push back against the water during the insweep so that propulsive drag forces are optimized and the large muscles of the trunk and shoulders can be used to apply propulsive force. The arm should not be sculled inward like an airfoil. Swimmers should flex the arms during the downsweep so that the arm is flexed nearly 90° when they make the catch and begin to apply propulsive force.

3. Although the arm will slide out a small amount during the downsweep, swimmers will delay the catch if they slide it too far out. They may also push water to the side if they attempt to forcefully direct the arm down and out, disturbing their lateral alignment. Swimmers should flex the elbow during the downsweep and they should keep the upper arm as high in the water as they can without shoulder pain. When they do this, the hand will naturally slide out to the side the proper amount without creating problems.

4. Some swimmers go to the other extreme and try to keep the arms under the midline of the body during the downsweep. This causes them to push the upper arm excessively downward through the water, and generally to sweep the arm too far under the body during the insweep and too far upward during the upsweep. All three of these actions unnecessarily increase the vertical movements of the arms. The backward movement of the arm should be as horizontal as possible during the insweep and upsweep. It should only travel deep enough to achieve a backward orientation at the catch, and then far enough upward to be near the surface when the propulsive phase of the upsweep ends.

Insweep Mistakes

The most frequent errors that swimmers make during the insweep are to (1) scull the arm in, and (2) bring the arm in too little or under the body too much.

1. The disadvantages of sculling were discussed in chapter 3. Swimmers fail to maximize propulsive drag force, they use a smaller surface area for moving water back, and they use smaller muscle groups for the application of propulsive force.

Many swimmers initiate the insweep by flexing the arm at the elbow and sliding the forearm and hand almost directly in to the midline of the body. Swimmers who stroke in this way are often among the competitors at major international meets, but they are seldom among the finalists. As explained earlier, there is a greater probability of generating more propulsive force when swimmers push back against the water with a flexed arm during the insweep.

2. The problems that result from bringing the arm in too little or under the body too much during the insweep were discussed earlier in this chapter. In short, not bringing the arm in far enough can shorten the propulsive phase of the armstroke. Bringing the arm too far under the body may create excessive sideward forces that will reduce the amount of propulsive force and cause swimmers to wiggle from side to side.

Upsweep and Release Mistakes

The most common errors during the upsweep and release are (1) extending the arm too rapidly at the elbow and trying to push against the water until the hand reaches the surface, and (2) not streamlining the hand as it travels the last few inches to the surface.

1. When swimmers extend and push the arm forcefully against the water until the hand and forearm reach the surface, they end up decelerating their forward speed and pulling the hips and legs down because they are pushing up instead of back against the water with the underside of the forearm.

Swimmers should keep the arm flexed with the palm and the underside of the forearm facing back throughout the propulsive phase of the upsweep. The small amount of arm extension that takes place should be used only to maintain backward pressure against moving water. At the same time, swimmers should stop pushing back against the water when the arm begins to move forward into the recovery or they lose a backward orientation with the forearm, whichever comes first.

2. The most common mistake swimmers make during the release and the first part of the recovery is not streamlining the hand as it travels the last few inches to the surface before leaving the water. Some swimmers, even those who stop pushing back against the water at the proper time, fail to turn the palm in after the upsweep is completed and the recovery has begun. This mistake causes an increase of interference drag as they pull the hand up through the water with the broad surface of the palm facing up. After the release, swimmers need to bring the hand out of the water with the small edges of the fingers facing up to reduce the surface area and, consequently, the resistive drag they encounter.

Kicking Mistakes

There are three major mistakes many swimmers make in the flutter kick: (1) kicking too high, (2) kicking too deep, and (3) bending the legs too much on the upbeat.

1. Swimmers are kicking too high when the entire foot and part of the leg come out of the water. Excessive upward leg movements may push the hips down. The feet should reach the surface during the upbeat of the flutter kick, but the entire foot should not come out of the water.

2. When swimmers kick too deep, they increase frontal surface area unnecessarily, which increases form drag. They may also push water forward during completion of the downbeat. The feet should be only slightly below the chest when they complete each downbeat.

3. Swimmers who bend the leg during the upbeat push the water forward with the underside of the lower leg. This, in turn, submerges the hips and decelerates forward speed, as illustrated in figure 4.16 (see page 121). The upbeat should be made with a straight leg and swimmers should not allow the lower leg to flex until it starts the next downbeat. Above all, they should not push the leg against the pressure of the water during the upbeat and the first part of the downbeat. Rather, they should allow the pressure of the water above the leg to maintain it in an extended position during the upbeat. Then they should allow the pressure of the water below the lower leg to flex it during the first part of the downbeat. The only time swimmers should push against the water is during the final portion of the downbeat, when they extend the lower leg vigorously at the knee.

Timing Mistakes

The usual problems in this area are (1) the movements of one arm get out of synch with the other, (2) body rotation gets out of synch with stroking movements, (3) the downsweep is started too soon, (4) the arm in front glides too long before starting the downsweep, and (5) poor synchronization between the leg and arms.

1. The recovering arm should enter the water when the stroking arm is starting the insweep. There are two possible mistakes in this respect. The recovering arm can enter the water either too early or too late in the stroke cycle.

If swimmers allow one arm to enter the water during the downsweep of the other, they will be rolling in the wrong direction and this will create pushing drag for the recovering arm. To correct this motion, they will have to slide the recovering arm into the water and outward rather than forward until the insweep of the other arm begins and they can start rolling in the opposite direction.

If swimmers put the recovering arm into the water too late, that is, after the upsweep has begun, their insweep will generally be wide and ineffective. Swimmers must roll toward the stroking arm during the insweep if they want to use it to full advantage. If the body is rotated in the opposite direction, they will tend to slide the arm under the body or they will reduce both the length and the inward movement of the arm and push straight back, outside the confines of the body, in one long upsweep. This should cause a serious reduction in distance per stroke.

2. Because the body should always rotate in the same direction the arm is moving, problems with body rotation and arm synchronization usually go hand in hand. The entire right side of the body should rotate down when the right arm is traveling down and up when the right arm is traveling. The same is true for the left side of the body during the left armstroke. Rolling in this manner is very natural. The arms tend to pull the swimmer's freely suspended body in the same direction they are moving.

When their armstrokes are synchronized incorrectly, swimmers will usually shorten or eliminate a particular phase with one armstroke to rotate the body in the proper direction for the other armstroke. For some swimmers, however, particularly those who have been taught to swim with a flat body position, it is not uncommon to resist the tendency to rotate altogether. In this case, they inhibit the natural tendency to rotate in synch with the lateral and vertical movements of the arms and the body torques out to the side, increasing form and pushing drag. Some swimmers also compromise the propulsive aspects of their armstrokes because they reduce the lateral and vertical movements of the limbs too much to prevent rolling.

3. The third problem is very common because it is natural for swimmers to commence pushing against the water as soon the hand enters the water. There are two very important reasons that they should not do this. First, they will be completing most of the propulsive phase of the other armstroke after the arm in front has entered the water. Consequently, before they start sweeping the entering arm downward, they need to keep it streamlined and in line with the body until those propulsive movements have been completed. Second, they may tend to terminate the upsweep of the stroking arm prematurely if they start pressing down and back with the other arm immediately after it enters the water.

4. Swimmers who glide too long make just the opposite error. They do not start sweeping down with the front arm until the other arm has completed its recovery and has entered the water. This mistake is commonly referred to as a *catch-up stroke.* The term *catch-up* is used because the downsweep of one arm is delayed until the other arm is almost extended beside it. In a sense, therefore, the entering arm is catching up with the one in front.

The reason the catch-up stroke is a mistake is really very simple. If swimmers are not applying propulsive force, their forward velocity will be decelerating. Any action that unnecessarily prolongs the interval of time between the end of the propulsive phase of one armstroke and the beginning of propulsion with the other will, therefore, reduce average velocity per stroke.

5. Poor timing between the arms and legs is seldom a problem for swimmers. Swimmers seem intuitively able to coordinate the leg beats and armstrokes regardless of the rhythm they use, whether a six-beat or one of the two-beat or four-beat tempos. I have observed, however, that some swimmers tend to deemphasize or overemphasize certain leg beats within a stroke cycle, even when the timing of those beats is correct relative to the armstroke. These *minor* and *major* leg beats probably indicate a problem with the particular phase of the armstroke they are paired with. For example, a swimmer who uses a small insweep will tend to deemphasize the accompanying kick. Likewise, when the kick accompanying the upsweep is minor, that phase of the armstroke has probably also been deemphasized.

By the same token, a very large and deep kick may signify too much pushing drag during a particular phase of the armstroke. Likewise swimmers may be using a large powerful kick in an attempt either to maintain the alignment of a particular body part or to overcome that drag. For example, an abnormally large downbeat during the downsweep of the arms indicates that swimmers may be pushing too far down and decelerating their forward speed. An unusually large downbeat during the upsweep probably means that the swimmer is pushing water up too much.

Body Position Mistakes

Mistakes in this area usually mean that swimmers have done something to disturb their (1) horizontal or (2) lateral alignment.

1. The major mistakes that cause a loss of streamlined horizontal alignment have already been mentioned: trying to hydroplane and kicking too deep. In both cases, the body inclines too far downward from the head to the feet, causing it to take up too much space in the water and thereby increasing its resistance to forward progress.

2. Most of the mistakes that disrupt lateral alignment have to do with the armstroke and were discussed in the section on recovery and entry mistakes. They are (1) overreaching, (2) recovering the arm too wide, and (3) pushing water in during the insweep. These mistakes cause swimmers to wiggle down the pool like a snake.

Another way swimmers can disrupt their lateral alignment is by pulling the head back when they breathe. This causes the trunk to twist to the side when breathing, which in turn causes the hips to swing to the opposite side. This sideward swinging increases the space the swimmer takes up in the water and creates additional resistive drag.

Breathing Mistakes

The most frequent mistakes that swimmers make when they breathe are (1) turning the face too soon, (2) turning the face too late (*late breathing*), (3) lifting the head, (4) returning the head to the water too slowly, and (5) pulling the head back and out of alignment. The effect of the last mistake was described in the previous section. The others are described in this section.

1. Swimmers interfere with their natural body rotation when they turn the head to breathe before the arm on the opposite side has entered the water. This is because they are trying to turn the head to the opposite side while the body is still rotated toward the side of the recovering arm. To breathe, they will most likely rush the recovery of the arm forward so that they can get the body rotated in the direction the head is turning. In doing so, they will probably also shorten the insweep and lose propulsive force. Swimmers must wait until the body rotates toward the breathing side before they start turning the face in that direction. This will be after the recovering arm has entered the water in front of them.

2. Swimmers who turn the head too late usually have what is called a *hitch* in their strokes. Turning the head too late causes them to breathe during the arm recovery instead of the underwater stroke. As a result, they hesitate or make a slow recovery to allow time to breathe. This hesitation delays the downsweep of the other arm, which in turn causes them to decelerate more than usual during that stroke phase.

3. The error of lifting the face from the water to breathe is seen only occasionally and then only among novice competitive swimmers. These swimmers usually try to swim without rolling the shoulders and have to lift the head forward to get the mouth out of the water. They should be taught to roll the body toward the breathing side, leaving the head in the water as they rotate the face to the side.

4. The mistake of not returning the head to the midline after breathing is common even among top-level swimmers. They do not rotate the head back to the middle after

breathing or they return it too slowly. In either event, they fail to rotate the body sufficiently toward the nonbreathing side. This causes them to sweep the hand too far outward during the upsweep and during the recovery of the arm on the nonbreathing side.

Stroke Drills

This section includes a number of teaching drills for the front crawl armstroke, the flutter kick, and the coordination between the two. Drills that will improve the techniques of breathing and body streamlining are also included.

Armstroke Drills

Drills for teaching the sweeps described in chapter 3 are some of the best I have found for teaching the front crawl armstroke. Other good drills are also described in this section.

CATCH-UP STROKE DRILL

This drill starts with swimmers in a prone position, with the hands extended in front, right hand over left. Swimmers execute one complete armstroke with the left arm, placing it over the right arm when it comes back to the starting position. Next, they execute a stroke with the right arm, placing it over the left arm to begin the sequence again. This drill helps swimmers focus on stroking correctly while using just one arm at a time. The drill can also be done holding a kickboard in front. The board should be held on the near end to allow enough space for complete stroking.

ONE-ARM SWIMMING DRILL

In this drill, athletes swim a set of repeats using only one arm at a time. The other arm can be stretched out in front or it can be extended back with the palm resting on the thigh. The arm-in-front position is good when swimming with the arm on the breathing side. The arm-behind position is best when swimming with the opposite arm. The arm-in-front and arm-behind positions on the breathing and nonbreathing sides cause the working arm to function more as it would in actual swimming because the body will be rotating as it would during actual swimming. Swimmers should stroke for one or more lengths of the pool before switching arms. One-arm swimming can be done as a swimming or pulling drill.

FIST SWIMMING DRILL

The purpose of this drill is to teach swimmers to use the arms for propulsion. Athletes should swim selected sets of repeats with the hands closed in a fist. With the hand closed, swimmers must rely on the arms for propulsion and, thus may become more effective at using them for this purpose. This should be done as a pulling drill for the arms to supply all of the propulsive force.

ONE-FIST SWIMMING DRILL

To perform this drill, an athlete swims or pulls any number of repeats with the hand of the nondominant arm open and the hand of the dominant arm in a fist. The hand velocity graphs in figure 4.3 (see page 99) show that most swimmers have one arm that is less propulsive than the other. One-fist swimming may help them improve propulsive force with the nondominant arm. Primarily, it allows swimmers to overuse that arm to increase its propulsive contribution to the whole stroke.

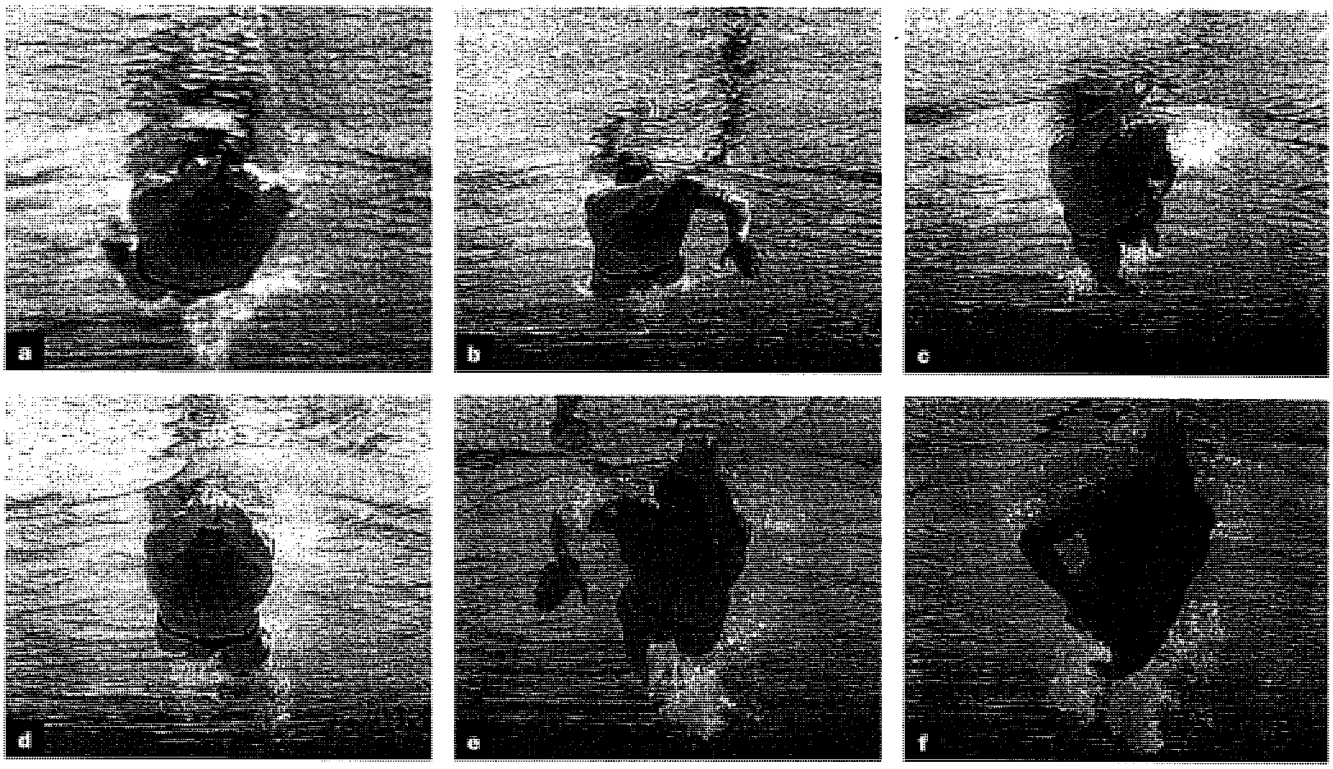


Figure 4.26 The dog paddle drill.

(a) Start of glide position.
(b) Catch with left arm.
(c) Insweep with left arm.
(d) Glide position.
(e) Catch with right arm.
(f) Insweep with right arm.

DOG PADDLE DRILL

This is an excellent drill for practicing the underwater armstroke because it slows the arms so that swimmers can think about executing the downsweep and insweep properly. The dog paddle drill is illustrated in figure 4.26.

The arms are recovered underwater as swimmers paddle down the pool using the typical dog paddle style. They stretch one arm forward and hold it in a streamlined position within the confines of the body while they stroke with the other arm. The armstroke should be a slow, deliberate sequence in which swimmers concentrate on performing the downsweep, catch, and insweep correctly with one arm, after which they return it to a stretched position in front and repeat the sequence with the other arm. Athletes should not swim with the head above water. They should keep the face in a normal position in the water for better streamlining and roll the body to the side to breathe. This should be done as a pulling drill so swimmers can concentrate on their armstrokes.

LONG DOG PADDLE DRILL

This drill is designed to incorporate the entire underwater armstroke. Swimmers should use a pull-buoy so that they can concentrate on their armstrokes. They start in a prone position with the arms extended in front. From there they slide the arm into the catch position and then complete the insweep and upsweep without completely extending the arm or removing it from the water. Then they return the right arm to the starting position and perform a similar stroke with the left arm.

Recovery and Breathing Drills

The catch-up drill described in the previous section is excellent for improving the arm recovery and breathing techniques, as are the following drills.

LANE SWIMMING DRILL

Athletes swim down the pool with one shoulder touching the lane line. In this position, they have to recover the arm nearest to the lane line with a high elbow or it will get caught underneath. They should alternate swimming up and down the pool on the same side of the lane to improve the recovery of both arms.

DRAG FINGERS DRILL

This drill also encourages a high elbow recovery. Athletes swim or pull while dragging the fingers through the water during the arm recovery. The elbow should be flexed so that it is pointing up and directly above the fingers, which should be dragged forward through the water in a nearly straight line beside the body.

SLIDE THUMB DRILL

This drill is similar to the previous one, except that swimmers slide the thumb along the side of the body, toward the armpit, before reaching forward for the entry. They do not need to drag the fingers through the water when performing this drill. They should keep the hands very close to the surface, however, and they should try to recover in a nearly straight line from exit to entry. This drill is also an excellent way to teach a high elbow recovery.

EAR HESITATION DRILL

This is yet another drill for teaching the high elbow recovery. While swimming, athletes bring the thumb to the ear during the recovery and hesitate in that position before reaching forward for the entry.

Kicking and Timing Drills

The primary purposes of this group of drills are to help swimmers perfect the flutter kick and develop coordination between the kick and armstrokes.

SIDE KICKING DRILL

This drill is excellent for teaching diagonal kicks and body rotation toward the nonbreathing side. Swimmers kick down the pool on their sides with the lower arm extended overhead and the other arm extending back and resting against the thigh. After kicking four, six, eight, or some other designated number of times, they should roll to the opposite side, reverse the positions of the arms, and repeat the sequence. The drill can be repeated for any number of pool lengths. At first, swimmers should kick at least one length of the pool before changing sides. Many swimmers are not very proficient at diagonal kicking on the nonbreathing side and will therefore shy away from kicking on that side unless required to do so. This drill will help them kick more efficiently on both sides. After they become proficient at doing this, swimmers can alternate sides after any number of designated kicks. In fact, doing so can help swimmers develop a six-beat kicking rhythm. Swimmers should be instructed to kick twice to the left, twice *while changing sides,* and twice to the right, in the rhythm of the six-beat kick.

KICKING WITH FINS DRILL

This is an excellent way to teach swimmers to keep the leg straight during the upbeat of the flutter kick and to keep the width of the kick at the minimum necessary for effective propulsion. Because fins sensitize swimmers to the movements of the legs, swimming with fins will make them be less likely to flex the legs during the upbeat or kick excessively downward.

STRAIGHT-LEG KICKING DRILL

This drill can also help swimmers correct the mistake of bending the knees excessively during the upbeat of the flutter kick. They should be instructed to kick from the hips with straight but very relaxed legs and ankles. In this way, they will tend to keep the legs straight on the upbeat, yet the water will naturally bend the legs during the downbeat.

UNDERWATER KICKING DRILL

Performed by kicking several series of underwater repeats between 12.5 and 25 yd or m, the underwater kicking drill should be done both in a prone position and while kicking on each side to develop the vertical and lateral components of the flutter kick. The arms should be overhead and together and the body should be very streamlined. Kicking drills of this type are also excellent for teaching swimmers to maintain a straight leg on the upbeat because they can feel the movements of the legs better when the entire body is underwater.

WALL KICKING DRILL

Swimmers kick for some prescribed length of time while holding onto the gutter. They should do the drill in a prone position and while kicking on both right and left sides. Side kicking is still another excellent method for helping swimmers to keep the legs straight during the upbeat of the flutter kick because they can watch and feel the movements of the legs. From an administrative standpoint, wall kicking is an excellent drill because the coach can walk along the deck and make suggestions to the swimmers.

Breathing Patterns for Races

Swimmers can generally swim faster when they do not turn the head to breathe. There are at least two possible reasons for this. Principal among these is that (1) the stroke on the nonbreathing side becomes more propulsive because a portion of the force is not being used to rotate the body back from the breathing side, and (2) rotating the body to breathe increases drag somewhat, no matter how efficiently it is done.

The dilemma facing swimmers is that restricting their breathing too much during a race will reduce their oxygen supply and may cause fatigue, whereas breathing too often may reduce their speed. Thus, it is important to determine the breathing pattern that is most effective for each race distance. While most coaches agree that breathing once during each stroke cycle is the best pattern for races of 200 yd or m and longer, many recommend restricted breathing patterns for races of 25 to 100 yd or m for the reasons just cited. My purpose in this section is to discuss the breathing patterns recommended for sprint races.

25 and 50 Races

Swimmers should restrict their breathing in these races because, over these short distances, the increase in velocity they can generate by not breathing too often overshadows any effect that oxygen deprivation will have on their performances. Races of 25 yd or m are usually swum without taking even one breath.

Swimmers eight and younger can be trained to swim these distances without breathing. Teenagers and older swimmers can be trained to swim 50 yd or m without breathing, although most find that they are faster if they take one to three breaths during the race. Preteens are best advised to take two or three breaths during a 50 yd or m race.

It is the buildup of carbon dioxide in the body when swimmers hold their breath, and not a lack of oxygen, that causes distress in 50 yd or m races. The time to swim this distance is too short for a significant amount of oxygen to travel into the lungs and out to the muscles. Therefore, breathing will not really improve the oxygen supply. The oxygen swimmers use in these races is actually inhaled as they dive into the water. The rapid energy expenditure in sprint races will produce a large amount of carbon dioxide in a short time, however, and swimmers need to expel that carbon dioxide periodically to reduce the distress they feel.

Swimmers in 50 yd or m events should experiment with taking one, two, and three breaths during the race to determine which produces the fastest time. While some swimmers prefer to take three breaths, most accomplished swimmers in their late teens and older should be able to swim the 50 distance with a maximum of two breaths. Where in the race swimmers should take a breath is discussed for each breathing pattern in the next three sections.

Three-Breath Patterns

When a three-breath pattern is used in 50 yd or m short course races, the first breath should be taken approximately 7 to 10 yd or m before the turn. The second breath should be taken on the final length, when the swimmer has completed approximately one-third of the distance, and the third breath should be taken when two-thirds of the distance has been completed.

The breaths can be taken at approximately the same positions in long-course races, except, of course, there is no turn. The first breath should be taken at the 20 m mark; the second at the 30 m mark, and the third at the 40 m mark.

Two-Breath Patterns

There are two different types of two-breath patterns that swimmers use when they swim 50 yd or m short course races. In the first method, the initial breath is taken 5 to 7 yd before the turn and the second breath at the halfway point of the second length. In the second method, the first length is swum without a breath and two breaths are taken during the second length. The first of these breaths is taken one-third of the way back, and the second is taken two-thirds of the way to the finish. Swimmers who use a two-breath pattern should breathe at the 20 and 40 m marks in long course races.

One-Breath Patterns

There are also several methods that swimmers can use when they wish to breathe only once during a 50 yd or m race. In short course races, the breath should be taken on the final length about one-third of the way back or at the halfway point on that length. Swimmers should breathe at the 30 or 40 m mark in long course races.

A one-breath pattern is recommended as the most effective way for accomplished senior athletes to swim races of 50 yd or m. An advantage of this method in short-course races is that swimming the first length without breathing should improve speed and increase the likelihood of turning faster. Swimmers will have the wall in view throughout most of the length and can adjust their strokes to hit the turn at full speed. Preteen and early-teen swimmers may find all of these breathing patterns too difficult because they require more time to complete their races. These swimmers should probably breathe once every two stroke cycles in races of 50 yd or m.

100 Races

Races of 100 yd or m present a complex problem where breathing patterns are concerned. A compromise must be struck between increasing speed by not breathing and delaying fatigue by increasing the oxygen supply. A popular breathing pattern is to take one breath on the first 25, two breaths on the second 25, and then one breath during every second arm cycle for the remainder of the race. Some swimmers restrict their breathing even more during the second half of the race, breathing only three times during each of the last two lengths (or six times during the final 50 m if they are swimming a long-course race).

I believe that all of these patterns are too restrictive and cause swimmers to fatigue too early in the second half of the race. It is my opinion that most athletes will swim these events faster if they take more breaths, particularly during the first half to three-quarters of these races. This is because oxygen requires several seconds to get from the lungs to the muscles. Therefore, the air inhaled during the first quarter of the race will be supplying oxygen to the muscles during the next quarter. Consequently, they should breathe more often during the first 25 and 50 yd or m of these races, even if they do not feel the need to do so. Fatigue will already be significantly advanced if athletes wait until they feel the need for a breath before taking one. While taking more breaths during the first half of the races may cause them to be slightly slower at the halfway point, their increased speed in the later portion of the race should more than compensate by allowing for a faster overall time.

Swimmers in 100 yd or m races should experiment with the breathing patterns described in the following list until they find the one that best suits them.

- Breathe once every second stroke cycle for the first quarter of the race and once every stroke cycle during the final three-quarters.
- Breathe once every second stroke cycle for the first half of the race and once every stroke cycle thereafter.
- Breathe once every second stroke cycle for the entire race.
- Breathe once every stroke cycle from start to finish.

This last suggestion may be a surprise. Most coaches feel that breathing so often will add too much time to a 100 race. In fact, there have been many very successful sprinters who have breathed once during each stroke cycle almost throughout the entirety of these races and, therefore, it would be a good idea for swimmers to try this method before dismissing it.

I suggest that swimmers use experimental swims in practice to determine how often they can breathe during a 100 race without losing speed. Athletes should swim a series of six or eight 50 repeats at the end of a particularly strenuous practice session. This drill should be done at the end of practice so that swimmers will be fatigued, as they would be during the second half of a 100 race. The send-off time for these repeats should provide between 20 and 30 sec of rest. The repeats should be swum as fast as possible.

Swimmers should randomly alternate two or more of the recommended breathing patterns throughout the set of repeats and someone should keep a record of the times and breathing patterns used. The pattern that consistently produces the fastest times should be the one used in competition. If two or more patterns produce identical times, the one that allows for more-frequent breathing should be used because that pattern will provide a greater oxygen supply.

It should be mentioned that, regardless of the pattern preferred, swimmers should always swim the final 5 to 10 yd or m of any race without breathing to finish as fast as possible. It should also be stressed that hypoxic training and other restricted-breathing drills be an essential part of the training program for sprinters so that they can swim these races with fewer breaths and less distress.

Longer Races

As mentioned earlier, it is generally accepted that swimmers should breathe once every stroke cycle in races of 200 yd or m and longer. Even so, there are some swimmers who mistakenly believe that they can save time by not breathing so frequently during the early stages of these races. Such swimmers should remember that the breaths they take early in the race will be supplying oxygen to their muscles later. Consequently, they can delay the onset of fatigue by breathing frequently early in the race, even if they do not feel that they need to breathe at that time.

5

Butterfly

New in this edition:

- A description of the butterfly armstroke based on drag-dominated propulsion
- A discussion of wave propulsion in the butterfly
- A discussion of propulsion from the body and reverse body waves
- A discussion of the underwater dolphin kick

The butterfly is, for most swimmers, the second fastest of the competitive strokes. It evolved from the breaststroke in the early 1930s when swimmers realized they could go faster by recovering the arms over, rather than under, the water. The above-water recovery, although radical, complied with the rules for the breaststroke in that the arms were recovered symmetrically and simultaneously.

With the introduction of the butterfly armstroke, breaststroke races became some of the most interesting events in competitive swimming. Some competitors continued to swim the breaststroke underwater, as was the custom during those years. Others swam the "new" butterfly-breaststroke on the surface. Still others swam a combination of the two styles. Soon enough, breaststroke races were all being won by butterfly-breaststroke swimmers. Later, swimmers discovered that they could swim the butterfly-breaststroke faster if they used what we now know as the *dolphin kick.* The dolphin kick also conformed to breaststroke rules in use at that time because the legs move simultaneously and in the same plane. With the introduction of the dolphin kick, the butterfly-breaststroke became so much faster than the conventional breaststroke that the butterfly was made a separate competitive stroke in 1955. The invention of the butterfly is credited to swimmer Jack Sieg and his coach David Armbruster of the University of Iowa.

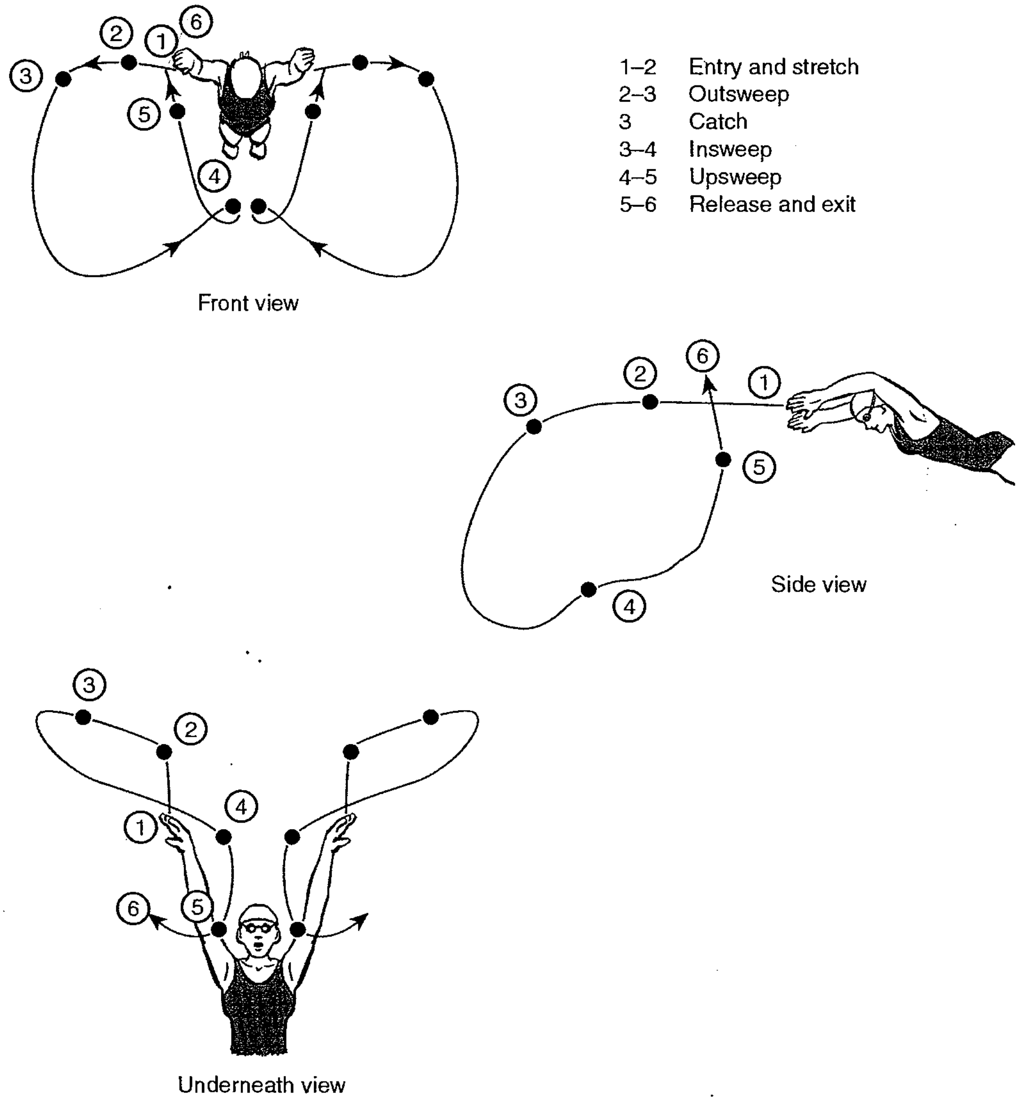
The butterfly stroke is described in this chapter using largely the same categories used to describe the front crawl stroke in chapter 4. The order of presentation will be stroke and velocity patterns, the armstroke, the dolphin kick, timing of the arms and legs, body undulations and breathing, common mistakes, and drills.

Stroke and Velocity Patterns

The butterfly armstroke consists of five phases: the entry and stretch, the outsweep and catch, the insweep, the upsweep, and the release and recovery. Swimmers execute two complete dolphin kicks during each stroke cycle. The downbeat of the first kick takes place when the hands enter the water in front and the downbeat of the second occurs during the upsweep of the armstroke. There are four distinct propulsive phases in this stroke. The first of these takes place during the entry of the arms and the downbeat of the first dolphin kick. The second starts at the catch and continues through the insweep. The third occurs during the upsweep and the downbeat of the second dolphin kick. The fourth propulsive phase takes place during the arm and leg recoveries and is the result of wave propulsion.

Stroke Patterns

Typical front, side, and underneath stroke patterns for the butterfly are illustrated in figure 5.1. These patterns were drawn from videos of Mary T. Meagher shot at the 1984



1–2	Entry and stretch
2–3	Outsweep
3	Catch
3–4	Insweep
4–5	Upsweep
5–6	Release and exit

Figure 5.1 Front, side, and underneath views of Mary T Meagher's stroke patterns for the butterfly.

U.S. Olympic training camp in Mission Viejo, California. They are plotted relative to a fixed point in the pool and illustrate the many and varied diagonal arm movements during this stroke.

From the side, the butterfly stroke pattern looks very much like the side view stroke pattern for the front crawl stroke. The hands sweep down in the beginning and up at the end. The pattern differs from the front and underneath, however, in that swimmers sweep the hands out a much longer distance at the beginning of the underwater armstroke and they use larger diagonal backward and inward motions during the insweep.

Following is a three-dimensional description of the arm movements for the underwater portion of the butterfly armstroke. After entering the water, the arms travel directly forward, just under the surface, while the downbeat of the first dolphin kick is completed. Then the arms sweep out to the side until the catch is made. From side and front views, it appears that the arms also move somewhat downward during the outsweep. The amount of downward arm movement is actually less than it appears to be. It is really the hands and forearms that are traveling down because the arms flex during the outsweep.

The catch is made when the arms are outside the shoulders. From there, the arms move under the body in a large, circular sweep that starts with the hands moving back, down, and in and end with them traveling back, in, and up under the body. The transition to the upsweep occurs as the hands approach the midline of the body, under the chest. At that point, the direction of the arms changes quickly, moving back, up, and out as the upsweep is completed. Pressure on the water is released and the arm recovery initiated as the hands pass the thighs on the way to the surface. The hands travel up, out, and forward out of the water after the release and during their recovery.

Swimmers seem to separate themselves into two distinct camps where the underwater armstroke of the butterfly is concerned. In one style, the hands are brought in to the midline of the body during the insweep, as shown in figure 5.2. In the second style, which is illustrated in figure 5.1, the hands are not brought in as much.

Swimmers who use the style shown in figure 5.2 usually have a distinct two-peak velocity pattern with propulsive peaks of nearly equal magnitude during the insweep and upsweep and a rather large period of deceleration during the transition between these two propulsive phases. The style illustrated in figure 5.1 lends itself to a one-peak velocity pattern in which the efforts of the insweep and upsweep are blended together into one large propulsive peak with little or no deceleration between stroke phases. The advantages and disadvantages of these two styles will be discussed later in this chapter in the section on velocity patterns.

The drawing in figure 5.3 shows a stroke pattern drawn relative to the swimmer's body. It depicts the "S" pattern, or *keyhole pattern,* commonly used to teach the butterfly armstroke, and rightly so. As was the case in the front crawl stroke, illustrating the hand pattern by this method is the best way to show the movements of the arms.

The outsweep corresponds to the first curve of the "S," the insweep to the middle curve, and the upsweep to the final curve. A simple set of instructions would be the following: After completing the first kick, sweep the hands out until they are outside

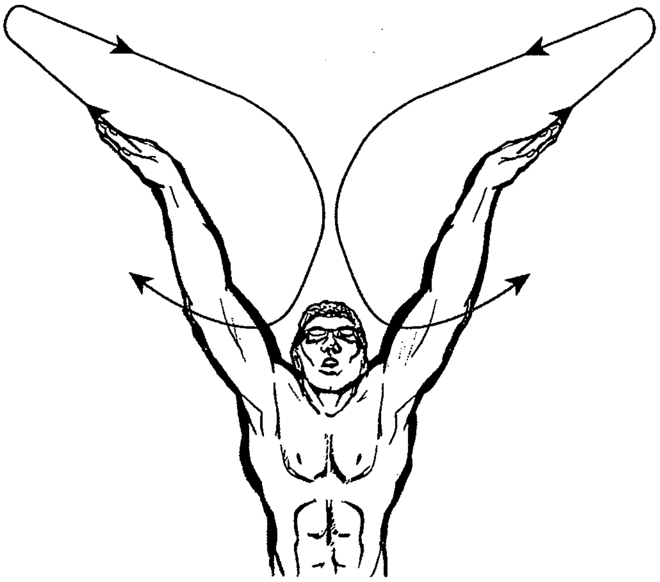


Figure 5.2 An underneath stroke pattern of butterfly where the hands are brought together under the body.

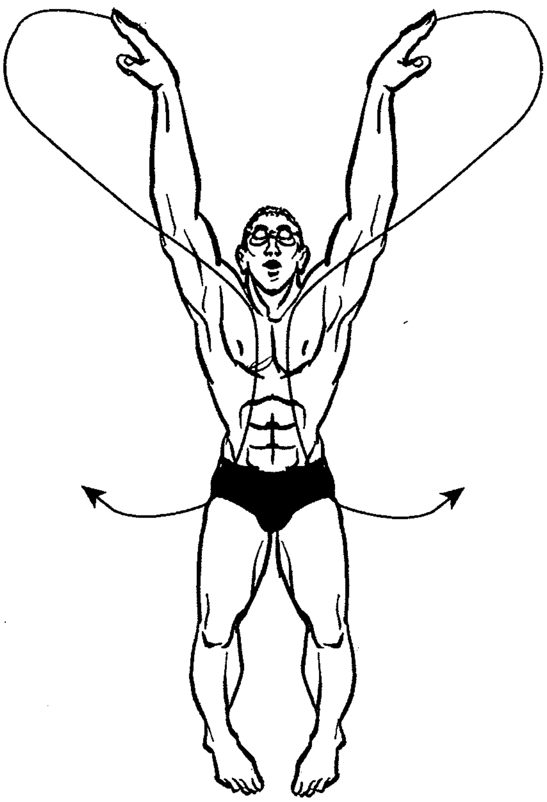


Figure 5.3 An underneath view of a stroke pattern for the butterfly drawn relative to the swimmer's moving body.

the shoulders. Then, sweep the hands in under the chest until they are almost together. Finally, sweep the hands out, up, and back toward the surface of the water. The first curve of the "S" is not propulsive and should be made gently. Hand speed should accelerate gradually during the final two curves, reaching peak speed during the third curve.

Forward Velocity and Hand Velocity Graphs

Forward and hand velocity graphs for Mary T. Meagher are illustrated for one stroke cycle in figure 5.4. The bottom graph depicts the forward velocity of her center of mass and the top graph shows the three-dimensional velocity of her hands.

Forward Velocity Graphs

The graph begins as her hands enter the water and while she is completing her first dolphin kick. She is at her lowest velocity (1 m/sec) at this time because she has just completed her arm recovery. Her body accelerates forward to approximately 2 m/sec as she kicks down and extends her arms forward. This is followed by a significant loss of velocity during the outsweep of her arms and the recovery of her legs. Her forward velocity drops to approximately 1.3 m/sec during this time. Once the catch is made, how-

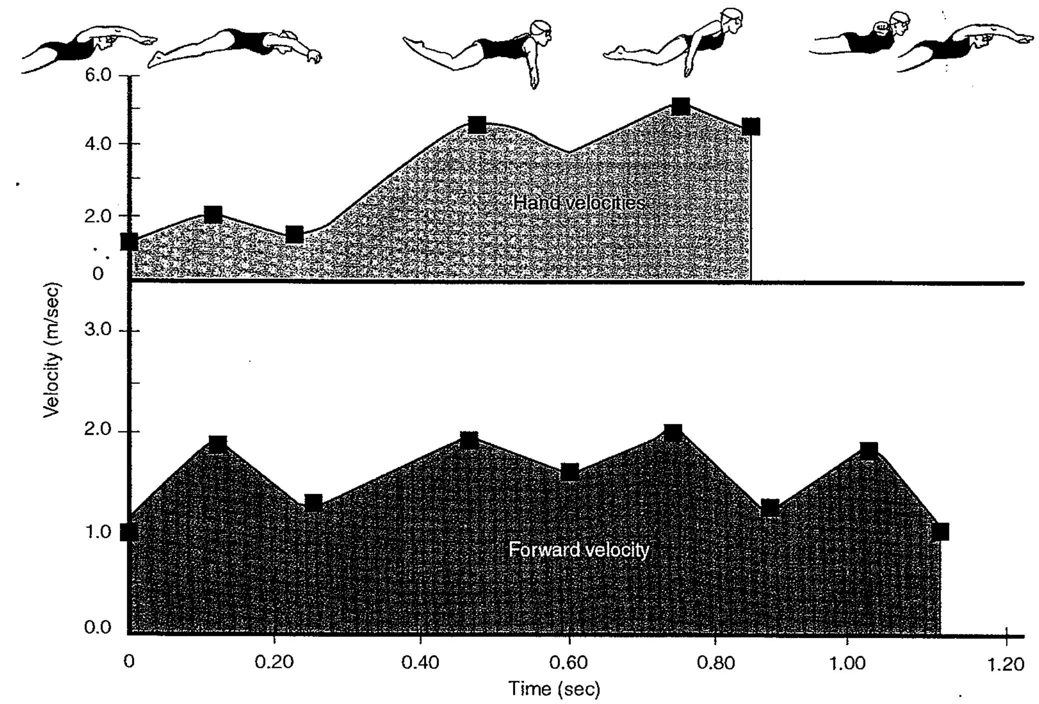


Figure 5.4 Hand and body velocity graphs for Mary T. Meagher during one butterfly stroke cycle.

ever, her forward speed accelerates quite rapidly to a velocity of 1.8 m/sec during the insweep. There is another very short period of deceleration during the transition to the upsweep, after which her forward velocity increases to a high of nearly 1.9 m/sec as she completes the upsweep with her arms and the second downbeat of her dolphin kick. Her forward velocity decelerates for a short time when she releases but increases again during the first half of her arm recovery. This increase is the result of wave propulsion. Then her forward velocity declines during the second half of the arm recovery until she returns to the starting position where her arms are entering the water for the next stroke cycle and the downbeat of her first kick is underway.

The upsweep is the most propulsive phase of the armstroke for most front-crawl swimmers. Other phases of the stroke cycle can be even more propulsive or at least as propulsive as the upsweep for many butterfly swimmers, however. In a study with seven national-level swimmers from New Zealand, Sanders (1996) reported that four attained their greatest velocity during the upsweep and second kick. Two others reached their fastest speeds during the entry of the hands and first kick. The greatest velocity for the final swimmer was recorded during the early portion of the insweep.

Hand Velocity Graphs

Just as in the front crawl stroke, the accelerations and decelerations of Meagher's arms coincide with similar changes in her forward velocity. Beginning with the entry of her hands, their velocity decelerates until they are pushed forward by her body during the period between their entry into the water and the point at which they begin the outsweep. This is indicated by the fact that the forward velocity of her center of mass and her hand velocity are nearly identical during this period.

The velocity of her hands remains very similar to her forward velocity during the outsweep of her armstroke, even though her hands are moving out as well as forward. This means that the forward velocity of her hands is somewhat slowed while their outward velocity increases. Once the catch is made, however, her arms accelerate rapidly as she executes the first propulsive phase of the armstroke, the insweep. This is followed by a small period of deceleration during the transition from insweep to outsweep. Her arms then accelerate, once again, reaching their peak velocity of approximately 5 m/sec during the upsweep. Hand velocities typically reach speeds of 3 to 4 m/sec during the insweep and 4 to 5 m/sec during the upsweep for many world-class butterflyers (Maglischo 1984; Schleihauf et al. 1988).

The velocity of her arms declines at the release point and continues to decline, although not greatly, until her hands leave the water. This indicates that she has stopped pushing back against the water, even before her hands leave the water. Her hands leave the water traveling at approximately 4 m/sec and continue to decelerate throughout the recovery until they are moving at approximately 1 m/sec when they enter the water to begin the next stroke cycle.

Velocity Patterns of Great Butterfly Swimmers

Many facets of Meagher's forward velocity pattern provide some insight into why she was such a great butterfly swimmer. This is particularly true when her forward velocity is compared to the forward velocity graph of a less skilled swimmer in figure 5.5.

The first and perhaps most important distinction is that Meagher maintains a high level of forward velocity for nearly twice as long as the national-level swimmer. Her body accelerates forward at a high rate of speed for nearly 0.70 sec during a 1.18 sec stroke cycle. Most butterfly swimmers, like the swimmer in figure 5.5, only accelerate forward for 0.30 to 0.40 sec during each stroke cycle. This is probably because they are able to use only one of the propulsive sweeps (the insweep or upsweep) effectively. By contrast, the best butterfly swimmers in the world achieve a sizable amount of propulsion from both sweeps. As shown, the national-level swimmer in figure 5.5 does not accelerate his body forward as much during the insweep, even though he actually reaches a greater forward velocity than Meagher during the upsweep.

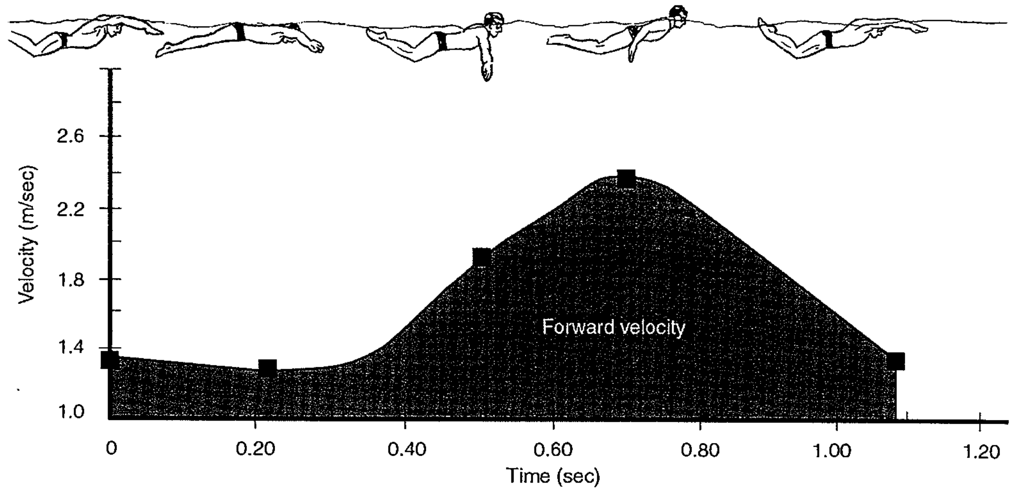


Figure 5.5 A forward velocity pattern for a national-level butterfly swimmer.

The second important difference can be seen during the arm recovery. Meagher decelerates less and for a shorter period of time. She decelerates for only 0.10 sec during this time (see figure 5.4 on page 148). By contrast, the national-level swimmer in figure 5.5 decelerates for nearly 0.40 sec. Meagher accelerates her body forward by means of wave propulsion during the first half of her arm recovery while the national-level swimmer does not. In addition, her increase in forward velocity during the first half of the arm recovery allows her to decelerate slightly less during the second half of her arm recovery. Another important difference between the two swimmers is that Meagher requires only 0.30 sec to recover her arms over the water while the swimmer in figure 5.5 takes almost 0.40 sec.

An important advantage that a great butterfly swimmer like Meagher has over other butterflyers concerns the relatively small difference between her maximum and minimum forward velocities during each stroke cycle. The difference is not more than 0.70 m/sec at any point. Her maximum velocity during the upsweep is approximately 2.10 m/sec and her minimum velocity during the arm recovery is approximately 1.40 m/sec. By contrast, the difference between maximum and minimum velocities is slightly greater than 1 m/sec for the butterfly swimmer in figure 5.5.

A final advantage is that Meagher gains a pulse of propulsion during the downbeat of her first kick and the national-level swimmer does not. This is because she executes the downbeat of her first kick simultaneously with the entry of her arms. As a result, her kick accelerates her body forward at a time when the pushing drag from her arm entry would tend to decelerate her forward velocity. The swimmer in figure 5.5 executes the downbeat of his first kick during the last part of his arm recovery. He pays a price for this when his arms enter the water. With the kick already completed, the pushing drag of his arm entry causes him to decelerate faster and longer during the outsweep of his armstroke.

The forward velocity graph of gold medalist Pablo Morales, in figure 5.6, further substantiates the key differences between great and nearly-great butterfly swimmers. This graph was constructed from data gathered during the preliminary heats of the 100 m butterfly at the 1992 Olympic Games. There are many similarities between his velocity pattern and that of Meagher in figure 5.4. Both swimmers maintain a propulsive peak of acceleration for nearly 0.70 sec and both decelerate only slightly during the arm recovery. In fact, Pablo's velocity decreases by only 0.50 m/sec during this time, which is actually less than Meagher decelerates during this same phase of her armstroke. Finally, both swimmers complete their arm recoveries in approximately 0.30 sec.

There are a few differences between the velocity graph for Pablo Morales and the graph for Meagher. Pablo has a very effective first kick. On the other hand, he deceler-

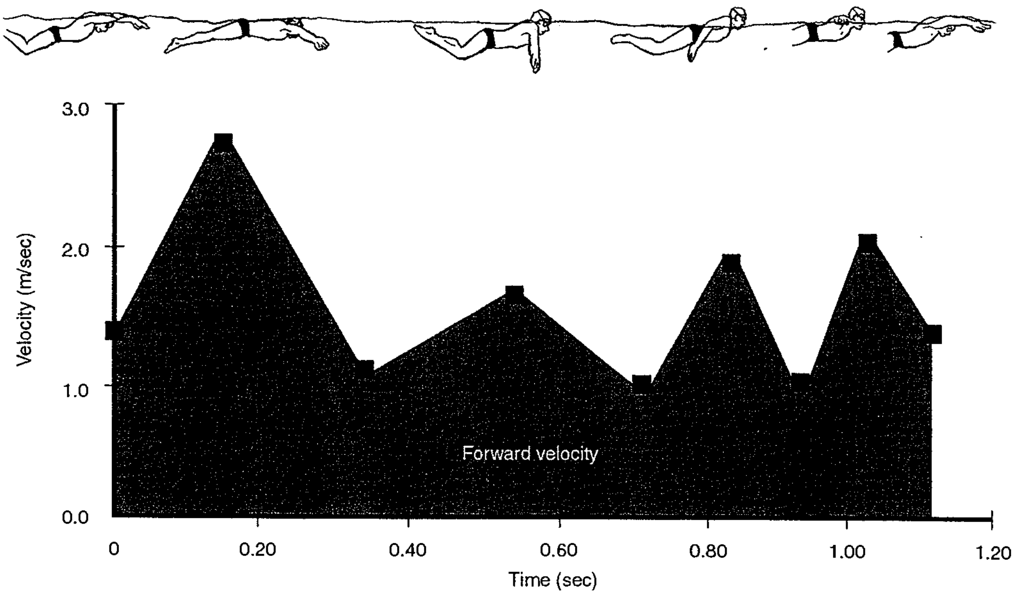


Figure 5.6 A forward velocity graph for Pablo Morales. The data for this plot were collected during the heats of the 100 m butterfly at the 1992 Olympic Games.

Adapted from Cappaert 1993.

ates more during the outsweep. These differences demonstrate that even the greatest swimmers make mistakes. They also demonstrate the importance of studying velocity patterns of several great swimmers in a particular stroke to fully understand the propulsive potential of that stroke.

One-Peak, Two-Peak, and Three-Peak Velocity Patterns

The velocity graphs of Meagher and Morales represent the style used by two of the greatest butterfly swimmers in the history of the sport. This style is characterized by four peaks of forward acceleration. Two of these occur during the armstroke. The third peak occurs during the time the hands are entering the water and the legs are executing the downbeat of the first kick. The fourth propulsive peak, due to wave propulsion, occurs during the first half of the arm recovery. The butterfly armstroke used by these two swimmers is similar to the two-peak pattern described for the front crawl stroke, with the first peak in forward speed taking place during the insweep and the other propulsive peak occurring during the upsweep of the armstroke. There is also a short period of deceleration during the transition between these two stroke phases, during which both swimmers change the direction of the arms from in to out.

I believe the two-peak armstroke has the greatest propulsive potential. Nevertheless, it must be said that many very successful world-class butterfly swimmers have used both one-peak and three-peak armstrokes. A one-peak pattern is illustrated in figure 5.7. In this style, there is a smaller acceleration of forward velocity during the insweep with little or no deceleration during the transition to the upsweep. This is followed by a large and rapid forward acceleration during this final phase of the underwater armstroke. The one-peak velocity pattern is generally used by swimmers who tend to push the arms almost straight back during the insweep. In other words, they press the hands back more and in less than two-peak swimmers during this phase of the armstroke. As a result, the stroke is very much like one long upsweep from the catch to the point when swimmers release pressure on the water.

I favor the two-peak velocity pattern because swimmers are more likely to achieve a greater average velocity per armstroke by using it. The body should accelerate more and longer during the insweep. In addition, it should also accelerate forward more during the upsweep because swimmers change directions and find quiet water to push

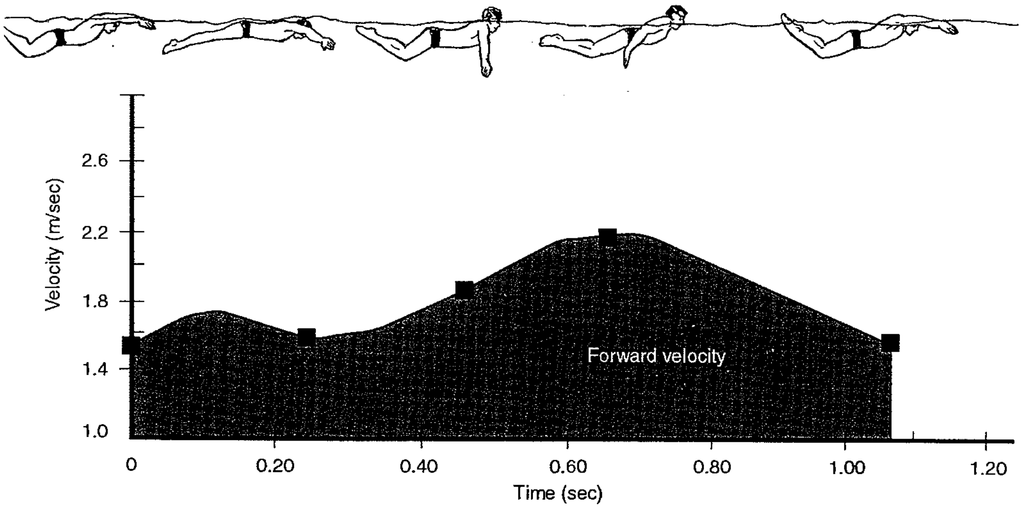


Figure 5.7 A velocity graph showing a one-peak acceleration pattern.

against when they change the direction of the arms markedly from in to out during the transition between the two stroke phases.

Nevertheless, as mentioned earlier, there have been several very successful world-class butterfly swimmers who have used the one-peak style. Therefore, swimmers should not change from one style to the other without testing to determine which method provides the greater average velocity per stroke for a particular swimmer. The danger in using the two-peak style, for some swimmers, lies in the fact that they may drop the elbows when they attempt to sweep the hands inward. If this happens, they will decelerate during the insweep and actually be worse off than if they had used a one-peak style.

Mason, Tong, and Richards (1992) reported that several elite Australian butterfly swimmers used a three-peak velocity pattern during their armstrokes and a total of five velocity peaks during their stroke cycles. A composite velocity pattern for these swimmers can be seen in figure 5.8.

Before going on, I want to clear up something about figure 5.8 that some may find confusing. There appear to be a total of six propulsive peaks in the velocity pattern shown in that figure. In fact, there are only five. The small peak at the catch can be discounted because it represents the swimmers' attempts to make the catch, followed by a slight slip before the catch is actually accomplished and the swimmers begin to accelerate forward.

When compared to the four-peak forward velocity patterns of Meagher and Morales, the extra peak for the Australian butterfly swimmers occurs during the insweep. Therefore, there are three propulsive peaks in their composite forward velocity patterns in figure 5.8, two during the insweep and one during the upsweep. When combined with the propulsive peaks during the downbeat of the first kick and during the recovery, this brings the total to five. By contrast, there are only two propulsive peaks during the armstroke in the forward velocity patterns of Meagher and Morales, one during the insweep and another during the upsweep, resulting in a total of four propulsive peaks.

It is difficult to say whether an insweep with two smaller propulsive peaks will be more propulsive than an insweep with one large propulsive peak. In the two-peak style, the first propulsive peak of the insweep takes place during the initial out and down portion of the insweep and the second during the inward portion of that sweep. Swimmers who use this style execute a strong outward and backward push with the arms just after the catch and before the hands actually start down and in. This is followed by a short period of deceleration when they change the direction of the hands and arms to down and in. The body then accelerates forward once again until they complete the insweep and make the transition to the upsweep.

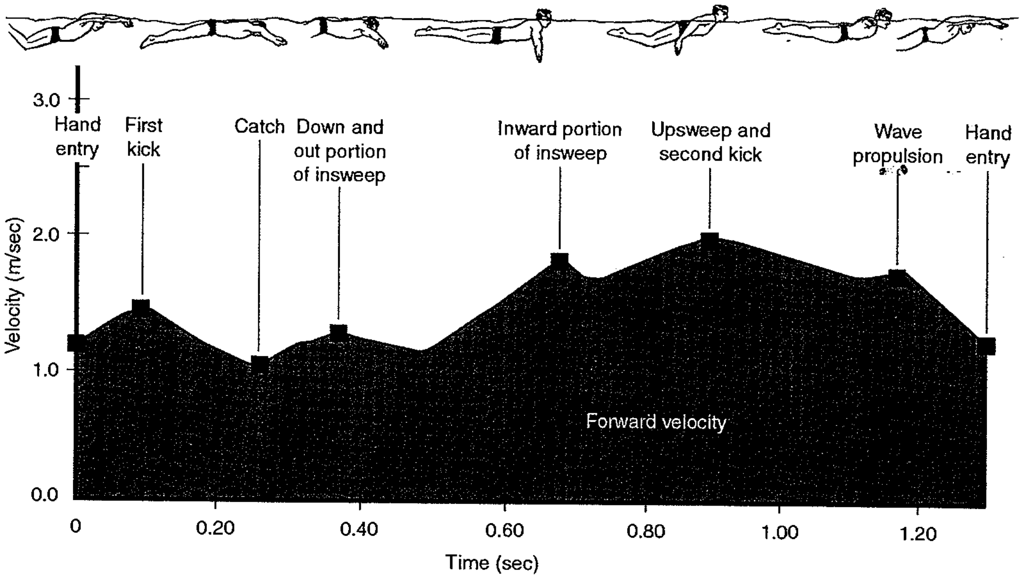


Figure 5.8 A five-peak butterfly velocity pattern with three peaks during the armstroke.

Adapted from Mason, Tong, and Richards 1992.

I suspect that the presence of two peaks indicates some "slippage" during the insweep from trying to scull the hands out and then in. The short period of deceleration occurs when swimmers change the direction of the arms from out to in. They will generally push down with the arms during this change of direction, which is the reason for the deceleration. Then, they will continue to decelerate until they get the elbows above the forearms and hands so that their backward orientation permits them to again push back against the water.

The transition from outsweep to insweep is a difficult one to negotiate without losing some forward velocity. Therefore, some swimmers may find it more effective to separate the insweep into three phases: an outward push, a downward push, and an inward push that produce two peaks of propulsion and one short period of deceleration. Those who eliminate the outward push and start pushing the hands down and in immediately at the catch will lose the first velocity peak. They will also have a longer period of deceleration during the beginning of the insweep, leaving only one small propulsive peak during the latter portion of the insweep.

Having said this, I would argue that swimmers who use shoulder adduction during the insweep should be able to maintain a backward orientation with the arms from the catch throughout the insweep. This may result in one large peak that will provide a greater increase in forward velocity than two smaller peaks. Once again, the average velocity achieved during the insweep is the critical factor as to the method a particular swimmer should use. I would suggest that swimmers try using shoulder adduction during the insweep as described later in this chapter. If they cannot perform this skill without dropping the elbows, they should then try using a two-peak insweep with a distinct outward and inward push. Both the one-peak and two-peak methods for executing the insweep will be described in the section on that stroke phase.

Armstroke

As described earlier, the butterfly armstroke consists of an entry and stretch, an outsweep, an insweep, an upsweep, and a release and recovery. Above- and underwater photos of the butterfly are shown from a side view in figure 5.9 and from a front view in figure 5.10 on pages 154–156.

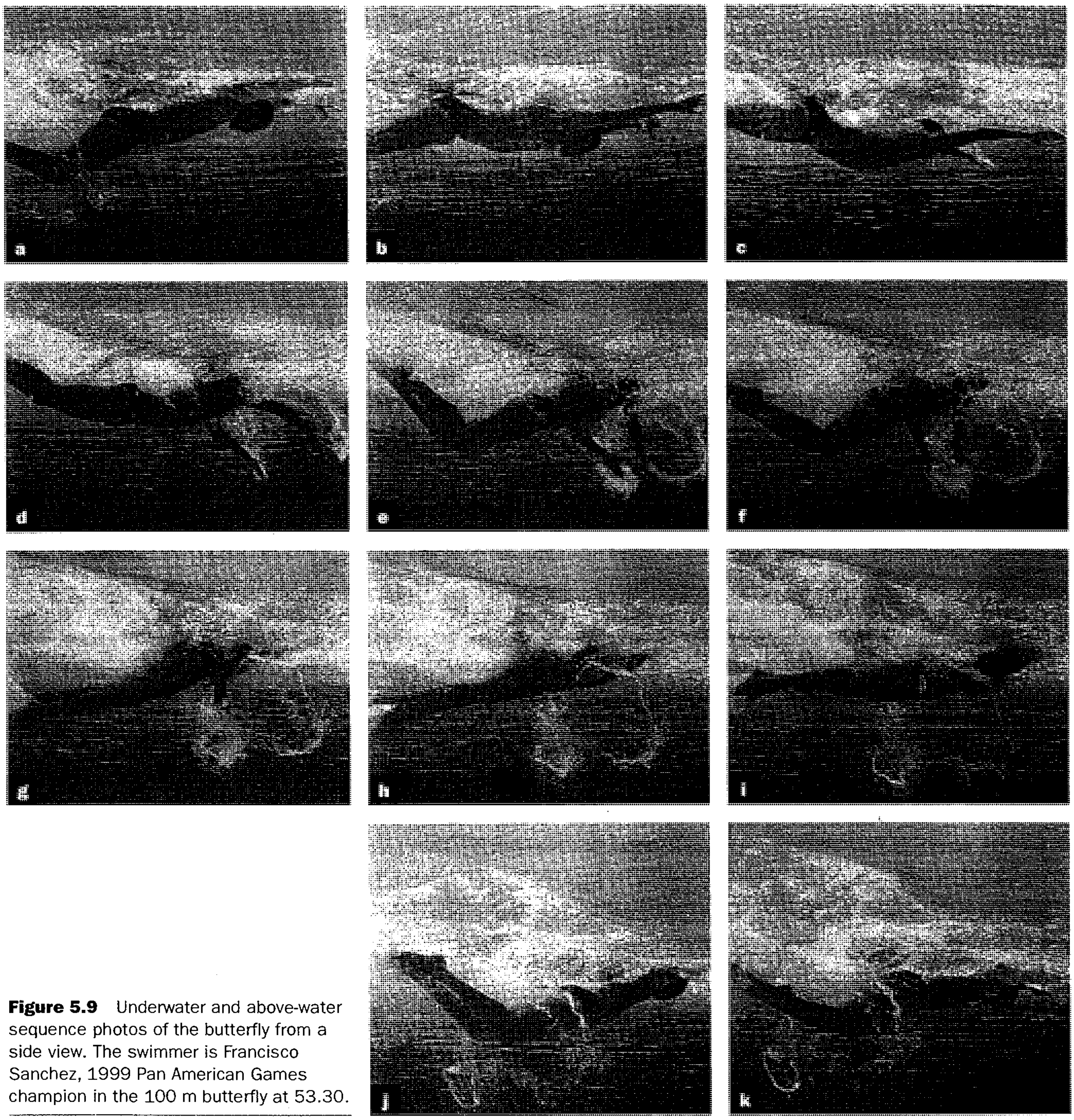


Figure 5.9 Underwater and above-water sequence photos of the butterfly from a side view. The swimmer is Francisco Sanchez, 1999 Pan American Games champion in the 100 m butterfly at 53.30.

Underwater views

(a) Downbeat of first kick and arm entry.
(b) End of downbeat of first kick.
(c) Outward and forward stretch with arms. Upbeat of first kick.
(d) Catch with arms. End of upbeat of first kick.
(e) Completion of insweep with arms. Start of downbeat of second kick.
(f) Transition from insweep to upsweep with arms. Continuation of downbeat of second kick.
(g) End of upsweep with arms. Continuation of downbeat of second kick.
(h) Release of arms. Completion of downbeat of second kick.
(i) Wave propulsion phase. Upbeat of second kick. Recovery with arms.
(j) Downbeat of first kick. Continuation of arm recovery.
(k) Downbeat of first kick. Entry with arms. Start of next cycle.

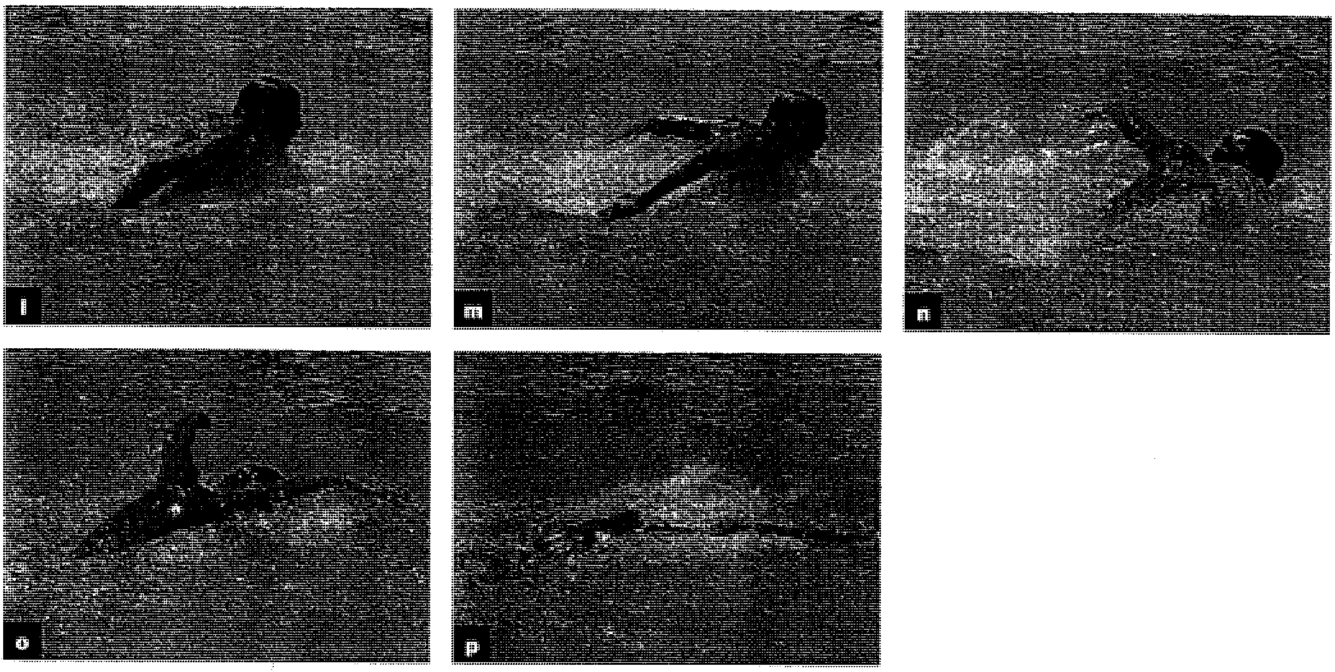


Figure 5.9 *(continued)*

Above-water views
(l) Start of arm recovery.
(m) Hands leave water.
(n) Wave propulsion phase. Arms recover over water.
(o) Arms continue recovery, start of first downbeat.
(p) Hands enter water. First downbeat underway.

Entry and Stretch

This phase should be more properly identified as the *entry, stretch, and downbeat* of the first dolphin kick. It is shown from a side view in figure 5.9, a and b, and from a front view in figure 5.10, a and b.

The entry of the arms should be timed so that it coincides with the downbeat. In this way, propulsion from the kick can be used to offset the pushing drag caused by the arms as they enter the water. The arms should enter the water in front of the body at or slightly inside shoulder width. The hands should be pitched slightly outward so that they can slice into the water on edge. After entering, the arms are stretched forward and slightly out, just under the surface of the water, while the downbeat of the first dolphin kick is completed. The arms should stay within shoulder width until the downbeat has been completed to minimize their resistive drag and maximize propulsion from the kick.

The amount of propulsion from the first dolphin kick can be seen in the velocity graph of Pablo Morales in figure 5.6 (see page 151). The movements of the head play an important role in facilitating the increase in forward velocity from the kick. Swimmers should be looking down at the bottom of the pool as the hands enter the water and the downbeat of the first dolphin kick gets underway. But the head should be lifted and swimmers should look forward as the hips rise and the shoulders and chest are being pushed deeper into the water. The action of lifting the head will help translate the vertical movements of the body into forward motion in a wave-like manner. I will have more to say about this *reverse body wave* later in the section on body position.

The amount of forward acceleration from the downbeat of the first dolphin kick can be increased or decreased according to how smoothly the entry is made. The pushing drag from the arms will be minimal if the arms are kept out of the water until they are

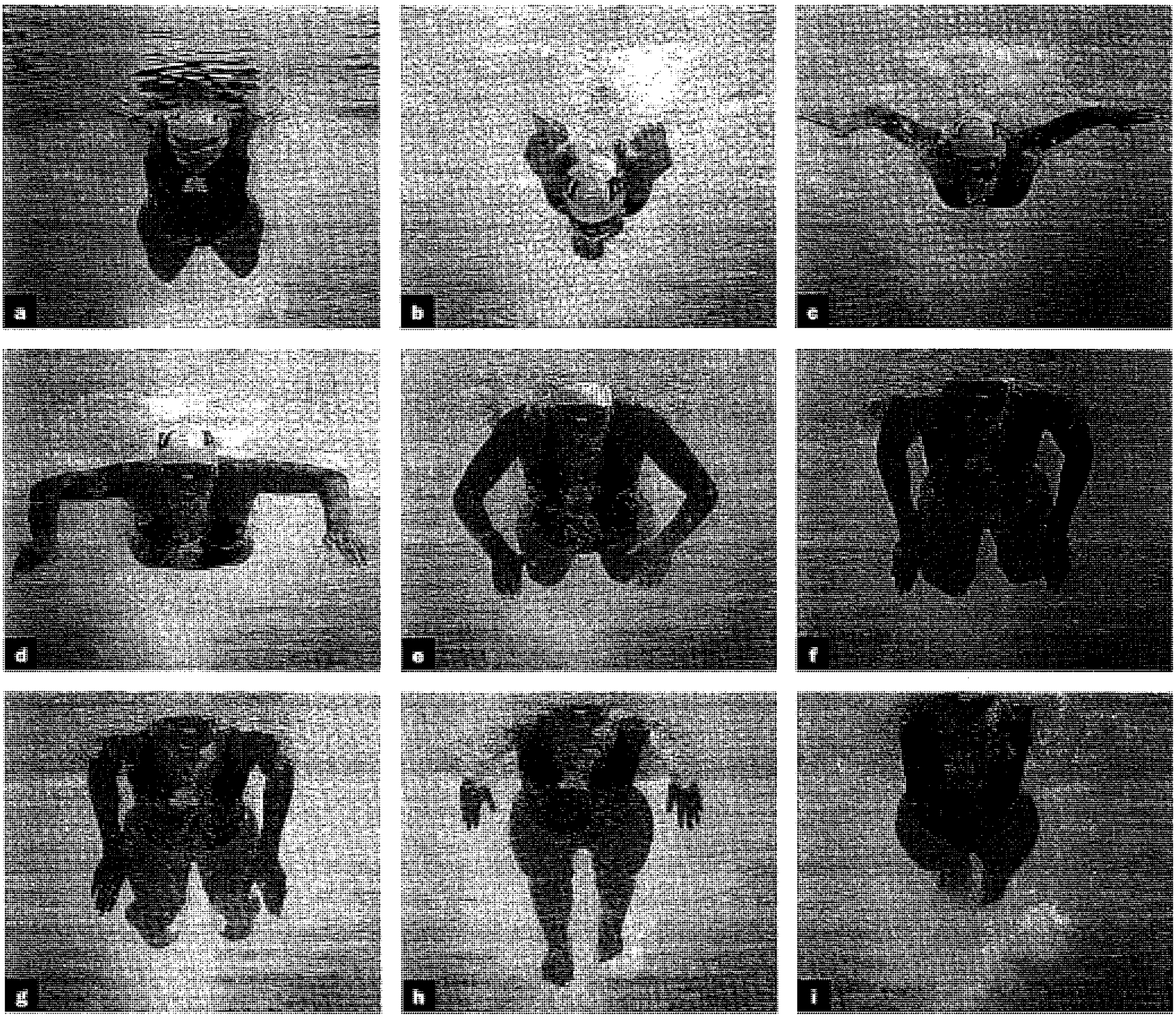


Figure 5.10 Underwater sequence photo of the butterfly from a front view. The swimmer is Sarah Baham, NCAA all-American in the 100 and 200 butterfly.

Underwater views

(a) Hands enter water. Legs begin downbeat of first kick.
(b) Completion of first downbeat. Stretch of arms.
(c) Catch with arms. Head continues moving up. Upbeat of first kick continues.
(d) First half of insweep. Head continues moving up. Upbeat of first kick continues.
(e) Finish of insweep. Head at surface. Downbeat of second kick begins.
(f) Upsweep. Head remains at surface. Downbeat of second kick continues.
(g) End of upsweep. Head remains at surface. Downbeat of second kick continues.
(h) Release and recovery of arms. Head remains at surface. Downbeat of second kick is completed.
(i) Wave propulsion phase. Arms recover over the water. Upbeat of second kick.

in front of the shoulders and in position for the entry. Drag will also be minimized if the hands are sliced into the water on edge and kept inside shoulder width while they are stretched gently forward.

Swimmers can enter the arms into the water in an extended position or with the elbows slightly flexed, so long as they do not drag them forward through the water as they enter. I prefer an entry with the elbows flexed simply because swimmers can generally get the arms a little further in front of the shoulders before entering the water. Thus, they are less likely to push the hands forward through the water after they enter.

In addition to its effect on increasing forward velocity, the downbeat of the first dolphin kick also facilitates the transition from the arm entry to the outsweep in the following manner. The upward undulation of the hips should reach its peak just as the downbeat of the first dolphin kick is completed. This action will push the shoulders and chest deeper into the water, which in turn will push the arms out. The kick then assists in overcoming the inward and forward inertia the arms had at entry and changing their direction to out and forward with a minimum of muscular effort. Making the entry with flexed arms also facilitates this change of direction from in to out because extending the arms forward after they enter the water aids in overcoming their inward inertia.

Outsweep and Catch

This portion of the stroke cycle is shown from a side view in figure 5.9, b through d, and from a front view in figure 5.10, b and c. The swimmer in figure 5.9 enters with his arms wide and starts his outsweep almost immediately because the downbeat of his first kick is weak. The swimmer in figure 5.10b waits until she completes the downbeat of her kick before she starts to sweep her arms out to the sides.

Once the kick is completed and the inward inertia of the arms has been overcome, swimmers should continue lifting the head toward the surface. They should also continue sweeping the arms forward and out to the side until they are outside the width of the shoulders where the catch is made. The palms should rotate out during the outsweep so that they will be facing back when the catch is made. The undersides of the upper arms and forearms should also be facing back when the catch is made. Swimmers should flex the elbows during the outsweep to shorten the distance the arms must travel to achieve a backward orientation to the water. Hand speed decelerates after the entry, until the hands are barely moving at the catch. They should be flexed approximately 90° when the catch is made.

The outsweep is not a propulsive phase of the underwater armstroke. Its purpose is to position the arms to deliver propulsive force during the insweep that follows. Any attempt to apply propulsive force before the arms are outside shoulder width and facing back will only result in pushing water to the side or down.

Insweep

Swimmers can be seen executing an insweep from a side view in figure 5.9, d and e, and from a front view in figure 5.10, c through e. Once the catch is made, swimmers should accelerate the arms back, out, down, and in, making a large semicircular sweep that ends when the hands are close together underneath the body. I think the swimmer in figure 5.10 could bring her hands in more under her body, although many world-class butterfly swimmers execute the insweep in this manner. Nevertheless, I recommend the style used by the swimmer in figure 5.9. He adducts his arms to a greater extent and brings his hands close together under his body during the insweep. This should make for more propulsion during this phase and the upsweep that follows. The way that propulsion is generated during the insweep is illustrated in figure 5.11.

This motion, like the insweep of the front crawl, is an example of shoulder adduction. Swimmers should press the arms back, down, and in until the hands are nearly together under the body and the elbows are nearly against the ribs. The undersides of the arms and the palms of the hands should be used like one large paddle to push back against the water during this motion. The pitch of the palms will change from out to in during the insweep but only because the arms are changing direction from out to in.

The insweep is not an inward scull. The arms should be flexed nearly 90° at the elbows when the catch is made and they should remain flexed throughout the insweep

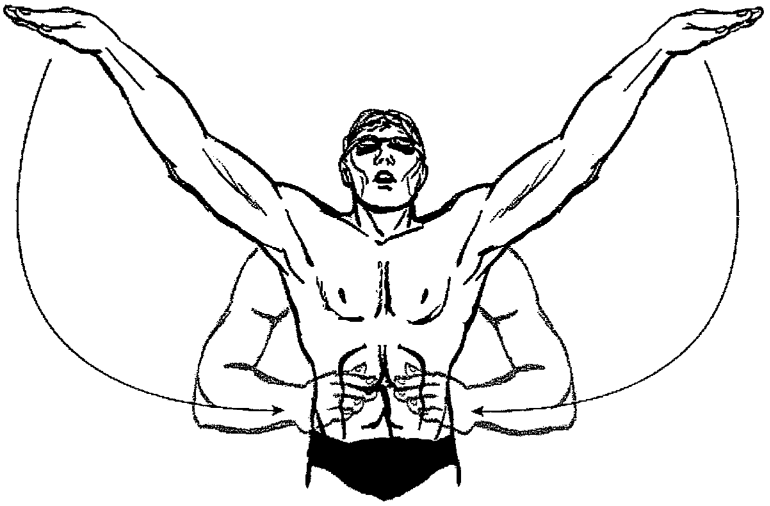


Figure 5.11 The insweep in the butterfly.

as the arms are adducted back, toward the ribs. Swimmers may increase the flexion of the arms slightly to bring the hands together under the body. But they should not scull the hands in under the body. That is, they should not start the insweep with straight or nearly straight arms and then hold the upper arms out at the side while they scull the hands and forearms down and directly in across the water by flexing at the elbow.

You might wonder how the hands get underneath the body without sculling when the insweep with the arms is outside the shoulders and near the surface of the water. The way this is accomplished is by pressing the upper arms back on a slight downward diagonal. If this action is performed correctly, the forearms and hands will quite naturally travel down, back, and in under the body.

I believe that, for most swimmers, propulsion will be greater during the entire underwater stroke if they bring the hands almost together under the body during the insweep. While the final part of the insweep is not very propulsive, it places the arms in position to press water back under the body for the first portion of the succeeding upsweep. This will allow the swimmer to use a two-peak velocity pattern, which, I believe, has the potential to provide more propulsion. Certainly, swimmers will decelerate more during the transition from insweep to upsweep with a two-peak style. Nevertheless, the insweep should be longer and more propulsive, and propulsion during the upsweep should increase so that the average overall velocity per armstroke will be greater.

Alternate Insweep Styles

Many swimmers find it difficult to make a smooth transition from the out-and-back portion of the insweep to the in-and-back portion without losing pressure on the water. These swimmers generally use one of two alternate insweep styles. In one of these, they separate the insweep into two parts. First, they press the hands out and back for a short distance. This is followed by a transition to a high elbow position similar to the one used in the front crawl stroke, after which they adduct the arms back to the sides during the second half of the insweep. This type of insweep produces two propulsive peaks: a small one in the first out and back portion, followed by a period of deceleration while the arms are repositioned, and then a second larger peak as the arms are adducted back. This insweep style was illustrated in figure 5.8 (see page 153).

Sanchez is using a two-peak insweep in the photos in figure 5.9 (pages 154–155). He presses out and back with his arm in figure 5.9c and then slides them into a high elbow catch position in figure 5.9d. Once this high elbow position has been achieved, swimmers should strongly press the hands and arms back and in until they have completed the insweep.

This style of insweep is generally used by swimmers who like to make a high elbow catch in the same manner they use in the freestyle. The style can be very effective, provided the swimmers make the sweep in two parts and do not try to sweep the hands down and in immediately from the catch. Swimmers who do this will lose the first propulsive peak and will decelerate forward speed as they push the arms down into the high elbow catch position. Pressing the hands and arms down and in immediately generally causes swimmers to stroke with the classic dropped elbow, pushing down against the water during the first half of the insweep until the arms are deep enough to achieve a backward orientation.

In the second style, swimmers simply slide the hands and arms into a high elbow position similar to the one used in the front crawl stroke before they begin to push back against the water. These swimmers slide the hands out to the side in the outsweep. Then they turn the hands down and allow the elbows to "ride" over them before they start the insweep. Swimmers who use this style must also be careful not to push against the water with the hands and arms until they are in the catch position, or they will decelerate their forward speed even more than it is already decelerating.

Executing the insweep in either of these ways is certainly superior to the dropped elbow style, but I doubt that it provides the sustained peak of forward velocity that could be achieved by adducting the arms in the manner described earlier. Nevertheless, many swimmers may find that it is the only way they can make a good catch without dropping the elbows.

Upsweep

The upsweep is pictured from a side view in figure 5.9, e, f, and g, and from a front view in figure 5.10, f and g. The transition from insweep to upsweep should begin as the hands are coming together under the body. At that point, the direction of the hands and arms should be quickly changed from in to out, after which the swimmer should press them out, back, and up toward the surface of the water. The transition from insweep to upsweep is shown in figure 5.9e. Once the upsweep is underway, the palms of the hands and the undersides of the forearms should be used like paddles to push back against the water as the arms travel out, back, and up toward the surface.

The arms should not be extended to any great extent during the upsweep. Contrary to popular opinion, the arms are extended during the recovery, not during the upsweep. The arms may be extended somewhat during the upsweep to keep up with the backward speed of the water and to make the transition to the recovery. But that extension should be minimal. The arms should remain flexed at the elbows enough that a backward orientation can be maintained with the forearms until the time comes to release pressure on the water.

The upsweep ends as the hands approach the thighs. Hand speed slows during the transition from insweep to upsweep and then accelerates until the upsweep is completed. The arms reach their greatest velocities of 5 to 6 m/sec during this phase of the underwater stroke. Propulsion during the upsweep is illustrated from a side view in figure 5.12a and from an underneath view in figure 5.12b.

Release and Recovery

The release of the hands can be viewed from a side view in figure 5.9h (see page 154) and from a front view in figure 5.10h (see page 156). The recovery can be seen best from the above-water views in figure 5.9, l through p (see page 155).

As the hands approach the thighs, it is no longer possible to maintain a backward orientation with the forearms. Therefore, swimmers should stop pushing back against the water and begin to recover the arms. The recovery should be made in the same direction as the previous upsweep. The arms should continue sweeping out and up, through the surface of the water. The swimmer should stop pushing back against the water, however. Pressure on the water should be released and the palms of the hands should be turned inward so that they can leave the water on edge with a minimum amount of pushing drag.

The upper arms and elbows should exit the water first, followed by the forearms and hands. The arms, which were extending slowly during the upsweep, now extend rapidly as they pass upward through the surface so that they exit the water traveling up and out to the side. Extending the arms to the side as they leave the water helps to

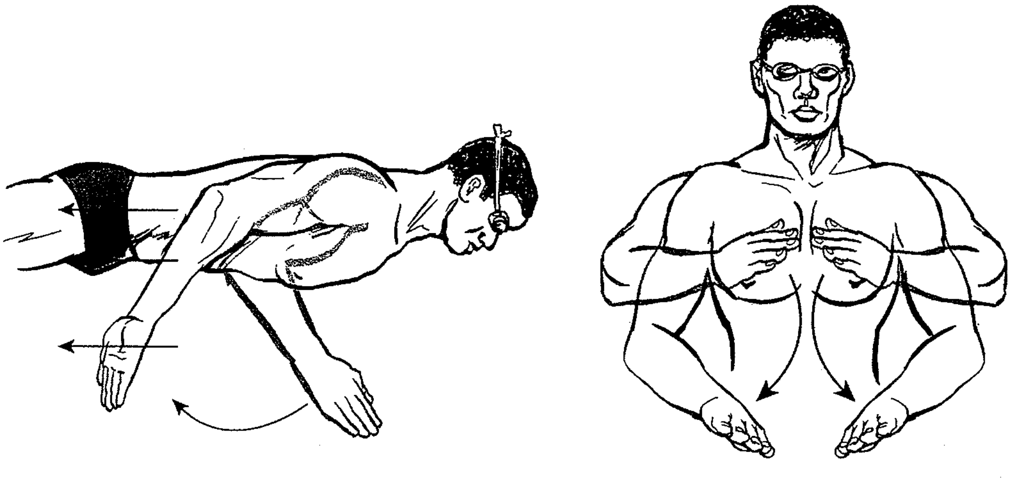


Figure 5.12 The upsweep in the butterfly.

overcome their backward inertia and start them moving forward as they recover over the water. Some swimmers extend the arms completely, while others, like Sanchez, extend them only partially (see figure 5.9, n and o, on page 155).

Once they leave the water, the arms should continue circling over the water until they are in front of the shoulders, where the entry is made. As indicated earlier, the entry can be made with the arms extended in front of the shoulders. It is preferable, however, to flex the elbows slightly during the second half of the recovery so that entry can be made with the arms slightly bent. The palms of the hands will be facing inward during the first half of the recovery and they will be facing outward during the second half simply because the direction of the arms changes from out to in during the latter portion of the recovery.

The recovery should be made quickly, but it should not be rushed. Swimmers need time to get the legs into position for the downbeat of the first kick before the arms enter the water. The arms should be relaxed as much as possible during their recovery to provide some rest for the muscles. Swimmers should let the momentum of the upsweep carry the arms through most of the recovery, using only enough muscular effort to effect the change of direction from backward to forward.

Pushing drag will be reduced if swimmers recover the arms high enough over the water that they reach the entry position before they make contact with the water. One way swimmers keep the arms free of the water is by allowing the head and shoulders to rise out of the water, much like the arm recovery in the breaststroke.

This description runs counter to traditional beliefs about the butterfly arm recovery. The usual recommendations are that swimmers should recover the arms low and laterally over the water and should keep the chin and shoulders in the water. Recovering the arms low supposedly reduces the work required while keeping the body horizontal to reduce form drag. In actuality, however, recovering the arms in this way makes it extremely difficult for swimmers to keep from pushing the arms forward through the water until they reach a position in front of the shoulders. On the other hand, allowing the head and shoulders to rise out of the water reduces form drag and encourages wave propulsion during the first half of the arm recovery, while also making it possible to bring the arms closer together in front before they enter the water. The photograph in figure 5.13 shows a butterfly swimmer whose body position is correct during the arm recovery.

At this point, a word of caution is in order. This shoulder lift can be overdone. Rising almost straight up out of the water will simply cause swimmers to decelerate more rapidly. They should keep the body moving forward as well as up during the recovery. This is accomplished by bringing the head and shoulders gradually and diagonally toward the surface during the entire insweep and upsweeps of the underwater armstroke.

I spoke of wave propulsion in the previous paragraph. The graphs of forward velocity in figures 5.4 and 5.6 (see pages 148 and 151) demonstrated that this phenomenon can cause swimmers to accelerate forward during the first half of the arm recovery. There is a whole sequence of events that must take place for the amount of wave propulsion to be significant, however. First of all, swimmers must release the water at the proper time, that is, when the body is traveling forward at its peak velocity during the upsweep. The sudden loss of propulsive force will reduce velocity, causing the wake to push the body forward. If swimmers try to push the water back until the hands reach the surface, they will decelerate long before the arms leave the water. This will allow the water around the body to adjust to the decrease in speed before the recovery begins so that wave propulsion will be minimal or nonexistent.

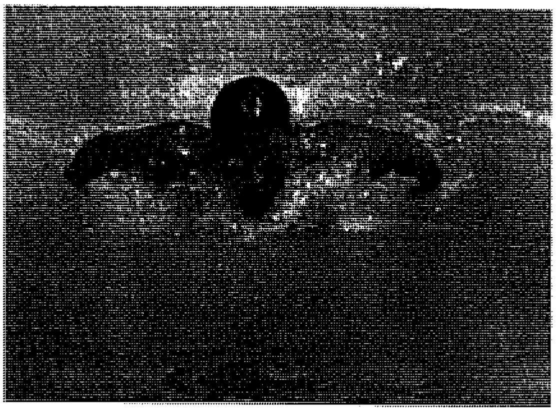


Figure 5.13 A butterfly swimmer taking a breath. Notice that his shoulders and a portion of his trunk are out of the water and that he does not extend his head back on his neck or jut his chin forward, as is traditionally taught.

Second, the amount of wave propulsion can be enhanced if swimmers are as streamlined as possible during the arm recovery. In this respect, the legs should be up and in line with the body and the head and shoulders should be out of the water. The pulse of wave propulsion will be completed as the hands pass the shoulders and the knees begin to drop in place for the downbeat of the first kick. Swimmers will decelerate at this point until they begin to accelerate the body forward by extending the legs.

Dolphin Kick

The kick used in butterfly is called a *dolphin kick* because the legs move as one unit, like the tail (fluke) of a dolphin. One dolphin kick consists of an upbeat and a downbeat, and swimmers execute two kicks during each stroke cycle. A sequence of photographs of the two dolphin kicks of each stroke cycle is shown in figure 5.14.

Upbeat

Figure 5.14, a through c, shows the upbeat of the second dolphin kick. The upbeat of the first kick is pictured in figure 5.14, f and g. The upbeat of the next dolphin kick begins as the downbeat of the previous kick is nearing completion. That downbeat starts a rebound reaction that pushes the thighs upward to initiate the upbeat. Continued extension of the hips keeps the legs sweeping upward until they pass above the body, where the upbeat ends and the next downbeat begins.

Most of the upbeat should be made with the legs extended. The lower legs and feet should be relaxed and passive so that the pressure of the water pushing down from above keeps them extended. Water pressure also pushes the feet into a natural position midway between extension and flexion.

Swimmers should gently flex the legs at the knees in preparation for the next downbeat just as the feet pass above the hips.

Downbeat

The downbeat is a whip-like motion that begins with flexion at the hips and continues with extension at the knees. The downbeat of the first kick is pictured in figure 5.14, d and e, and the downbeat of the second dolphin kick is pictured in figure 5.14, h and i.

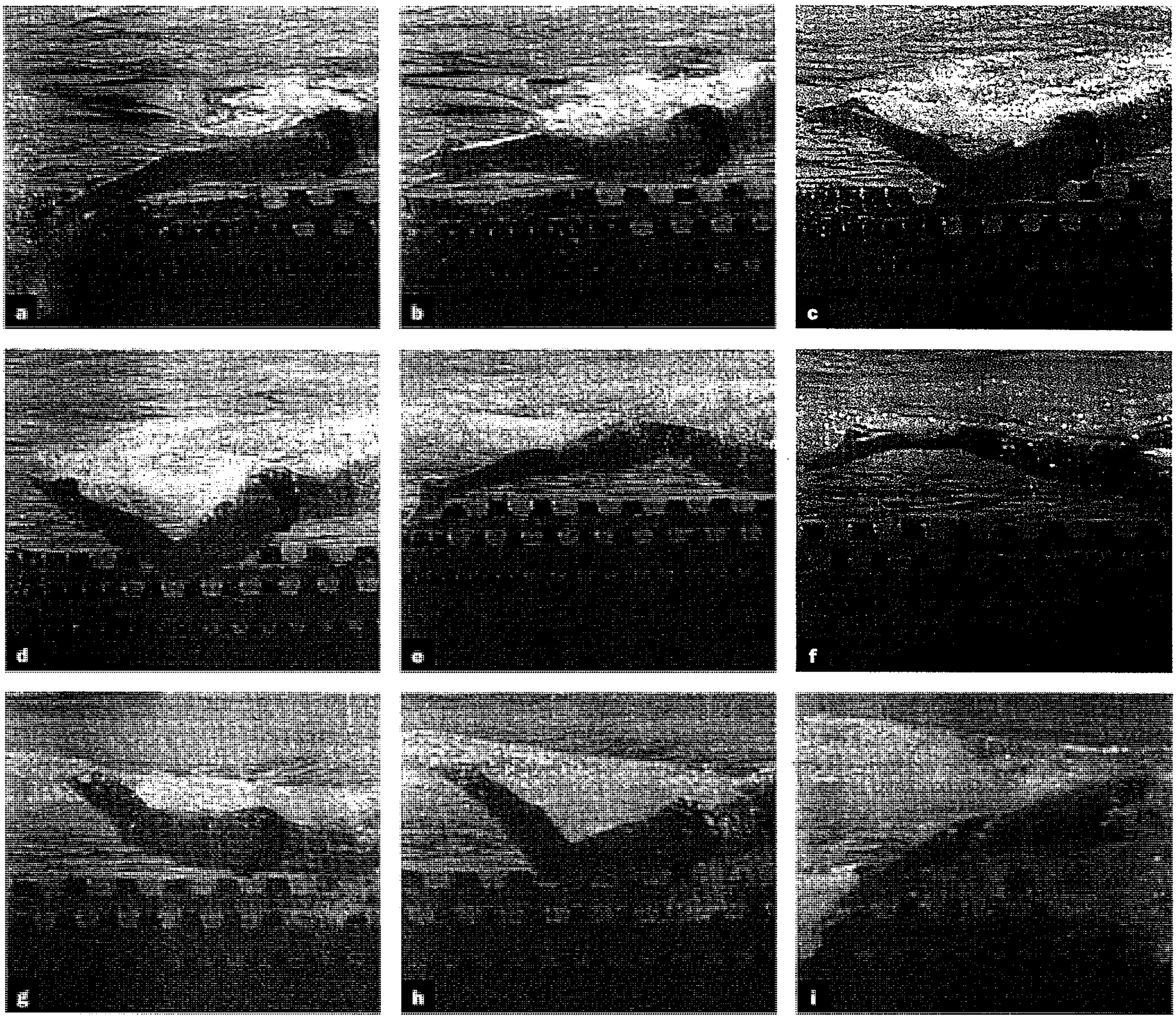


Figure 5.14 The dolphin kick.

(a) Upbeat of second kick begins.
(b) Upbeat of second kick continues.
(c) Upbeat of second kick ends.
(d) Downbeat of first kick. Leg extension begins.
(e) Downbeat of first kick ends.
(f) Upbeat of first kick.
(g) Upbeat of first kick ends.
(h) Downbeat of second kick begins.
(i) Downbeat of second kick ends.

The downbeat begins when swimmers press down with the thighs as the feet pass above the body during the preceding upbeat. The water pressure, which is now pushing up from underneath, causes the lower legs to flex upward even further. Water pressure also pushes the feet up and in to an extended and pigeon-toed position (plantar flexed and inverted), even as the thighs are pressing down. The thighs do not press down for very long. Once they start down, their movement initiates a wave-like extension that travels down the thighs to the lower legs, which are then forcefully extended at the knees. The downbeat of each kick ends when the legs are completely extended and the feet are slightly below the trunk (see figure 5.14, e and i). The way that propulsive force can be generated during the downbeat of the dolphin kick was described in chapter 3.

The ability to extend the feet at the ankles is probably essential to fast dolphin kicking. Barthels and Adrian (1971) concluded that it was more important than strength. With good extension ability, the feet can remain in a position to press back against the water throughout the majority of the downbeat. Butterflyers should be able to extend the feet 70° to 85° from the vertical.

Dolphin kickers spread the knees at the beginning of the downbeat and then bring them together at the end because, with the knees apart, the feet can be pitched in and up to a greater extent during the downbeat. The legs are brought together by inward rotation at the hips, which probably adds to the muscular force swimmers apply during the downbeat.

Differences Between the First and Second Dolphin Kick

What the first and second dolphin kicks of each butterfly stroke cycles have in common is that they contribute to forward propulsion. There are several other ways in which they are different, however. As you can see in figure 5.14, d through g, the first kick is the longer of the two. Both the downbeat and upbeat of that kick are longer. The downbeat pushes the hips up and forward through the surface, after which they travel down and forward during the subsequent upbeat.

The upbeat of the first kick is longer because the hips are high in the water as the arms sweep out underwater. The legs are able to rise to and slightly above the surface of the water without disrupting horizontal alignment. In fact, this long upbeat actually brings the legs above the body so that swimmers are very streamlined as they go through the first half of the underwater armstroke. The downbeat of the second kick is generally shorter, with less hip flexion, perhaps because swimmers do not want to push the hips out of the water while finishing the armstroke. The upbeat of that kick is also shorter. This is because the hips are lower as the arms recover over the water and, therefore, the legs cannot move upward very far before they pass above the hips and begin pushing them down.

Timing of the Armstroke and Kicks

There are two complete dolphin kicks during each stroke cycle. The proper timing between these kicks and the various phases of the armstroke can be seen from a side view in the sequence of underwater photos in figure 5.9. The downbeat of the first kick takes place during the entry and stretch of the arms, as shown in figure 5.9, a and b, and the downbeat of the second kick occurs during the upsweep of the underwater armstroke, as shown in figure 5.9, e through g. This explanation, although correct, is an oversimplification of the complex timing between the arm and leg movements in this stroke. I will now describe that timing in greater detail.

The downbeat of the first kick should begin during the second half of the arm recovery and should continue through the entry and stretch of the arms. The thighs should begin pressing down as the arms near the entry position, and leg extension, the major propulsive phase of the kick, should take place during the entry, stretch, and the first part of the outsweep of the arms. In addition to overcoming the pushing drag of the entering arms, this kick should also be powerful enough to accelerate swimmers forward. That downbeat will push the hips up and forward through the surface in an undulating manner, accelerating the body forward at the same time.

The upbeat that follows the first downbeat of the dolphin kick should take place during the remainder of the outsweep of the arms and the first part of the insweep (see figure 5.9, c and d, on page 154). In this way, the legs are brought up and the hips down so that they are streamlined above the body during that first propulsive phase of the armstroke. This will reduce form drag so that swimmers will accelerate forward more during the insweep. Skilled butterfly swimmers actually appear to be swimming downhill during the first half of the insweep.

The downbeat of the second kick should be executed in time with the upsweep of the arms. The downbeat actually begins by pressing the thighs downward during the transition from the insweep to the upsweep of the armstroke. The most effective part of the kick, however, the extension of the lower legs, takes place during the upsweep of that armstroke.

The next upbeat of the second kick takes place during the arm recovery (see figure 5.9i on page 154). This action performs the same two functions as the upbeat of the first kick. It brings the legs up, near the surface, so that the body is more streamlined during this phase of the stroke cycle and it places the legs in position for the downbeat of the next kick. The streamlining aspect of this upbeat will increase the amount of forward acceleration from wave propulsion during the first half of the arm recovery. The extent of that wave propulsion will be greater if swimmers rebound the legs up quickly and gently during the upbeat of the second kick. It will be diminished if swimmers allow the legs to "hang" down below the body or if they bend the knees and force the feet upward in preparation for the next kick.

There is little doubt that the downbeat of the first kick can contribute significantly to forward propulsion, as illustrated in the forward velocity graph of Pablo Morales in figure 5.6 (see page 151). The downbeat of the second kick probably contributes to propulsion as well, while also supporting the hips near the water surface for better streamlining during the upsweep. There is some controversy over whether the upbeats of the dolphin kick are propulsive, however.

I explained why I don't believe those upbeats are propulsive in chapter 3—because the legs travel up and forward. Consequently, they could not be accelerating water backward. I recommend, therefore, that the upbeats of the two dolphin kicks be made quickly but gently. Any unnecessary force will only decelerate swimmers more than they are already decelerating.

With this in mind, the upbeat should be performed in the following manner. The force of the downbeat of the preceding kick should be used to overcome the downward inertia of the legs and start them rebounding upward. That is, extension of the lower legs will push the thighs upward. This will help to overcome downward inertia and allow them to start upward with a minimum of muscular effort. Once the upbeat is underway, swimmers should keep the thighs traveling upward with hip extension (pulling up with the gluteal muscles).

Major and Minor Kicks

For years, experts have debated whether one of the dolphin kicks in each stroke cycle should be made more forcefully than the other. They speak in terms of *major* and *minor* kicks. There are three options available. Some experts believe that the first kick should be emphasized most because it can accelerate the body forward at a time when the arms cannot be used for this purpose. Others think that the second kick should be made with more effort so that swimmers can accelerate forward more during the upbeat and, also, to assist in keeping the hips at the surface of the water. Finally, there are those who believe that the downbeats of both the first and second dolphin kicks should be made with equal force.

I believe strongly that the downbeat of the first dolphin kick is the more propulsive of the two. Consequently, it should always be emphasized. The propulsion that can be gained from that downbeat is absolutely essential to fast butterfly swimming.

The question that remains is, should the second downbeat be just as forceful or should it be softer? I believe equal effort should be applied during both downbeats, particularly in the 50 and 100 events. The first concern of swimmers should be to generate as much propulsive force as possible in these events. Making two strong dolphin kicks should help them do this.

At the present time, I cannot state whether it is advisable to place equal emphasis on both kicks in the 200 event, however. Underwater videos taken during major competitions reveal that several of the most successful butterflyers of modern times have used a slightly incomplete leg extension during the second downbeat of the dolphin kick in 200 races. This, of course, signifies that they are kicking with less effort. Having said this, I must also make it clear that many world-class 200 butterfly swimmers also extend their legs completely during both kicks.

Even so, several of those swimmers appear to soften the downbeat of the second kick as compared to the effort expended during the first kick. For this reason, I believe that most swimmers should make the downbeat of the second dolphin kick with somewhat less effort when they swim a 200 event. Softening the second downbeat could be advantageous if swimmers can save energy without submerging the hips during the upsweep of the armstroke. It would not be advisable to soften the second kick if they cannot maintain a horizontal body position during the upsweep, however.

Regardless of the effort applied, the downbeat of the first dolphin kick will and should be the longer of the two. Because of this, it will generate more forward propulsion. By the same token, the downbeat of the second kick will be the shorter of the two and will probably generate less propulsive force, even when both are made with equal force. Differences in the lengths of these two kicks are probably due to body position rather than the effort expended in kicking. The hips will naturally travel up and forward for a longer distance during the downbeat of the first dolphin kick because the head is down and the arms are outstretched in front.

The upbeat of the first kick will also be longer for the same reasons. On the other hand, the shoulders and trunk will be elevated and the arms will be back at the hips when the downbeat of the second dolphin kick occurs, so the hips cannot and should not rise as much when it is executed. If the hips did rise above the surface, the resulting undulation would push the head and shoulders down when swimmers are trying to breathe and recover the arms over the water. For this reason, I believe the downbeat of the second dolphin kick should be shorter and used only to maintain the hips at the surface, not push them above the surface. The upbeat of the second kick, the one that takes place during the arm recovery, will also be shorter because the trunk is elevated during the time it is taking place. Therefore, swimmers will not be able to sweep the lower legs up over as long a distance without pushing the head and shoulders down.

Body Undulations and Breathing

It is useless to talk of one body position for the butterfly because swimmers are constantly changing positions as they undulate through the water during each stroke cycle. Undulation is an important propulsive tool in the butterfly. Although resistive drag would certainly be reduced by staying horizontal, propulsion would be compromised to such an extent that the average velocity per stroke cycle would be reduced considerably if athletes swam this stroke with a flat body position. The effect of body undulations on forward propulsion will be discussed in the next section, followed by a description of the breathing technique used by skilled butterfly swimmers.

Body Undulations

Most people think that body undulations are centered in the hips during butterfly swimming. In reality, however, the vertical movements of the head and shoulders actually exceed those of the hips (Sanders, Cappaert, and Devlin 1995). The precise sequencing of vertical head movements appears to be the major player where proper undulation is concerned. It may initiate a backward body wave that could enhance the propulsive force of the first dolphin kick. I believe that proper head movements are definitely responsible for what I have termed a *reverse body wave,* which permits the force from the downbeat of the first dolphin kick to accelerate swimmers rapidly forward.

Butterfly swimmers should not push the hips up and down in an effort to undulate properly. This will do no good. Upward hip movement appears to be merely an effect of both the downbeat of the first dolphin kick and the downward movement of the head and shoulders during the entry and stretch of the arms. Subsequent downward hip motions are merely the result of gravity and the upbeats of the dolphin kicks.

For years, traditional wisdom has dictated that butterfly swimmers should stay low in the water when they breathe because elevating the head and shoulders above the surface was believed to increase form drag. I disagreed with this notion earlier with regard to increasing wave propulsion and reducing drag during the arm recovery. Another reason for elevating the head and shoulders during the arm recovery is because the subsequent downward undulation of these body parts establishes the conditions for a body wave and a reverse body wave that may contribute significantly to forward propulsion. While raising the body requires an additional expenditure of energy initially, energy is saved and even reused to aid propulsion when the head and trunk drop back into the water.

According to Sanders, Cappaert, and Devlin (1995), "As the head and then shoulders started moving downward the stored energy was used to increase the downward velocity of the upper body." In other words, the subsequent downward and forward movement of the head and trunk that occurs after the hips pass the peak of upward undulation should actually aid in accelerating forward speed because of the force of gravity.

The possibility that the undulating movements in the butterfly also create a body wave that enhances propulsion was discussed in chapter 3. Sanders and associates suggested that butterflyers use such a mechanism. These researchers believed that the downward movements of the head and shoulders were followed by elevation of the hips, culminating in a summation of forces at the knees and ankles that add to the propulsive force of the first downbeat. That summation could be likened to the cracking of a whip where the sequential movements of the whip culminate in a "crack" of energy at the end. The body wave, as proposed by Sanders and his associates, is illustrated in figure 5.15.

I have no difficulty accepting the notion that elevating and then submerging the head, shoulders, and trunk can reduce deceleration during the arm entry. However, I do have some doubt regarding the existence of a body wave that travels back from head to feet and increases the propulsive force of the kick. Nevertheless, I think the body undulations that follow the downbeat of the first dolphin kick can produce what I have termed a *reverse body wave.* This is a wave that travels from feet to head, improv-

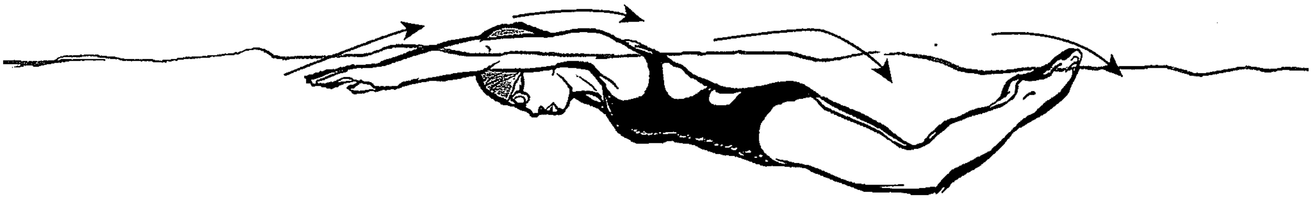


Figure 5.15 The body wave in butterfly swimming.

ing the amount of forward acceleration received from the downbeat of the first dolphin kick. The possible sequence of events is as follows.

The hips will be accelerated up and forward over the water during the downbeat of the first kick. The head and arms will be entering the water at the same time. Most of the force from that kick is directed downward, so at first glance, it would seem to push the hips up without propelling swimmers forward very much. It is possible, however, that the downward force of that kick could be translated to forward propulsion if swimmers look forward and stretch the arms forward precisely as the hips pass the peak of their upward undulation and start down and forward. By doing so, the downward momentum of the hips will be transferred to the head and arms, which will then be pushed forward by the force of that kick and by gravity. The possible operation of a reverse body wave is illustrated in figure 5.16.

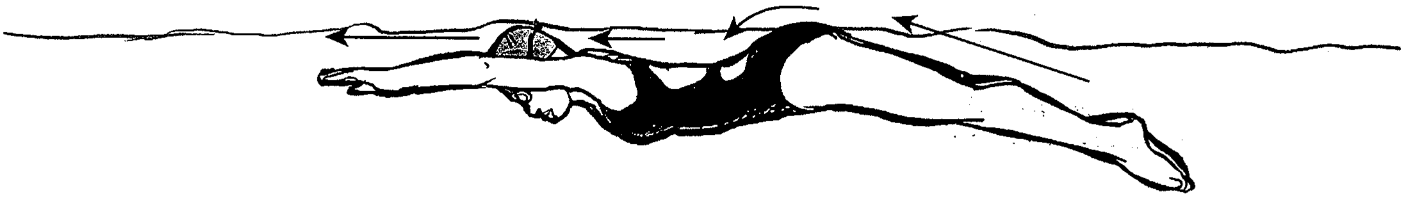


Figure 5.16 The reverse body wave.

To utilize the reverse body wave to enhance forward propulsion, the sequence of undulating movements must be precise. In addition, the vertical portions of the undulations cannot be overdone. Put simply, swimmers cannot be pushing the body up and down at steep angles. The undulations must be gradual, with body parts always moving up and forward or down and forward. Sanders (1996) reported that the vertical motion of the center of mass of international-level New Zealand butterfly swimmers was approximately 18 cm (7 in) for males and 14 cm (5.5 in) for females.

In addition to their effect on enhancing propulsion, the proper sequence of body undulations should also reduce resistive drag. In this respect, swimmers should try to keep the body as horizontal as possible during the propulsive phases of the armstrokes. The roles of the upbeats of the first and second dolphin kicks and the downbeat of the second kick in maintaining that position were described earlier.

Breathing

I disagree with the traditional belief that butterfly swimmers should keep the head and shoulders low in the water and jut the chin forward when they breathe. Breathing in this way can actually reduce body undulation and the additional propulsion gained from it. For this reason, I recommend that butterfly swimmers breathe in the manner that is now taught for wave breaststrokers. That is, they should breathe by elevating the shoulders and trunk above the surface so that they do not have to extend the head up and back to take a breath. The head should stay in a natural position, neither flexed nor extended on the neck, as it breaks through the surface. In other words, swimmers breathe by elevating the trunk above the water, not by lifting the head up and back. Teaching points that can be used to help swimmers breathe in this manner are keeping the chin down when they breathe and focusing the eyes down and forward on the water in front of them. They should not jut the chin forward, nor should they look up and forward toward the opposite end of the pool.

The above-water view in figure 5.9 (see pages 154–155) shows the proper way butterfly swimmers should bring the head above the surface for a breath. Notice the position of the head and shoulders in figure 5.9l. The shoulders are out of the water and the head is inclined forward with the chin down and the eyes focused down and forward on the water immediately in front of the swimmers. Neither swimmer has the head flexed back on the neck.

Swimmers should begin to raise the head, shoulders, and trunk toward the surface during the outsweep of the armstroke. These body parts should continue moving gradually up and forward, toward the surface, finally breaking through the surface during the transition from insweep to upsweep of the armstroke. Swimmers should exhale slowly as the head moves toward the surface and complete the exhalation with a burst as the head breaks through the surface. Swimmers should inhale during the upsweep and the first half of the arm recovery and return the head to the water during the second half of the arm recovery.

The body should travel up and forward through the surface on a slight diagonal. The shoulders and trunk need to be elevated above the surface to allow swimmers to do this. The head should remain in a normal position on the spine so that they appear to be traveling forward more than upward as they take a breath. Keeping the head in line with the spine should encourage a gradual rise to the surface, whereas looking up and extending the head back on the neck will cause a sudden and steep rise toward the surface that will reduce forward velocity.

There are several additional reasons breathing in this manner should be more efficient than the traditional method. First, elevating the trunk and shoulders above the water aids in recovering the arms over the water without dragging them through it. Second, the subsequent downward and forward motion of the trunk probably aids in producing a body wave that enhances propulsion. Third, maintaining the head in a natural position while it is brought to the surface encourages elevation of the shoulders and trunk above the surface, whereas lifting the head may discourage sufficient elevation of the shoulders and trunk.

The sequence of head movements toward the surface is exactly the same during the outsweep on the nonbreathing stroke. Swimmers should look up to encourage the body wave. Instead of breathing, however, they should again look down once the head reaches the surface. This will improve horizontal streamlining during the insweep and upsweep of the underwater armstroke. Head movements during the nonbreathing stroke are pictured from a front view in figure 5.10 (see page 156).

Breathing to the Side

Some butterfly swimmers breathe to the side. The usual reasons given for breathing in this way are to save energy and maintain a more horizontal body position. Some believe that the energy cost of lifting the head will be reduced if they rotate the face to the side, as they do in the front crawl. They also feel that it helps them maintain good horizontal alignment because the act of lifting the head out of the water tends to submerge the hips.

This reasoning is fallacious because it overlooks an important difference between the butterfly and front crawl. Front-crawl swimmers can roll the body to bring the face above the surface. Butterflyers must rotate the head while the body is in a prone position. In a perfectly prone position, the range of motion in the neck is usually too limited to permit the mouth to come above the surface, unless they elevate the head and trunk above the surface to begin with. Consequently, butterflyers who breathe to the side must lift the head and shoulders out of the water as much as or more than swimmers who breathe to the front to get the mouth out of the water. The photograph in figure 5.17 shows a swimmer breathing to the side. Notice

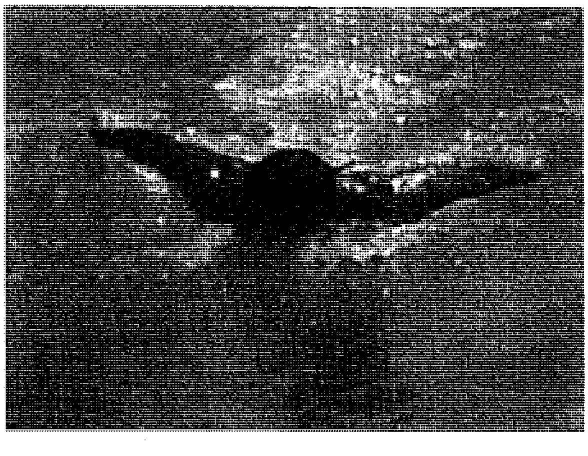


Figure 5.17 Side breathing in the butterfly.

how high his head and shoulders are above the surface. Notice also that his arms are not symmetrical. Swimmers who breathe to the side usually raise one shoulder and recover one arm higher than the other.

Far from being a mistake, elevating the trunk and shoulders in this way may actually be a blessing in disguise because, as described in the earlier section on body waves, returning the head and shoulders into the water after they have been elevated may reduce the amount of deceleration associated with arm recovery. Nevertheless, it is neither necessary nor advisable for swimmers to breathe to the side. The trunk and shoulders can also be elevated by breathing to the front. In fact, breathing to the front better fits the nature of the stroke. Butterfly swimmers remain in a prone position throughout the stroke cycle and they drive the body forward with both arms simultaneously. Therefore, it makes sense to lift the head forward in the direction the body is traveling.

There is one additional problem that swimmers usually encounter when breathing to the side. They tend to rotate the body slightly in the direction they turn the head. This can reduce propulsion from the arm on the opposite side if the elbow is allowed to drop.

Breathing Frequency During Races

Butterfly swimmers are usually advised not to breathe during every stroke cycle when they race. Breathing is thought to decrease velocity because the hips and legs drop deeper in the water, and the upsweep tends to be shorter and the first kick weaker (Hahn and Krug 1992; Alves, Cunha, and Gomes-Pereira 1998). The most common recommendation is to breathe once every two armstrokes in 100 races. This is referred to as a *1-and-1* breathing pattern and is considered a good compromise between the need to consume oxygen and the desire to maintain forward velocity at the highest possible level.

Some coaches also recommend this breathing pattern for 200 races. Others feel it is too rigorous, however. They recommend patterns where breaths are taken for two or three consecutive strokes before a nonbreathing stroke is completed. These breathing frequencies are termed *2-and-1* and *3-and-1* patterns. The extra breathing strokes increase oxygen consumption and the periodic nonbreathing strokes are used to regain horizontal alignment.

Despite the seeming wisdom of restricting breathing, many world-class butterfly swimmers have breathed once per stroke cycle during many of their best swims. This has been particularly true of 200 races, although some successful butterfly swimmers have also breathed during every stroke cycle in the 100 event.

The obvious dilemma swimmer's face is whether they should try to increase their average velocity by using some restricted breathing pattern or delay the onset of fatigue by breathing as often as possible. I tend to believe that delaying fatigue is more important to race success. For this reason, butterfly swimmers should make every effort to perfect their breathing mechanics so that they can breathe regularly with little or no slowing of their forward velocity. In this respect, Alves, Cunha, and Gomes-Pereira (1998) reported that increases in trunk inclination were not significantly different for skilled butterfly swimmers during their breathing and nonbreathing stroke cycles. Thus, there is some evidence that breathing does not increase form drag.

Swimmers should use sets of experimental repeats to determine the most effective breathing pattern for each race distance. They should complete sets of eight to twelve 50 or 100 yd or m butterfly repeats on short or medium rest intervals. All repeats should be swum with similar efforts that are close to race speed. Sets of 50s on 1 min are very good for simulating 100 races. Sets of 50s on shorter rest and sets of 100s on short to medium rest are best suited for simulating the stress of 200 races.

Breathing frequencies should be alternated from one repeat to the next, using 3-and-1, 2-and-1, 1-and-1, and every stroke pattern until they can determine which pattern produces the fastest times, or the same time with less effort. Swimmers should repeat these sets over several days, discarding the patterns that are obviously less effective, until they find the one that is consistently faster for a particular race distance. This is the pattern they should use in competition. If there is no difference in speed between certain patterns, swimmers should use the one that provides the greatest oxygen supply.

Underwater Dolphin Kicking

The international rules of competitive swimming now permit swimmers in butterfly races to dolphin kick underwater for 15 m of each pool length before they must come to the surface and swim the full stroke. Underwater dolphin kicking has become tremendously popular in backstroke races, with most swimmers finding that they can kick underwater faster than they can swim on the surface. For this reason, many butterfly swimmers have also taken to kicking sizable portions of their races underwater. The primary advantage of underwater dolphin kicking over surface swimming lies in the greater number of propulsive thrusts that swimmers can deliver during each minute. Swimmers typically use rates of 120 to 170 kicks/min when they dolphin kick underwater at fast speeds. Compare that number of propulsive thrusts to the usual stroke rate in butterfly races, typically between 44 and 56 strokes/min.

At first glance, this would seem to favor underwater dolphin kicking. Remember, however, that butterfly swimmers are already achieving propulsion from at least one dolphin kick during each cycle, in addition to attaining at least two propulsive peaks during the armstroke and another propulsive peak from wave propulsion during the arm recovery. When viewed in this way, the butterfly swimmer is producing over 200 propulsive peaks during each minute they swim, as compared to 150 to 170 peaks when they kick underwater. For this reason, I doubt that underwater kicking is really faster than surface swimming for most butterfly swimmers.

Before making a decision to use this technique, however, butterfly swimmers should test whether they are faster when they dolphin kick underwater. Some swimmers' dolphin kicks are so effective that they can kick faster underwater than they can swim on the surface. Some butterflyers can kick faster than they swim the full stroke because they have serious flaws in their armstrokes or the timing of their arms, legs, and breathing. These swimmers should train themselves to dolphin kick as much of the race underwater as is permissible according to the rules. Swimmers who find they are faster swimming the full stroke would obviously be better advised to swim most of their races on the surface. As for those swimmers whose speeds are similar underwater and on the surface, they should also swim their races on the surface because the additional oxygen they consume will allow them to swim faster in the latter parts of their races.

Dolphin Kicking Off the Start and Turns

Even butterflyers who swim most of their races on the surface should take three to five underwater dolphin kicks after the start and after each turn. One advantage of doing this is that they can stay deeper in the water for a longer period, reducing the speed interference of the backwash from the wall and the turbulence caused by incoming or outgoing swimmers. A second advantage is that taking three or four kicks allows swimmers to push off the turn deeper and move toward the surface on a gradual diagonal that will not compromise their speed as much as it would be slowed by a less gradual ascent. Swimmers who use only one or two underwater dolphin kicks must push off much closer to the surface to prevent the slowing effect of a steep ascent.

Staying underwater for a few additional kicks should not compromise the oxygen supply of butterfly swimmers. The time they spend underwater is not significantly longer than the time required to approach the wall, turn, and break out in front-crawl swimming. Thus, they are already accustomed to holding their breath for time that is at least equal to the time it would take for three to five dolphin kicks after a butterfly turn. Therefore, it should not be very difficult to train butterflyers to stay underwater for that number of kicks. The suggested depth for underwater dolphin kicks is between 0.4 and 0.6 m (1.5 and 2 ft) (Lyttle et al. 1998).

Side Dolphin Kicking

Side kicking is a recent innovation in underwater dolphin kicking. It has been suggested that kicking on the side is faster than kicking in a prone position, for two reasons. First, the vortices that swimmers shed in a backward direction when they dolphin kick become more-effective propelling agents because they are not interrupted by running into the surface or bouncing off the bottom of the pool. Second, swimmers encounter less drag on their sides. I doubt that either of these suggested advantages of side dolphin kicking actually provide any advantage over dolphin kicking in a prone position, however.

As explained in chapter 1, it is doubtful that swimmers actually gain propulsion from the production and shedding of vortices with the legs. Certainly, they accelerate some water backward with the kick, which in turn accelerates them forward. At the same time, the water behind them becomes turbulent when they kick against it. Nevertheless, this does not mean that they are shedding organized vortices backward with sufficient intensity to propel them forward. Even if they could, those vortices would probably dissipate so rapidly that most, if not all, of the effect would be lost almost immediately after the vortices were shed. In other words, any propulsive effect would occur immediately after the vortices were shed backward and they would dissipate soon thereafter. Consequently, it would make no difference if the water swirled around for a greater distance without reaching the surface or rebounding from the bottom of the pool. The energy from the backward-moving water would have dissipated earlier and would no longer be available to produce a reactive force that would propel them forward.

I also doubt that form drag is reduced when swimmers are on their sides under the water. When swimmers are totally submerged, the width of the body should present the same drag profile whether they are in a side or prone position. The width of the body would be the same and water could be diverted over two surfaces.

I have tested swimmers and found no differences in their speeds over 25 yd when they kicked underwater in a prone or side position. Both seem to be equally effective. An important thing to remember is that side kickers must change to the prone position at some point in races and they will probably decelerate for a short period of time while negotiating that change. That should not be the case with prone kicking, however. Consequently, it makes better sense to kick in a prone position.

Underwater Dolphin Kicking Mechanics

The mechanics of dolphin kicking underwater in a prone position are shown in the sequence of photographs in figure 5.18. The amplitude of the underwater dolphin kick is smaller and the legs move faster than they do when swimming the full stroke. Otherwise the mechanics are the same. The downbeat begins as the legs pass above the body during the preceding upbeat. It begins with a slight amount of hip flexion that starts the thighs downward and allows the water to flex the lower legs and extend the feet in preparation for a whip-like downward extension at the knees that takes place soon thereafter. The upbeat is made with straight legs.

It is very important for swimmers to keep the trunk, head, and arms as streamlined as possible while they kick underwater. The arms should be close together overhead, with one hand over the top of the other, forming a V that allows streams of water to separate gradually over all four surfaces of the body as it passes through it. The separation of water streams should start at the very smallest surface of the fingertips and pass gradually backward along the arms and trunk. The head should be tucked between the arms with as little of the head protruding above or below the arms as possible.

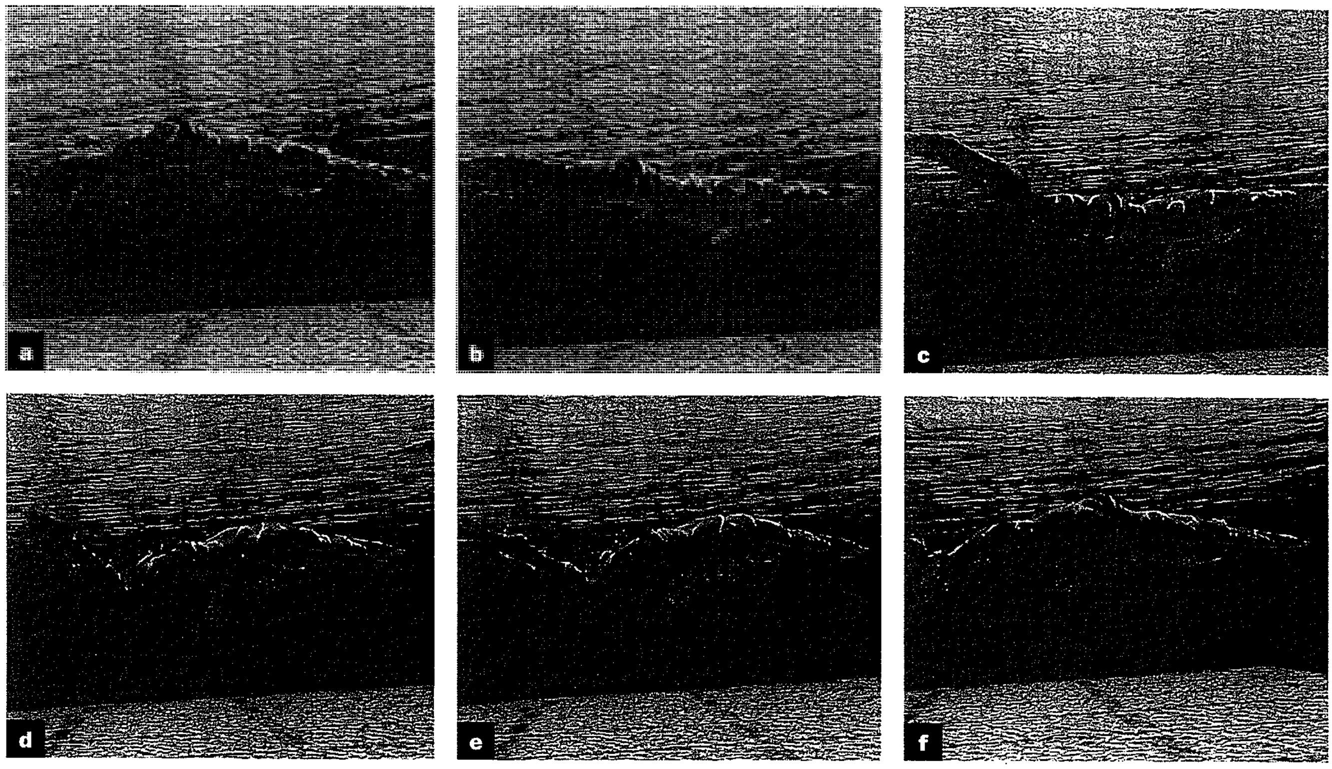


Figure 5.18 Sequence photographs showing the mechanics of the underwater dolphin kick. The swimmer is Guillermo Diaz DeLeon of Arizona State University.

(a) Start of upbeat.
(b) Continuation of upbeat.
(c) Start of downbeat. Start of hip flexion.
(d) Continuation of downbeat. Start of leg extension.
(e) Continuation of leg extension.
(f) Start of next upbeat.

Just as in full-stroke swimming, some body undulation is necessary to translate the downward movements of the legs into forward propulsion. This is accomplished through a mechanism termed a *body shimmy* (Boomer 1996). In this case, however, it is the arms, and not the head, that are used as the locus of translation. The shimmy, as its name implies, is a series of small alternating up and down movements of the arms that accompany the upbeats and downbeats of the dolphin kick. These arm movements are timed precisely with the kicks to keep the body traveling forward. The sequence of arm movements is as follows.

The downbeat of the kick will push the trunk, head, and arms forward and down as it elevates the hips up and forward. Gravity will cause the hips to travel down and forward during the next upbeat. Swimmers should raise the arms slightly and stretch them forward as the hips pass the peak of their upward undulation (see figure 5.18, a and b). This will allow the subsequent downward movement of the hips and trunk to push the body forward. The swimmers will then push slightly downward with the arms as they execute the downbeat to keep the upper body traveling forward (see figure 5.18, d and e).

Common Stroke Mistakes

Swimmers can make many mistakes when they swim the butterfly. The most common of these are described in this section.

Armstroke Mistakes

The most common armstroke mistakes are described in this section, along with suggestions on how to correct them.

Entry and Stretch Mistakes

Many swimmers do not maximize kick propulsion because of the way they enter the arms into the water. Smashing the arms and hands into the water will increase drag. Attempting to push back on the water immediately after they enter will also increase pushing drag and reduce propulsion from the downbeat of the first dolphin kick. Swimmers should enter the arms softly with hands turned out. They should then wait until they have pushed the body forward with the downbeat of the first kick before they start to push back.

Outsweep Mistakes

The most common mistakes swimmers make during this phase of the armstroke are to put too much effort into the outward movement of the arms and to direct the arms down too much and out too little.

The outsweep is not propulsive, so swimmers should not push the arms out vigorously against the water. They should slide the arms out. At the same time, they should slide them directly out until the arms and hands are facing back. The arms should not be pushed down, as this will force the body up and decelerate forward speed even more than it is already decelerating during this phase of the armstroke. Butterfly swimmers who do this will be committing the mistake of dropping the elbows. Of course, sliding the arms out will also introduce some unwanted lateral force. That force, however, will not slow swimmers as much. The effect the lateral motion of one arm would have on lateral alignment will be cancelled because the other arm will be applying an equal amount of lateral force in the opposite direction. Conversely, when swimmers push down with both arms, no matter how gently, they will double the force that decelerates them.

Another mistake that some swimmers make is to keep the arms straight throughout the outsweep. This lengthens the time it takes to reach the catch position and encourages too much flexing of the arms during the succeeding insweep.

Insweep Mistakes

The most serious mistake swimmers make during the insweep is pushing the hands and arms down and in immediately when they make the catch. This creates a classic case of dropped elbows, causing swimmers to push down on the water, instead of back, through the entire first portion of the insweep. This will simply push the body up and decelerate forward velocity when they should be accelerating forward. This is such a common mistake that even skilled butterfly swimmers make it. They try to catch by using a downward-sweeping motion similar to the one used in the front crawl stroke. They think they are pulling the hands and arms back and in, but in reality they are pushing them down and in because they failed to gain a backward arm orientation before they started to apply force.

The photograph in figure 5.19 shows the position of a swimmer's hands and arms just after the catch. Notice that his palms and forearms are facing down instead of back. As a result, he will push down vigorously with his arms, which will push his body up and decelerate his forward speed.

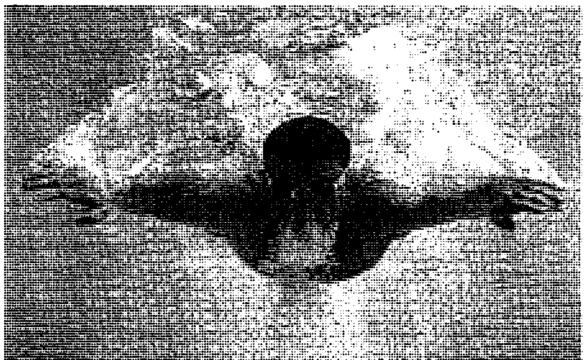


Figure 5.19 Position of the hands and arms just after the catch. The palms and forearms are facing down, not back, which will cause his speed to decelerate.

Swimmers should slide the hands directly out to a backward-facing position at the catch and, then, initiate the insweep by pressing back, not down. Those who simply cannot sweep inward without pushing the hands and arms down should consider using one of the alternate insweep methods described earlier in this chapter.

A second mistake swimmers make is to catch with extended arms and then flex them during the insweep. This causes them to scull the hands almost directly in across the water with minimal backward movement of the hands and arms. The result will be that they apply very little effective propulsive force. Water will simply slide out and forward past the hands. Some of that water will be displaced backward as it passes under the palms, which will propel swimmers forward. But the amount of forward propulsion will not be nearly as great as could be achieved by pressing water back and in with the hands and arms.

The arms should already be flexed when the catch is made and the upper arms should be adducted back, toward the ribs, during the insweep. As described earlier, this will increase propulsion by allowing the large muscles of the back to participate more fully in the insweep.

The next most common mistake concerns the failure to complete the insweep underneath the body. Swimmers who make this mistake do not bring the hands very close together under the body, nor do they adduct the arms back near the ribs.

Swimmers who stroke this way generally try to push the hands and arms almost directly back from the catch. They combine the insweep and upsweep into one continuous motion in which they must accelerate water back for a long distance. The problem with this style is that it decreases distance per stroke. The insweep is cut short and the first half of the upsweep takes place near the outer borders of the body, rather than down the midline where it would be more effective. It should be said that several very successful butterfly swimmers have used this type of one-peak arm velocity pattern. Nevertheless, I believe its propulsive potential is less than that of a two-peak arm velocity pattern and should only be used if swimmers cannot master a longer insweep.

Upsweep Mistakes

The mistakes butterfly swimmers make during this phase of their underwater armstrokes are similar to the mistakes mentioned in connection with the front crawl stroke. Swimmers may extend the arms too rapidly and push water up rather than back. They may also try to push back against the water until the hands reach the surface. This action will also cause them to push water up excessively. The effect of these errors is illustrated in figure 5.20.

The swimmer in this figure is extending his arms while making the upsweep. If swimmers extend the arms before the hands reach the surface, they will be pushing up with the palms and the undersides of the forearms during the final part of the upsweep. This will force the body down and decelerate forward speed.

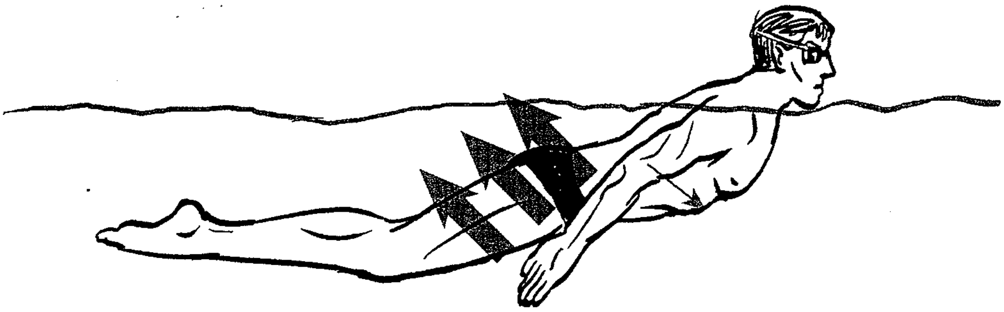


Figure 5.20 Position of the hands and arms during the upsweep. The palms and forearms are facing up, not back, which will cause his speed to decelerate.

Swimmers should extend the elbows slowly and minimally during the upsweep, and they should release pressure and begin arm recovery as the hands pass the thighs. The arms should not extend rapidly until they have released pressure and the arms are leaving the water in the recovery.

Recovery Mistakes

The three most common mistakes swimmers make when they recover the arms are to recover them too high, recover them with too much effort, and drag them through the water.

The point has been made that dragging the arms through the water will considerably reduce forward velocity. The shoulder muscles should also be given some time to relax during recovery. Therefore, swimmers should use the minimum force necessary to overcome the backward inertia of the arms and get them moving forward. They should not thrust them forward into the water with great muscular effort.

Recovering the arms high overhead requires shoulder flexibility that is outside the range of most swimmers. It is neither necessary nor even advisable for swimmers to recover the arms in this manner. The only reason for recovering high would be to keep the arms from dragging through the water. Dragging can be prevented with a lateral recovery, however, provided swimmers let the trunk and shoulders rise out of the water during the upsweep and recovery.

Kicking Mistakes

Ankle extension ability is a major asset in dolphin kicking. Swimmers should be able to extend the feet more than 70° from the vertical. Those who do not possess this ability will need to increase the range of motion with specially designed ankle flexibility exercises.

The drawings in figure 5.21 illustrate the importance of good ankle extension during the downbeat of the dolphin kick. Figure 5.21a shows how good ankle extension allows swimmers to maintain a backward orientation to the water with the feet until late in the downbeat. Figure 5.21b demonstrates that, with poor ankle extension ability, the feet would simply be pushing down on the water during most of the downbeat.

Another frequent mistake swimmers make is to kick too deep when they dolphin kick. This problem is particularly common during the downbeat of the second dolphin kick. The feet should be only slightly deeper than the trunk when the downbeats of the dolphin kick are completed. Kicking deeper than this will only increase form and pushing drag because the legs will be well below the body and they will be kicking forward as well as downward during the final portion of the downbeat.

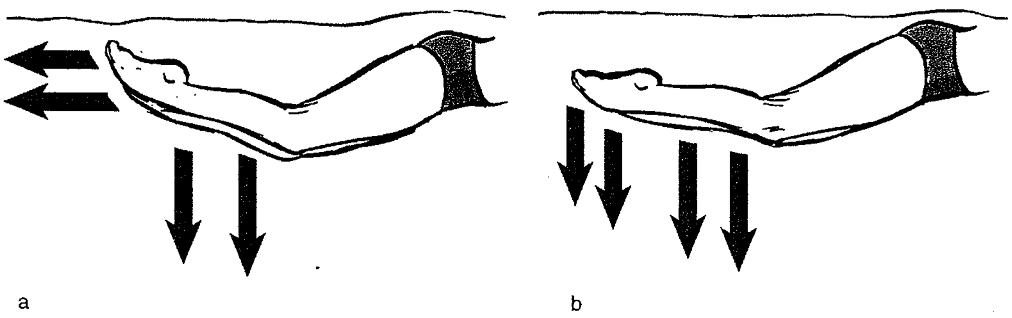


Figure 5.21 Examples of the effects of good and poor ankle extension ability on kicking. The swimmer in *(a)* has better-than-average ankle extension ability and, therefore, is able to maintain a backward orientation to the water with his feet until late in the downbeat. Contrast this with the swimmer in *(b)* who has poor ankle extension ability. His feet, like his legs, are simply pushing down on the water during the latter part of the downbeat.

Another common mistake swimmers make is to bend the legs during the upbeat of the dolphin kick. This error, perhaps more than any other, reduces the propulsion many butterflyers achieve from kicking. The effect of this mistake is that swimmers will push the water up and forward with the legs, increasing pushing drag and decelerating forward speed. Swimmers should not bend the knees until the downbeat begins, that is, until they begin pressing down with the thighs.

Timing Mistakes

The common mistakes swimmers make with regard to timing are: kicking too early during the recovery, gliding too long after the entry, and kicking only once during each stroke cycle.

Kicking too early during the recovery— Some swimmers finish the downbeat of the first dolphin kick before the hands enter the water. These swimmers usually have difficulty recovering the arms without dragging them through the water. Therefore, they kick down at this time to offset the pushing drag they create by pushing the arms through the water before the hands enter. Unfortunately, kicking at this time will only reduce their rate of deceleration during the arm recovery. They will not be accelerated forward enough by the downbeat of the first dolphin kick.

Swimmers should try to time the downbeat of the first dolphin kick so that it takes place just as the hands enter the water and stretch forward. They should try to raise the head and trunk out of the water more, and flex the elbows as they reach forward for the entry, so that they are not as likely to drag the arms forward through the water before the hands enter.

Gliding too long after the entry—This mistake is common among young swimmers when they first learn the butterfly stroke. They will stretch the arms forward after the entry and kick down twice before starting the outsweep of the armstroke. Butterfly swimmers must be coached to kick down only once as the arms enter the water and then to wait until they are midway through the underwater armstroke before kicking down again. Two good drills for correcting this problem will be described later in this chapter.

Kicking only once per stroke cycle— In reality, the one-kick butterfly is really a one-and-one-half-kick butterfly because swimmers start but do not complete the downbeat of the second kick. This makes it difficult for them to maintain the hips near the surface and the inclined body position will increase form drag during the finish of the underwater armstroke and recovery.

The one-kick butterfly is difficult to correct because the solution is not as obvious as it seems. Simply telling swimmers to kick twice will not remedy the situation. Butterfly swimmers who kick only once during each stroke cycle usually try to catch too quickly and then push straight back without sweeping the hands in under the body. This sets up a chain of events that makes the underwater armstroke so short that swimmers do not have enough time to bring the legs up and then kick them down a second time before the hands leave the water. As a result, they only have time to execute a partial downbeat. One-kick butterflyers should be instructed to exaggerate the outsweep and insweep of their armstrokes to provide enough time to get the legs in position to complete the second downbeat of the dolphin kick before the hands leave the water.

Body Position Mistakes

Problems occur if butterfly swimmers undulate too little or too much during a stroke cycle. Too little undulation reduces forward velocity because both the kick and the body wave are not sufficiently propulsive. Swimmers may undulate too little if the outsweep of the armstroke is too short because they inhibit the upward movement of the hips by trying to catch too quickly after the arms enter the water.

Excessive undulation increases resistive drag because swimmers tend to kick too deep in back and drive the head too deep in front in an effort to make the hips rise high above the water. The effect of excessive undulation is illustrated in figure 5.22.

The swimmer in figure 5.22a is kicking deep enough to gain propulsion but not so deep as to increase form and pushing drag unnecessarily. The swimmer in figure 5.22b is both kicking excessively deep and driving her head down too much as her arms enter the water. This increases her form drag because she takes up more space than necessary in the water. It probably also reduces propulsion from her kick because her head and arms are moving down instead of forward at the time she completes the downbeat of her first kick.

When the dolphin kick is executed properly, the hips should flow up to and just over the surface, in a forward path during the first downbeat, and they should fall just below the surface on the subsequent upbeat. The down- and upbeats of the second kick should merely cancel upward forces from the armstroke and the hips should remain stable near the surface with no upward or downward undulation.

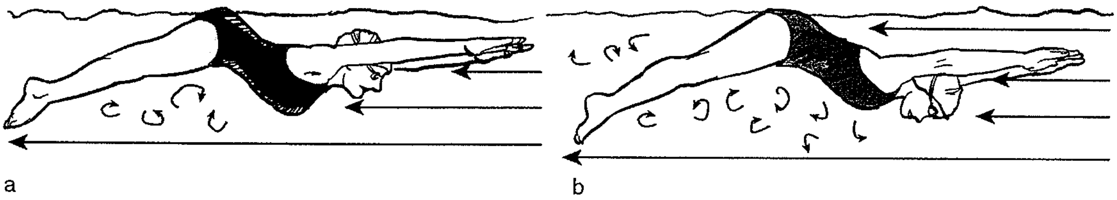


Figure 5.22 The mistake of undulating too much. The swimmer in *(a)* is undulating correctly, while the swimmer in *(b)* is undulating too much.

Breathing Mistakes

Some swimmers keep the head and trunk too low in the water when they breathe, while others bring them too high out of the water. Other common mistakes are to breathe too early or too late during the stroke cycle.

Swimmers who stay too low in the water when they breathe will invariably drag the arms through the water during the last half of the recovery. It should be prevented by elevating the head and shoulders enough that they remain clear of the water until just before the hands enter the water. At the same time, swimmers do not need to raise the head and trunk any higher than necessary to keep the arms from dragging through the water.

Swimmers who breathe too early generally use a glide stroke. They glide after the arms enter the water so that they can take a breath before they start the outsweep. These swimmers must be taught to keep the arms moving forward and out after they enter and to keep the face in the water until mid-stroke.

When swimmers breathe too late, they develop a *hitch* in their strokes. That is, they hesitate to breathe before bringing the arms out of the water. There may be three reasons they do this. The first is because they keep the head down too long after the entry and do not get the face above water until late in the armstroke. Accordingly, the face does not reach the surface until the upsweep is nearly completed and, therefore, they must hesitate to inhale before they can start the arm recovery. These swimmers must be taught to get the face above the water during the insweep and to breathe during the upsweep.

The second cause for breathing late may be because some swimmers push up too much with the arms during the upsweep. The large amount of downward force created requires them to kick very deep on the second downbeat to prevent the body from sinking. As a result, the hips rise excessively above the surface and they have to delay inhalation and the start of the arm recovery until the hips return below the surface.

These swimmers should be taught to release the water before the hands reach the surface, which will reduce the perceived need to kick down so hard during the upsweep.

The third, and perhaps most common, cause for a hitch among young butterfly swimmers is that some turn the palms down before the hands leave the water. This change of hand position from up to down interrupts the arms' movement out of the water and it delays inhalation and the start of the arm recovery. Certain swimmers mistakenly try to swing the arms forward before they leave the water. Instead of allowing the upward and outward swing to overcome the backward inertia of the arms, they stop the backward movement of the hands abruptly and begin reaching forward while the arms are still underwater. These swimmers should be taught to swing the arms up and out of the water and they should let the hands trail the arms as they recover forward over the water. These swimmers should also understand that the hands should leave the water on edge, with the little fingers leading, and that the palms should be facing back during the first half of the recovery.

Stroke Drills

The butterfly is the most difficult stroke to design drills for because it is so difficult to practice isolated aspects of this stroke and still maintain a semblance of swimming the butterfly. Nevertheless, there are a few drills that have become popular. Those drills are described in this section.

Armstroke and Timing Drills

There are four drills I can recommend for this purpose: (1) one-arm butterfly swimming, (2) butterfly pulling, (3) swimming the butterfly with fins, and (4) swimming one butterfly stroke cycle at a time with a hesitation between each cycle.

ONE-ARM BUTTERFLY DRILL

This drill is excellent for teaching the armstroke because swimmers can concentrate on moving the arms one at a time. Athletes swim the butterfly using only one arm going through the outsweep, insweep, upsweep, and recovery phases slowly and deliberately while concentrating on correct execution during each phase. The other arm can be extended overhead or placed at their sides. Extending the other arm in front makes the drill easier to navigate but inhibits undulation somewhat. Swimmers can undulate more naturally with the unused arm at their sides, but it is somewhat more difficult to breathe. Although swimmers will naturally tend to roll on their sides and breathe to the side when they do this drill, they should not be permitted to do so. They should stay in a prone position and breathe to the front, just as they would if they were swimming the full butterfly stroke.

This drill can be done with a dolphin kick or with a pull-buoy between the legs. The pull-buoy allows swimmers to concentrate on the movements of the arms, but it also inhibits undulation. Using a dolphin kick makes the drill more like swimming the butterfly, but for beginners, it can interfere with concentration on the armstroke.

There is a variation of the one-arm drill that serves as a good lead-up skill to full-stroke butterfly swimming. Swimmers swim each pool length by stroking a specified number of times with the right arm (for example, three times in a 25 m pool)..Then they take an equal number of strokes with the left arm. Finally, they finish the pool length by swimming with both arms.

BUTTERFLY PULLING DRILL

The purpose of this drill is to allow swimmers to concentrate on the armstroke and breathing while swimming a full butterfly stroke. The athletes swim the butterfly with a pull-buoy between their legs. The pull-buoy helps them to remain horizontal so that they can practice the movements of the arms and the sequence of breathing more easily.

Butterfly pulling is also a good drill for teaching the two-kick timing of this stroke. After doing this drill for a short time, swimmers will find that the legs naturally make two small downward thrusts during each stroke cycle and that those thrusts are properly synchronized with the armstrokes. Swimmers should be encouraged to let the legs wave up and down and to undulate the body, even though they are pulling and they should be paying attention to the synchronization of the downbeat of the legs with the armstroke. When these leg waves start looking natural, swimmers can remove the pull-buoy and accentuate the downward leg strokes to fine-tune the timing of the butterfly stroke.

SWIMMING WITH FINS DRILL

Swimming with fins makes it easier for butterfly swimmers to remain in good horizontal alignment while they practice the armstroke, the breathing sequence, and the timing between the arms and legs. The fins provide the added support that enables neophyte butterflyers to swim the stroke for a long enough distance to practice all of these aspects of the stroke.

ONE-STROKE-STOP DRILL

This drill is very good for practicing the entire butterfly stroke. Swimmers start from a motionless prone float in the water. Then they complete one exaggerated butterfly stroke cycle before standing up. They progress down the pool alternately laying out in a prone float, executing one stroke cycle, standing up, and then assuming the prone float position once again.

Kicking Drills

There are several ways that swimmers can strengthen and perfect their kicking techniques in practice. Six drills are described in the following sections.

BOARD KICKING DRILL

This drill is good for practicing the downbeat of the second kick and for conditioning the legs. It does not provide enough body undulation to simulate the downbeat of the first kick, however, because the hands and trunk are elevated by the kickboard and, in this relatively flat position, they are not able to undulate very much.

UNDERWATER KICKING DRILL

This is a good drill for teaching the first kick. Swimmers imitate dolphins by kicking underwater with hands at their sides. They can kick 25 yd or m sprints underwater. If they wish to kick longer repeats, they can kick underwater three or four times, come to the surface for a breath, and then drop under and kick three or four more times. This cycle should be repeated until they have covered the desired distance.

KICKING ON THE SURFACE DRILL

This drill is done without a board. It is another good drill for teaching the first kick because swimmers can undulate more when they are not holding a board in front of them. Swimmers kick down the pool with arms extended in front. They take a breath after every third, sixth, or eighth kick.

BACK KICKING DRILL

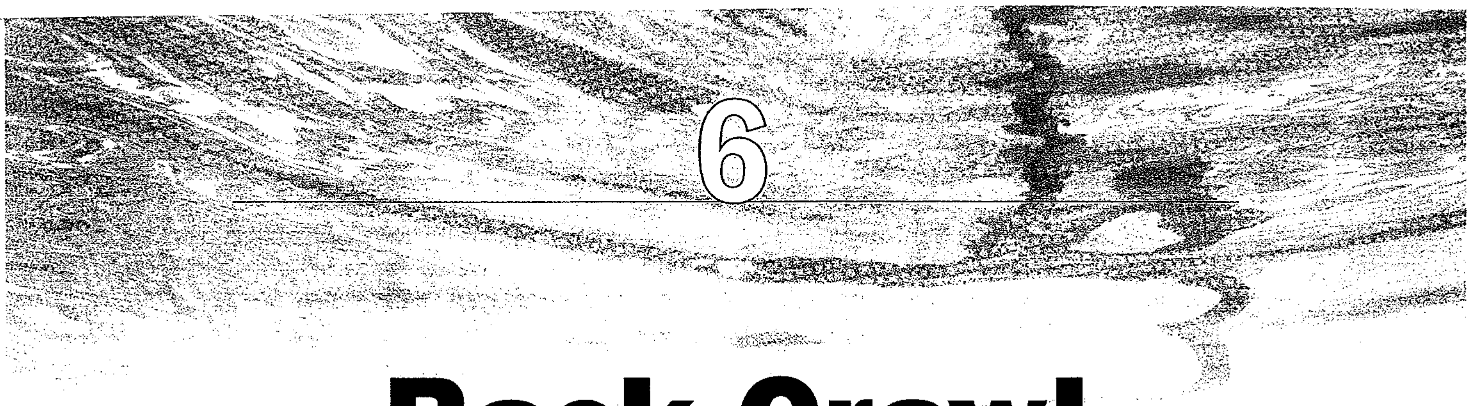
Swimmers dolphin kick on their backs with the arms extended overhead for any desired distance. This is a good drill to teach how to open and close the legs during the dolphin kick so that they can position the legs and feet to deliver propulsive force more effectively.

SIDE KICKING DRILL

Swimmers kick down the pool on their sides, hands at the thighs. They can do repeats of any desired distance. Kicking can be done by changing sides each length or by executing a specified number of kicks on one side (for example, five kicks before changing sides). This is a good drill for teaching swimmers to perform the upbeat correctly because they can feel the undulations of the legs and they can concentrate on making the upbeat with the legs straight. This drill can also teach the proper sequence for lowering and lifting the head by having swimmers look forward each time they kick downward. A variation on this drill is to kick with the hands overhead, which requires slightly more flexibility in the lower back.

THREE DOWN, TWO UP KICKING DRILL

This is an excellent drill for simulating the first dolphin kick of the butterfly stroke cycle. It is also a good method for improving aerobic capacity and breath-holding ability because athletes can swim long distances without losing their rhythm. Swimmers should complete a set of repeats, alternating three dolphin kicks underwater with two butterfly stroke cycles on the surface during each pool length. They should try to kick underwater using a strong thrust from the legs and adequate body undulation (head below hips on the downbeat of the legs) with each kick. They should use the two surface strokes primarily to catch their breath. Swimmers will find that they can swim the butterfly for long sets of repeats and long continuous distances in a very short time with this drill and this should help their endurance during butterfly races.



6

Back Crawl Stroke

New in this edition:

- A description of the armstroke based on drag-dominated propulsion
- A discussion of underwater dolphin kicking as used by backstroke swimmers

The back crawl, or backstroke, evolved from the inverted breaststroke (breaststroke swum on the back). Over time, competitors found that they could swim faster and still comply with the rules by recovering the arms over the water in an alternating manner. The modern backstroke later came into being when the flutter kick was found to be faster than the wedge kick.

From 1930 to 1960, backstroke swimmers used a style that was popularized by the great champion Adolph Kiefer. During their underwater armstrokes, swimmers pulled the arms to their sides, just beneath the surface, with a straight arm. They also recovered the arms over the water with a low, lateral swing. This style changed dramatically in the 1960s. With increasing use of underwater filming, experts realized that the most successful backstrokers of the day were using an S-shaped pulling pattern. The arms were bending early in the stroke and extending later. In addition, backstrokers were recovering the arms straight overhead rather than to the sides.

Today, the mechanics of the backstroke are very much like those of the front crawl, except that the backstroke is performed in a supine position. As in the front crawl, swimmers stroke alternately with the arms and the great majority complete six kicks per stroke cycle.

There have been further changes in the backstroke during the last decade. A great number of successful world-class swimmers are now using an underwater armstroke that has three, rather than two, propulsive phases. There has also been a considerable increase in the number of backstroke swimmers who dolphin kick underwater for large portions of their races. The rules now permit a swimmer to dolphin kick underwater for 15 m after the start and after each turn. Although, to date there have been no comparative studies to support underwater dolphin kicking, it is obvious that many backstrokers can travel faster by kicking underwater than they can when swimming backstroke on the surface.

The techniques for this stroke are presented in a similar order as those for the front crawl and butterfly. The typical stroke and velocity patterns for backstroke swimmers are described first. This is followed by descriptions of the armstroke, the kick, the timing of the arms and legs, and the body position in the water. Because of its increasing use, a section on underwater dolphin kicking has been added since the previous edition of this book. The final sections deal with common stroke faults and drills for teaching the backstroke.

Stroke and Velocity Patterns

Traditionally, we have believed that backstrokers use a two-peak propulsive pattern in the armstroke with the first propulsive peak coming as they sweep the arm up toward the surface, to mid-stroke and the second as they extend the arm toward the side to end the underwater armstroke. According to forward velocity measurements, however, many of the most successful backstrokers of the last two decades produce three propulsive peaks, with the third peak occurring as they bring the arm toward the surface in a phase that was once considered part of the arm recovery. Thus, the present crop of world-class backstroke swimmers seems to fall into two categories: those who use a

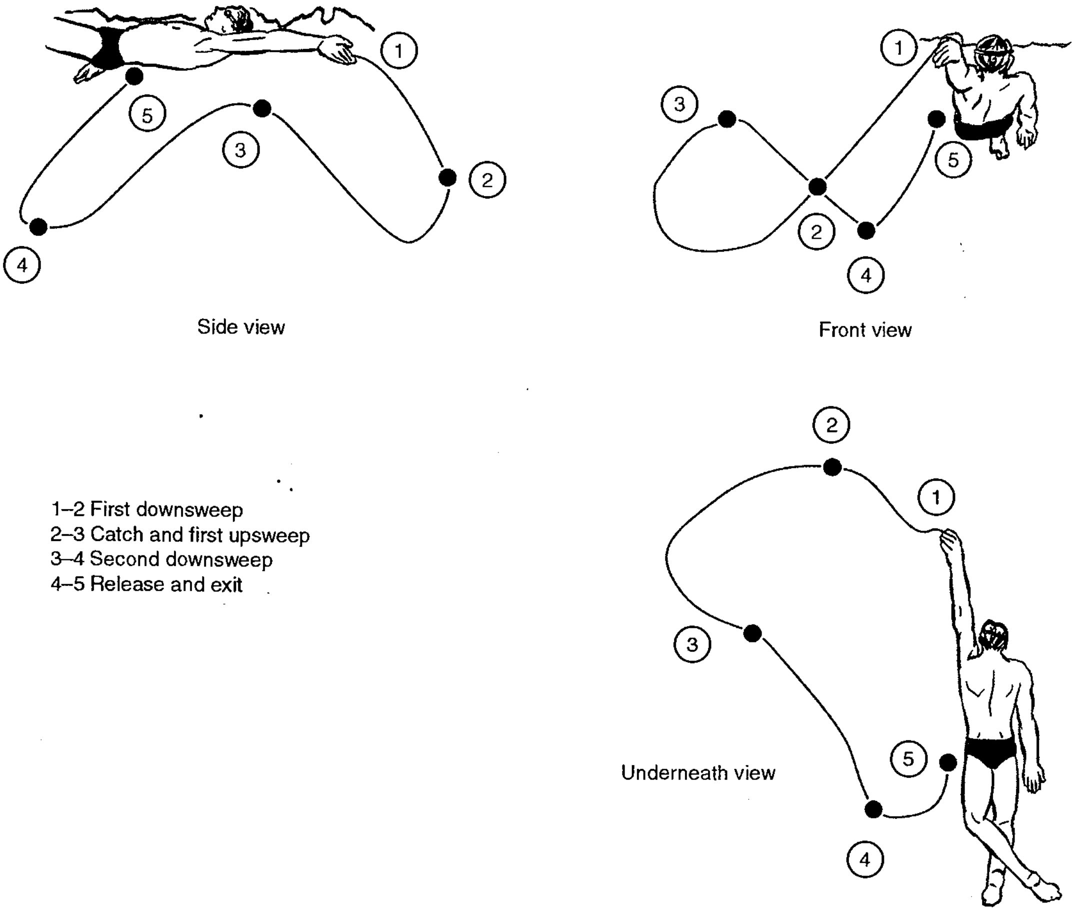


Figure 6.1 Side, front, and underneath views of the stroke patterns for a two-peak backstroke.

two-peak velocity pattern and those who produce three propulsive peaks during each underwater armstroke.

I believe that the three-peak pattern has the potential to be the most propulsive of the two methods and I will give my reasons for this statement later in this chapter. First, however, I begin with stroke patterns.

Stroke Patterns

The stroke patterns in figure 6.1 are for the traditional two-peak propulsive pattern. The stroke patterns in figure 6.2 are for a three-peak propulsive pattern.

Two-Peak Stroke Pattern

The side, front, and underneath stroke patterns in figure 6.1 illustrate the way that most two-peak backstrokers move the hands through the water. These patterns are drawn relative to a fixed point so that they represent the true directions of the hands during the underwater armstrokes.

Each underwater armstroke consists of five distinct parts: the first downsweep, the catch, the first upsweep, the second downsweep, and the release and exit. Two of these phases are propulsive, the first upsweep and the second downsweep.

In figure 6.1, the first downsweep occurs between points 1 and 2. After it enters the water, the hand travels forward, down, and out until it reaches the catch position. The catch takes place at point 2. The first upsweep, which is the first propulsive phase of the armstroke, is completed between points 2 and 3. The swimmer sweeps his hand up,

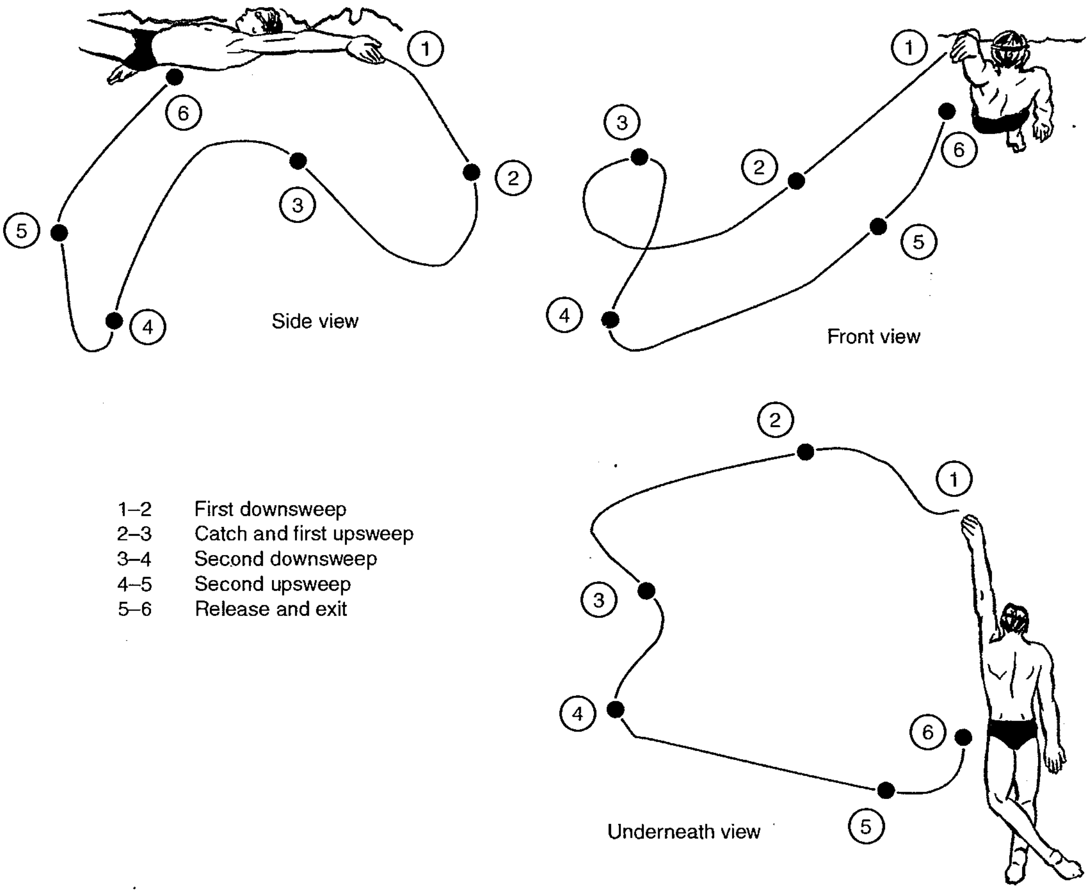


Figure 6.2 Side, front, and underneath stroke patterns for a three-peak backstroke.

back, and in until it is near the surface and opposite his ribs. The second downsweep, the second propulsive phase of the armstroke, takes place between points 3 and 4. The swimmer sweeps his arm down, in, and back until it is completely extended and just below his thigh. From there, the swimmer releases the water at point 4 and recovers his arm up and forward out of the water and back overhead for the next armstroke. His arm leaves the water at point 5.

Three-Peak Stroke Pattern

This pattern is illustrated from side, front, and underneath views in figure 6.2 on page 183. Like figure 6.1, it is drawn relative to a fixed-point in the pool. Swimmers who use this style have six, instead of five, phases to their underwater armstrokes and three of those phases are propulsive. The six phases are the first downsweep, the catch, the first upsweep, the second downsweep, *the second upsweep*, and the release and exit.

In figure 6.2, the first downsweep takes place between points 1 and 2. The catch takes place at point 2. The swimmer's arm travels in much the same direction as described for the two-peak style. It sweeps forward, down, and out. The first upsweep, the first propulsive phase of the armstroke, occurs between points 2 and 3. It is an upward and backward movement of the arm that ends as the swimmer's hand nears the surface and is opposite his shoulders. The first upsweep is much shorter in the three-peak pattern than it is in the two-peak pattern.

The next propulsive phase, the second downsweep, takes place between points 3 and 4. The swimmer sweeps his hand back and down until his arm is completely extended and well below his thigh. It will also be out away from his thigh much more than it is in the two-peak style. The third propulsive phase, the second upsweep, occurs between points 4 and 5. The swimmer sweeps his hand up, back, and in to his thigh, pushing water back with the palm of his hand and the underside of his forearm. The release occurs at point 5, and his arm leaves the water at point 6.

Two elements of the stroke patterns in figure 6.2 may have been surprising. The first concerns the depth of the hand during the second downsweep. Teachers of the typical *bent-arm* backstroke believe that swimmers should push the hand back and in to the thigh during this phase. Personal observations and stroke patterns drawn from films of world-class swimmers, however, show that three-peak backstrokers sweep the hand very deep below the thigh during this phase of their underwater armstrokes (Luedtke 1986).

It may also have been surprising that the second upsweep was a propulsive movement, because, as I said before, that sweep has traditionally been considered the first part of the arm recovery. According to propulsive force calculations of members of the 1984 U.S. Olympic swimming team and center of mass velocity patterns for several modern-day world-class swimmers, however, many backstroke swimmers do gain propulsion from this sweep (Luedtke 1986; Maglischo et al. 1987; Maglischo, Maglischo, and Santos 1987).

Forward Velocity and Hand Velocity Graphs

The graphs in figures 6.3 and 6.4 depict the forward velocity and hand velocity patterns for world-class two-peak and three-peak backstrokers. Figure 6.3 illustrates a typical two-peak forward velocity pattern for backstroker Theresa Andrews, a member of the 1984 U.S. Olympic swimming team. Only her right armstroke is shown. The propulsive peaks in her armstroke take place during the first upsweep and the second downsweep. There is no propulsive second upsweep. She simply stops pushing back against the water at the end of the second downsweep and she brings her arm up out of the water into the recovery.

There seem to be three propulsive patterns within the two-peak style. For some swimmers, the first upsweep is the most propulsive phase of the underwater armstroke. For others, it is the second downsweep. Still others accelerate forward almost equally during both sweeps.

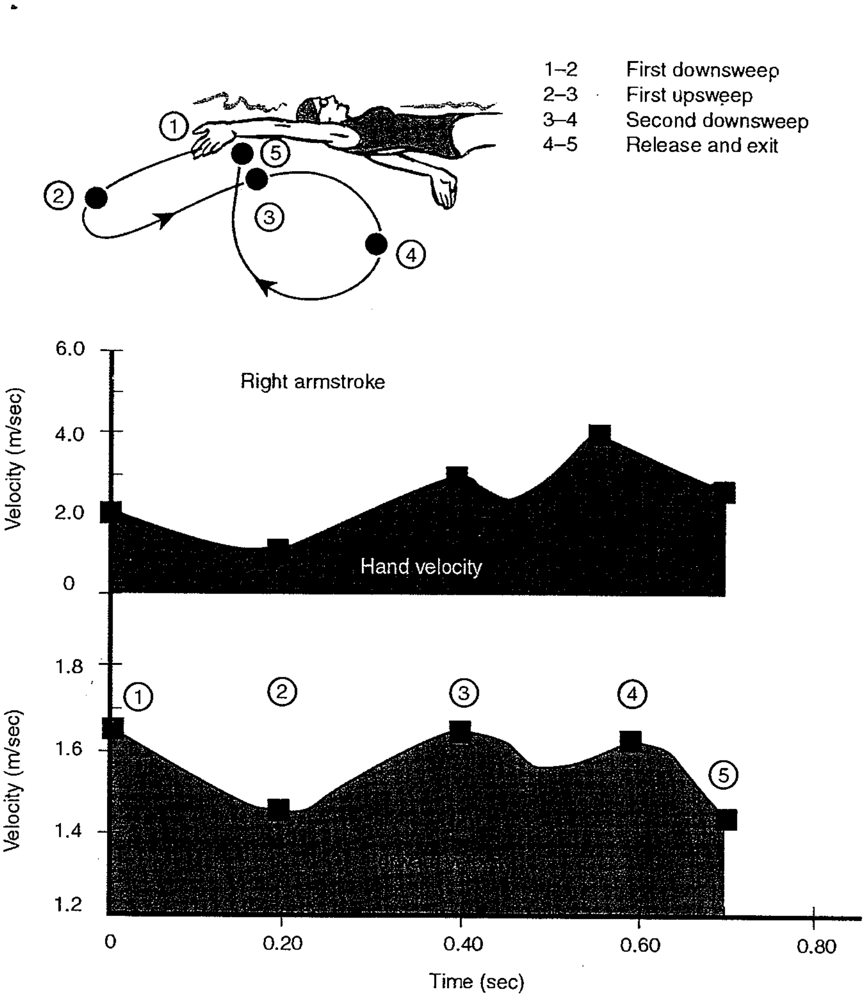


Figure 6.3 Forward velocity and hand velocity graphs for Theresa Andrews, a member of the 1984 U.S. Olympic swimming team. She uses a two-peak propulsive style.

Adapted from Luedtke 1986.

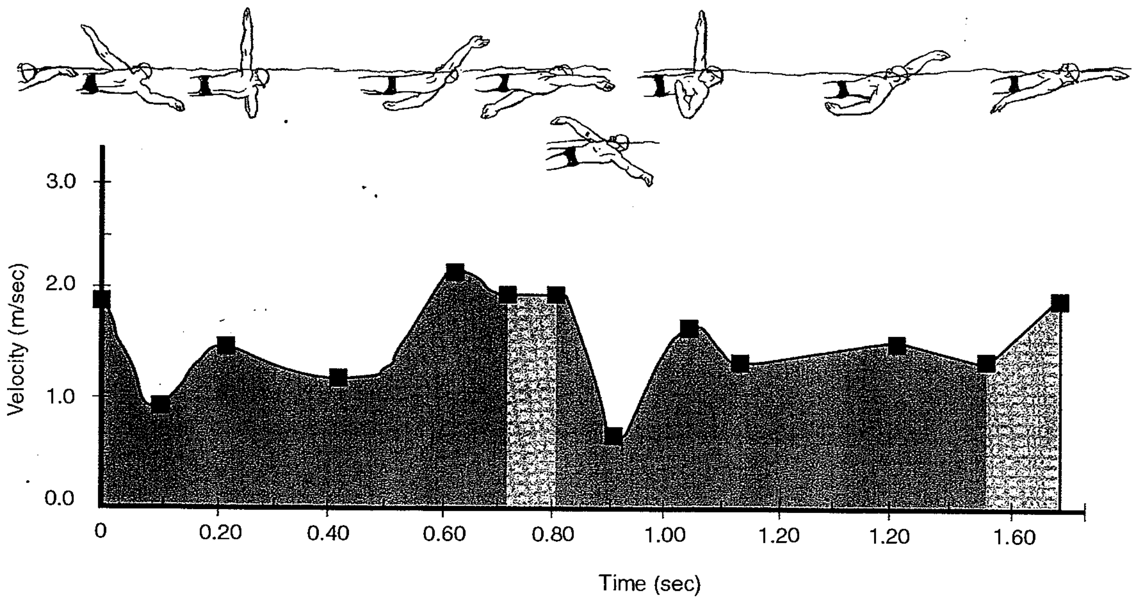


Figure 6.4 A forward velocity graph for backstroker Martin Lopez-Zubero, former world record holder in the 200 m backstroke.

Adapted from Cappaert 1993.

The forward velocity graph in figure 6.4 is that of Martin Lopez-Zubero, former world-record holder and Olympic gold medalist in the backstroke, swimming in 200 m backstroke heats at the 1992 Olympic Games. Lopez-Zubero has three propulsive peaks during each armstroke. The first occurs during the first upsweep, the second during the second downsweep, and then he generates a third propulsive peak during his second upsweep, designated by the lightly shaded area on the right. He maintains a reasonably high level of forward velocity during the second upsweep of his right armstroke and he actually achieves a peak in forward velocity during the second upsweep of his left armstroke.

The point I have tried to make by showing this graph is that the second upsweep can be used to accelerate the body forward. All swimmers would do well to use it for propulsion. I believe it is potentially the most effective way to swim this stroke. Observation of underwater videotape indicates that more and more world-class backstroke swimmers are using a three-peak propulsive armstroke. This is surprising because most were probably taught the two-peak style. The fact that many have adopted a three-peak style without, in many cases, being aware that they have done so lends support to the belief that this may be a superior way to swim the backstroke. In fairness, it must be said that many skilled backstroke swimmers still use a two-peak velocity pattern.

The graphs in figure 6.5 show what I believe to be ideal forward and hand velocity patterns for backstroke swimming. The graphs illustrate a three-peak propulsive style. These patterns are a composite of the best parts of the strokes of several world-class backstroke swimmers.

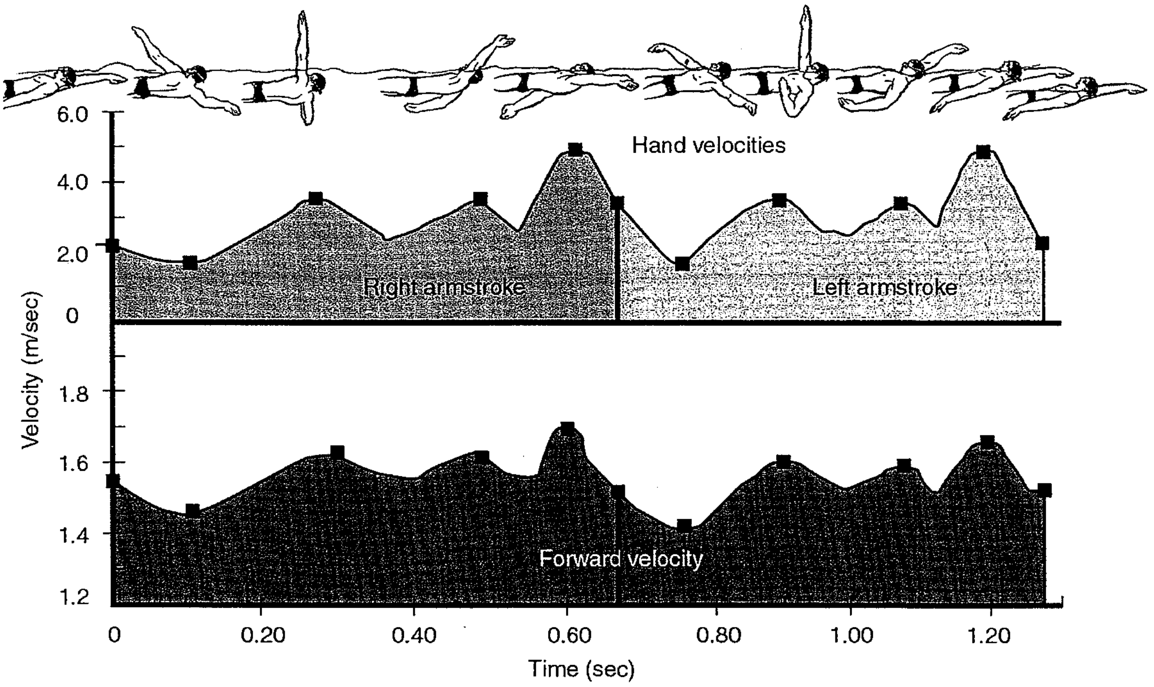


Figure 6.5 Ideal forward velocity and hand velocity patterns for the backstroke.

Forward Velocity Graph

In figure 6.5, the forward velocity graph for the center of mass begins at the zero point on the time axis, just after the right hand has entered the water and the swimmer has released pressure with the left hand. Notice that the forward speed decelerates 0.10 m/sec during the first downsweep of the right armstroke while the arm is moving down into position for the catch. Once the catch is made, forward speed accelerates and continues accelerating through the first upsweep. There is a slight loss of speed during the transition from the first upsweep to the second downsweep, followed by another acceleration of forward velocity during the second downsweep. The swimmer then decelerates for a short time during the transition from the second downsweep to the second upsweep, after which his forward velocity accelerates once again during the second upsweep. He stops pushing back against the water with his right hand at the end of the second upsweep and his forward speed decelerates while he brings it up out of the water.

In the meantime, his left arm has entered the water and is sliding forward, down, and out to the catch position. He makes the catch with his left arm shortly after his right leaves the water. After that, his accelerations and decelerations in forward speed follow the same pattern for the three propulsive sweeps of the left arm that were described for the right armstroke. Notice, however, that the velocity peaks tend to be somewhat lower and shorter and that the valleys are slightly deeper and longer for the left armstroke. These differences between the dominant (right) and nondominant (left) armstrokes are typical of most backstroke swimmers, just as they were of front-crawl swimmers. (Possible reasons for velocity differences between dominant and nondominant arms were discussed in chapter 3.)

Hand Velocity Graph

The top graph of figure 6.5 represents an ideal pattern of hand velocities for one stroke cycle (two armstrokes). As with other strokes, the peaks and valleys for hand velocities tend to mirror those for forward velocity.

The right hand enters the water traveling fairly fast, approximately 2 m/sec (7 ft/sec). After entry, the hand slows down until it is traveling at approximately the same speed as the body when the catch is made. This indicates that the swimmer's hand is simply being pushed forward by his body at this point. Once the catch is made, the hand accelerates and decelerates in a three-peak pattern, with each peak corresponding to one of the three propulsive sweeps in the underwater armstroke.

The right hand accelerates to approximately the same speed (nearly 4 m/sec) during the first upsweep and second downsweep. It accelerates even more during the second upsweep, however, reaching a velocity of nearly 5 m/sec during this phase. Hand speed decelerates when the swimmer releases the water and it continues to decelerate throughout the recovery until his right arm reaches the catch position for its next armstroke.

In the meantime, the swimmer's left hand has entered the water while his right hand was completing its second downsweep. After entering the water, he slides his left hand forward until the propulsive phase of his right armstroke has been completed. The velocity of his left hand continues to decelerate during this time. Once he stops pushing back against the water with his right arm, however, he sweeps his left hand down and out to the catch position. Once again, his hand continues to decelerate until it almost stops moving when the catch is made. After that, the velocity of his left hand accelerates and decelerates in a three-peak pattern that corresponds to the three propulsive sweeps of the armstroke.

One-Peak Velocity Pattern

Another velocity pattern that has been used by some world-class backstrokers is illustrated in figure 6.6. The swimmer is Tori Trees, another member of the 1984 U.S. Olympic swimming team. Her forward velocity is shown for her right underwater armstroke only. The velocity pattern begins when her right hand enters the water and ends when it leaves the water.

She has one major propulsive peak: during the last portion of the first upsweep and the first portion of the second downsweep. There is no second upsweep phase. She goes from the second downsweep immediately into the release and exit phase. Her hands do sweep up and down somewhat in the typical S pattern, but swimmers who

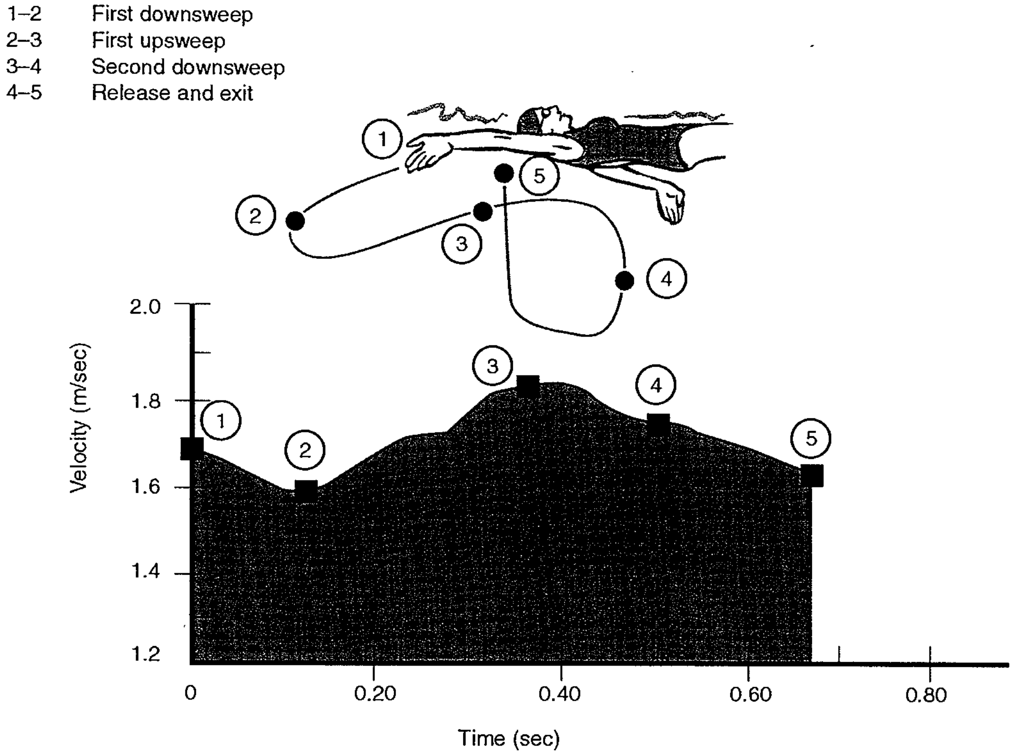


Figure 6.6 A one-peak velocity pattern for Tori Trees, member of the 1984 U.S. Olympic swimming team.

Adapted from Luedtke 1986.

use this style tend to minimize movements in these directions and they push the hand back to a much greater extent. Essentially, one-peak swimmers grab a handful of water at the catch and fling it back toward the feet.

Although many swimmers have reached world-class level with this pattern, I believe that it is vastly inferior to the three-peak and two-peak patterns described earlier. Swimmers using three-peak and two-peak velocity patterns can accelerate more water back over a greater distance, with less effort, by making major changes in hand direction two or three times during each underwater armstroke. Thus, they should be more efficient than swimmers who make these changes only once during each armstroke.

In the next section, I describe the armstroke for a three-peak propulsive style because I believe it is the superior method for swimming the backstroke. Following that, I will discuss the differences between this and the armstroke of swimmers who use a two-peak style.

Three-Peak Armstroke

For purposes of description, I have separated the back crawl armstroke into eight phases: (1) the entry and stretch, (2) the first downsweep, (3) the catch, (4) the first upsweep, (5) the second downsweep, (6) the second upsweep, (7) the release and exit, and (8) the recovery. The underwater sequence photos in figure 6.7 show the armstroke from a front view. The armstroke is also shown from a side view in figure 6.8 to provide an additional perspective. The swimmer in figure 6.7 and 6.8 (pages 190–192) is using a three-peak propulsive style.

Entry and Stretch

This portion of the underwater armstroke is shown for the left arm in figure 6.7, a and b, and for his right arm in figure 6.7, f through i. The arm should enter the water when the stroking arm is completing its second downsweep. The entry should be made with the arm in a fully extended position and directly forward of the shoulder. The palm should be facing out so that the hand can slip into the water on edge.

There is great potential for creating excessive pushing drag during the arm entry. This should be avoided. Because the arm is recovered over the water in an extended position, the upper arm will enter the water first, followed by the forearm and, finally, the hand. All will be pushing forward against the water as they enter. Therefore, the entry should be made as gently as possible with no effort to push the arm forward faster than it is already moving.

After entering, the arm should be streamlined by stretching it forward while completing the second upsweep with the other arm. This stretch will be very short compared to the stretch used in the front crawl stroke. The arm will be forward for only a short distance before starting the downsweep.

The hand will enter the water traveling fairly fast, but its velocity should decrease until it is simply being pushed forward by the body during the stretch. This stretch is very short, lasting no more than a few hundredths of a second. Once the propulsive phase of the other armstroke has been completed, swimmers should begin the first downsweep with the arm that has entered the water as soon as the propulsive phase of the underwater armstroke has ended.

First Downsweep

The first downsweep is pictured for the left arm in figure 6.7c and for the right arm in figure 6.7j. The first downsweep should begin immediately when swimmers stop pushing back against the water with the other arm and it should continue until the arm reaches the catch position. They should sweep the arm forward, down, and out until it is facing back against the water. They should flex the elbow while doing so to get the arm facing backward at the earliest possible time. The palm, which should have been facing out when the hand entered the water, should now be rotated down slowly until it is pitched down and back when the catch is made. The arm should also flex gradually at the elbow during the first downsweep to achieve a backward orientation with the arm at an earlier point in this sweep.

The first downsweep is not propulsive. Its primary purpose is to place the arm in position to apply propulsive force. It may also play a role in supporting the head and shoulders while the opposite arm is recovering over the water. Neither of these purposes requires any great expenditure of effort, however. Consequently, the first downsweep should feel like a gentle motion of stretching the arm forward, down, and out until it reaches the catch position. The velocity of the arm will increase slightly when the downsweep begins, but it will slow at the catch until the hand is merely being pushed forward by the body once again.

It was very popular to use a deep downsweep in the 1970s and 1980s. This method is no longer as popular, however. Most swimmers now sweep the arm downward only a moderate amount, between 50 and 60 cm (20 to 24 in). At the same time, they slide the arm out 65 to 75 cm (25 to 30 in) to make an earlier and more effective catch and first upsweep.

Catch

The catch takes place when the arm has traveled down and out to a position where both it and the hand are facing back against the water. The hand is generally 45 to 60 cm deep (1.5 to 2 ft) and approximately 60 cm (2 ft) wide of the shoulder at the catch (Schleihauf et al. 1988). The arm will be flexed nearly 90° when the catch is made and the hand should also be aligned with the forearm, with no flexion or extension at the wrist. A common teaching technique is to associate the position of the arm to the hours on a clock. In this case, swimmers should make the catch when the left arm is at approximately 2 o'clock and when the right arm is at approximately 10 o'clock.

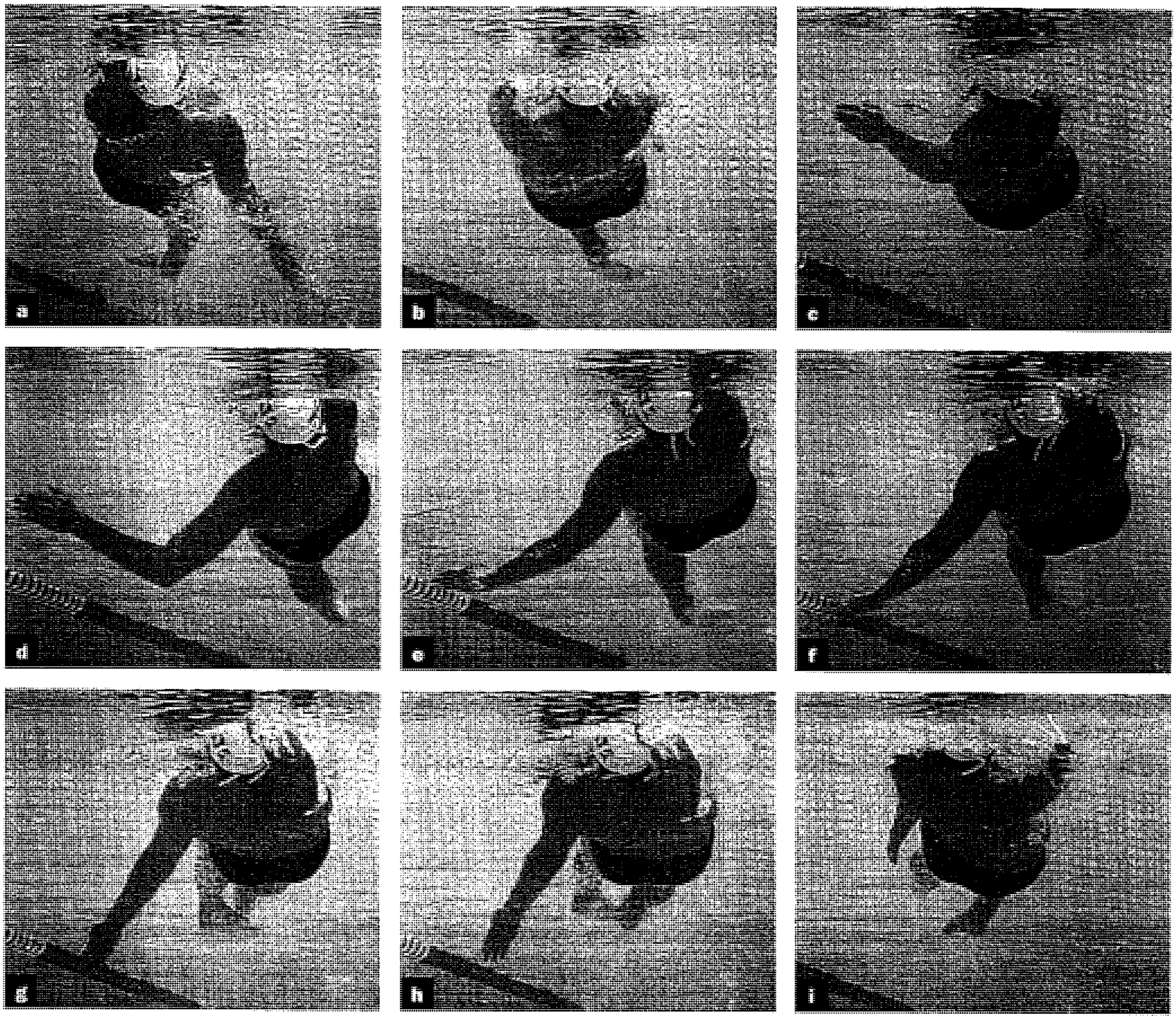


Figure 6.7 A front view of the backstroke from underwater. The swimmer is Pablo Abal, NCAA all-American from Arizona State University and a member of the 2000 Argentina Olympic swimming team.

(*a*) Entry of left arm. Second upsweep with right arm.
(*b*) Exit of right arm. Forward stretch with left arm.
(*c*) First downsweep with left arm. Recovery with right arm.
(*d*) First upsweep with left arm. Continuation of recovery with right arm.
(*e*) Second downsweep with left arm. Continuation of recovery with right arm.
(*f*) Transition from second downsweep to second upsweep with left arm. Entry of right arm.
(*g*) Beginning of second upsweep with left arm. Stretch with right arm.
(*h*) Continuation of second upsweep with left arm. Stretch with right arm.
(*i*) Exit of left arm. Forward stretch with right arm.

First Upsweep

This phase of the armstroke is shown for the left arm in figure 6.7d and for the right arm in figure 6.7k. The first upsweep is the first propulsive sweep of the back crawl armstroke. It is a semicircular movement of the entire arm that begins at the catch and ends when the arm is near the surface and opposite the shoulder. The first upsweep is

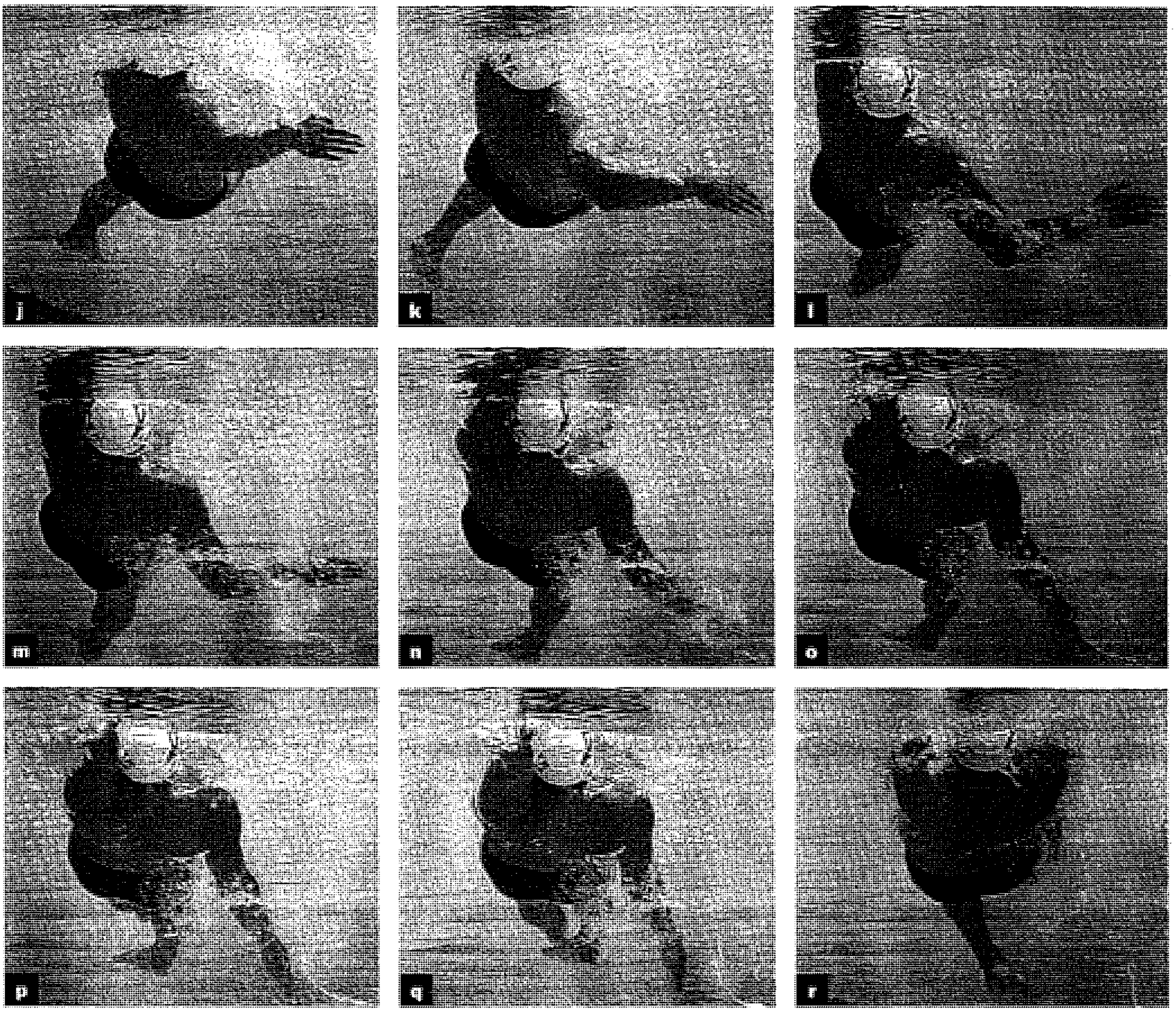


Figure 6.7 *(continued)*

(j) Downsweep with right arm. Recovery with left arm.
(k) First upsweep with right arm. Continuation of recovery with left arm.
(l) Transition from first upsweep to second downsweep with right arm. Continuation of recovery with left arm.
(m) Second downsweep with right arm. Continuation of recovery with left arm.
(n) End of second downsweep with right arm. Continuation of recovery with left arm.
(o) Transition from second downsweep to second upsweep with right arm. Entry of left arm.
(p) Second upsweep with right arm. Forward stretch with left arm.
(q) Release with right arm. Continuation of stretch with left arm.
(r) Exit of right arm. Continuation of stretch with left arm.

another example of shoulder adduction similar to the insweeps of the front crawl and butterfly strokes. If you can picture a backstroke swimmer in a prone position, you will see that the first upsweep of the back crawl is very similar to the insweep of the front crawl in the way that propulsive force is generated.

The first upsweep is executed by adducting the entire arm back, in, and up, toward the side. The forward movement of the arm ceases at the catch and swimmers should

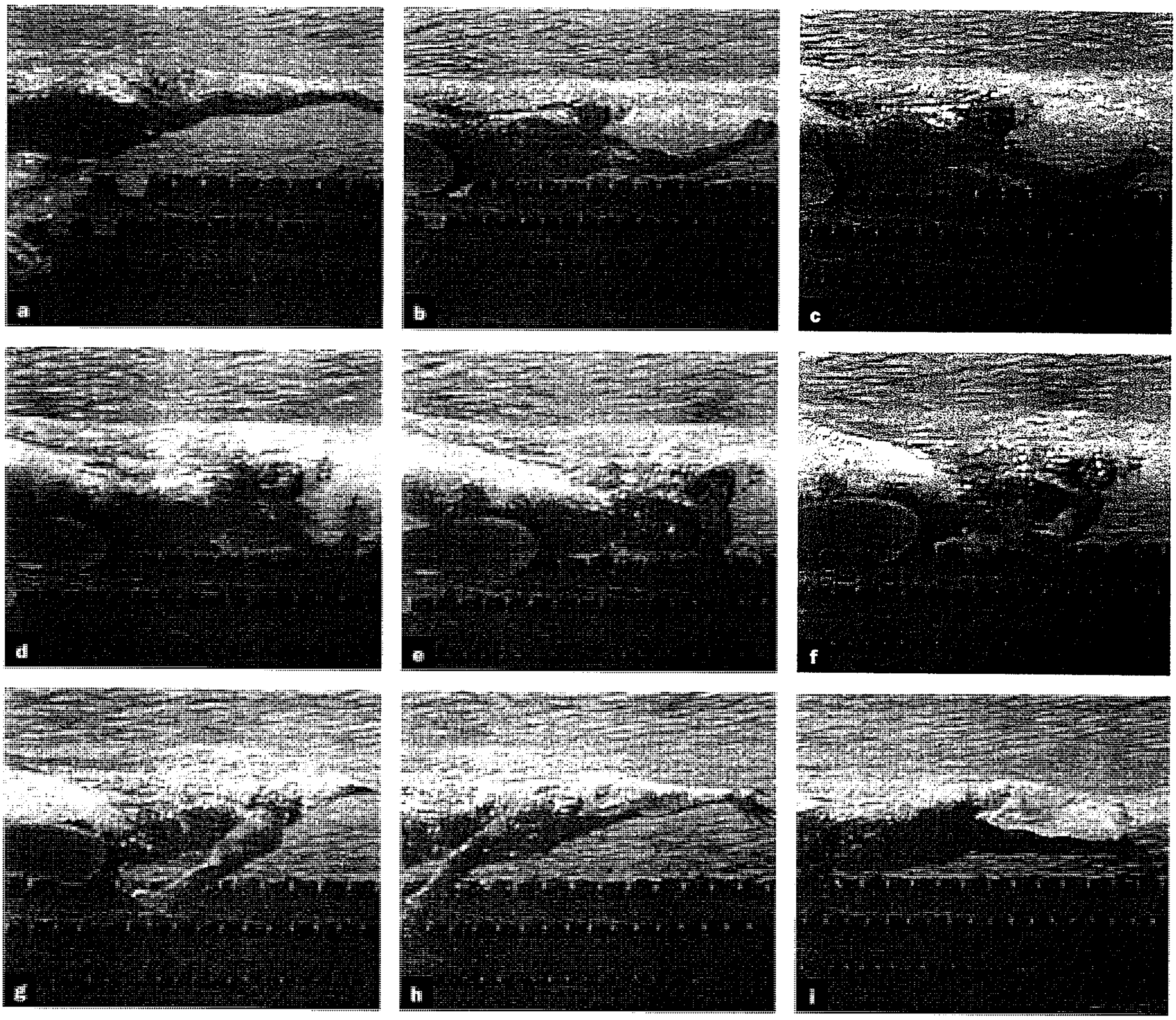


Figure 6.8 A side underwater view of Pablo Abal swimming the backstroke

(a) Entry of left arm. Completion of second upsweep with right arm.
(b) First downsweep with left arm. Release and exit with right arm.
(c) Catch with left arm. Recovery with right arm.
(d) Continuation of first upsweep with left arm. Continuation of recovery with right arm.
(e) Transition to second downsweep with left arm. Continuation of recovery with right arm.
(f) Second downsweep with left arm. Continuation of recovery with right arm.
(g) Finish of second downsweep with left arm. Entry of right arm.
(h) Release with left arm. Stretch with right arm.
(i) Exit of left arm. First downsweep with right arm.

begin pushing back and up against the water with the underside of the upper arm and forearm and the palm of the hand. The arm should be flexed at the elbow approximately 90° when the first upsweep begins and the degree of flexion should not change appreciably throughout the sweep. During the first half of this stroke phase, the arm should continue moving down and out in the directions established during the first downsweep. That changes quickly, however, as the arm begins to circle up and in. The second upsweep ends when the arm is near the surface and when it is passing the shoulder (and the shoulder is passing the arm).

The palm of the hand, which was pitched downward at the start of the first upsweep, will be pitched up and in at its completion. This is not because the swimmer has rotated the palm up but simply because the direction the arm was moving changed from down to up during this phase of the armstroke.

The upper arm, forearm, and palm of the hand should push back against the water like one welded unit throughout the first upsweep. Once the catch is made, the hand should remain in alignment with the arm with no flexion or extension at the wrist joint. The major difference between the first upsweep of the backstroke and the insweep of the front crawl stroke is that backstrokers do not adduct the arm in to their sides. The transition to the next propulsive phase, the second downsweep, begins just as the arm passes the shoulder and before it has traveled inward to any great extent. The transition from first upsweep to second downsweep is shown for the right armstroke in figure 6.7l.

The arm will be almost motionless at the catch and will accelerate moderately throughout the first upsweep, reaching a velocity between 3 and 4 m/sec near the end of the sweep. Figure 6.9 illustrates how propulsive force is probably generated by the arm during the first upsweep.

Some swimmers sweep the hand up a long distance and others use a short upward motion during the first upsweep. The choice probably depends on the depth of the arm when the catch was made and how effective swimmers are at propelling themselves forward during this phase of the armstroke. If the first upsweep is an effective propulsive phase, swimmers will tend to enlarge the semicircular motion to extend its propulsive potential over a longer distance and time. By the same token, if the first upsweep is not very effective, they will cut it short and move on to the second downsweep.

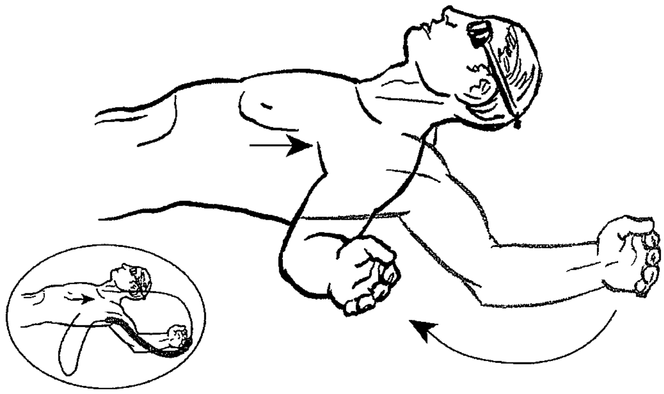


Figure 6.9 Propulsion during the first upsweep of the back crawl armstroke.

Second Downsweep

The second downsweep is pictured for the left armstroke in figure 6.7e, and for the right armstroke in figure 6.7, m and n (see pages 190–191). The second downsweep should be a back, down, and somewhat outward extension of the arm that begins during the transition from the previous sweep and continues until the arm is completely extended and well below the body.

Swimmers should push back against the water in an almost horizontal direction during the top portion of the second downsweep, from the time the hand is just passing the shoulder until it is opposite the waist. Swimmers will be pushing back against the water with the underside of the forearm and the palm of the hand during this time, with very little extension of the arm. The arm should be directed back and down during the second portion of this stroke phase, extending it vigorously at the elbow. The second downsweep should end when the arm is completely extended, well below the body. The illustration in figure 6.10 shows how propulsion is probably generated during the second downsweep.

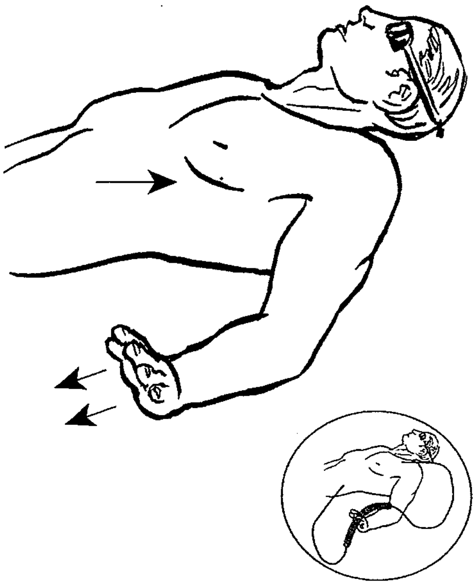


Figure 6.10 Propulsion during the second downsweep of the back crawl armstroke.

Some swimmers also sweep the arm in toward the thigh during this phase of the stroke. I believe, however, that it is better for them to sweep the arm not only back and down but also somewhat out during the second downsweep. Sweeping out will allow swimmers to keep the forearm facing back somewhat longer during the top portion of the sweep.

The fingertips should remain facing out throughout the second downsweep. Swimmers should not turn the fingers up during this phase. While this was a popular teaching technique in the 1970s, underwater films now show that the majority of today's world-class backstrokers keep the fingers facing to the side during the second downsweep. This enables them to keep the palm facing back for a longer time during the sweep and it also makes the transition to the next propulsive phase, the second upsweep, easier. The hand, which was pitched up and in at the end of the previous upsweep, will be facing down, toward the bottom of the pool, when the second downsweep is completed. It should be kept facing back as long as possible, however.

Second Upsweep

The transition from the second downsweep to the second upsweep is shown in figure 6.7f for the left arm and in figure 6.7o for the right arm (see pages 190–191). The second upsweep is shown for the left arm in figure 6.7, g and h, and for the right arm in figure 6.7p.

The second upsweep is an up, back, and inward sweep of the arm. It begins at the end of the second downsweep and continues until the arm approaches the thigh on its way to the surface. Swimmers quickly turn the palm up and push back against the water with it and the underside of the forearm. This continues for a short distance until the arm travels up near the rear of the leg, at which time it stops pushing back against the water and begins recovering up and out of the water. The arm should remain extended throughout the second upsweep.

The hand will decelerate during the transition from the second downsweep to the second upsweep and then it should accelerate rapidly until the sweep has been completed. Hand velocities may approach their highest values for the entire armstroke, between 5 and 6 m/sec, during this stroke phase.

The drawing in figure 6.11 illustrates how propulsion can be generated during the second upsweep. As shown, swimmers use the hand and forearm to push back against the water as they sweep the arm up and in. Backstrokers who can hyperextend the arm at the elbow have an obvious advantage during this phase of the armstroke because they will be able to push back with the forearm for a slightly longer distance. Indeed, many of the great backstrokers in swimming history have possessed this ability.

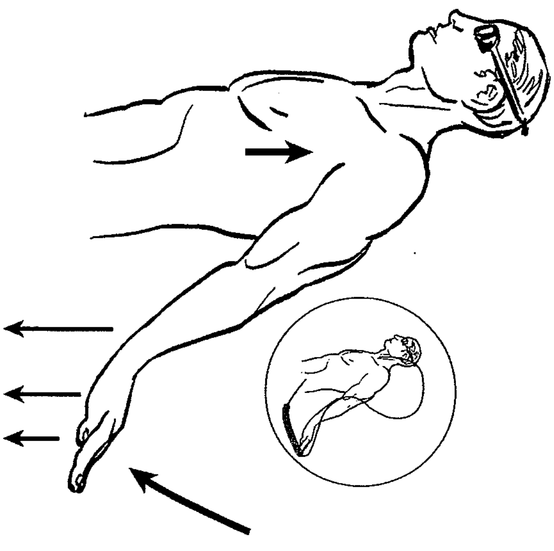


Figure 6.11 Propulsion during the second upsweep of the back crawl armstroke.

The second upsweep should not continue until the arm reaches the surface of the water. It is a very short but also a very effective propulsive movement. As shown in the graph of Lopez-Zubero in figure 6.4 (see page 185), forward velocity is quite high during this phase. It is short lived, however, because the arm can only push back against the water for a short time during its upward path, before the backward force it produces dissipates and is replaced by upward force. The transition from pushing water back to pushing it up will take place as the hand approaches the rear of the thigh. Therefore, swimmers must stop pushing against the water at the time they recover the arm up and out of the water.

Swimmers who use the second upsweep for propulsion will be more effective if they use a wide stroke. They need to finish the second downsweep with the arm deep and well to the side of the body because they must sweep the arm in as well as up to generate propulsive force during the second upsweep.

Release and Exit

The exit of the left arm is shown in figure 6.7i and the exit of the right arm is pictured in figure 6.7r (see pages 190–191). The release takes place as the hand approaches the rear of the thigh. Swimmers should stop pushing back against the water as the arm approaches the thigh. They should turn the palm inward so that the hand travels through the water on edge with a minimum of resistive drag. Although the arm should continue moving upward, its backward inertia must be overcome so that it can also travel forward. This is accomplished by rolling the body toward the stroking arm and shrugging the shoulder of the recovering arm up and forward. The hand should leave the water thumb first—not little finger first, as some experts have suggested. Hand speed should decelerate markedly once the release is made, allowing the upward momentum from the second upsweep to carry the arm out of the water and into the recovery with a minimum of muscular effort.

The above-water sequence in figure 6.12 shows the out-of-water portion of the arm recoveries from a side view. After reaching the surface, the arm should travel up and over the water until the entry is made. The recovery should be made high and overhead, not low and to the side. A high, overhead recovery reduces any tendency for the arm to pull the hips and legs out of lateral alignment.

The hand should leave the water thumb first. The palm should face in or down during the first half of the recovery. It should be rotated out during the second half, however, so that entry can be made little finger first. This change in direction of the palm from in to out should take place quickly as the arm passes over the head at the peak of the arm recovery. Arm recovery should be made quickly but gently. The hand and arm should be relaxed as much as possible so that the muscles receive some rest between underwater armstrokes.

The upper arm and forearm will hit the water long before the hand enters, as shown in figure 6.12, g and h, which necessitates pushing water forward with the arm as it enters the water. There is nothing backstroke swimmers can do to prevent this. They can, however, reduce pushing drag in two ways. The first is by entering the arm softly with a minimum of backward force. The second is by carrying the shoulder high during the recovery and maintaining it in a high position until the arm passes overhead. Keeping the shoulder high will permit swimmers to keep the arm free of the water for as long as possible during the recovery. Rolling the body toward the opposite side facilitates maintaining the shoulder high out of the water during the recovery. Swimmers who do not roll to the side at least 45° will find that the upper arm will be pushing back through the water before it is midway through the recovery. Consequently, body roll is a very important aspect of good backstroke swimming.

Timing of the Arms

The arms should stroke in an alternating windmill fashion. The precise relationship of one arm to the other is very important in maintaining good lateral and horizontal alignment when swimming the backstroke. The recovering arm should enter the water when the stroking arm is completing its second downsweep. For better streamlining, the entering arm should be stretched forward while the rear arm is executing its second upsweep. The first half of the recovery of one arm should take place while the stroking arm is completing its first downsweep and first upsweep. In this way, swimmers can remain rolled toward the stroking arm and the recovering arm can remain free of the water. Swimmers should begin to rotate back toward the other side as the recovering

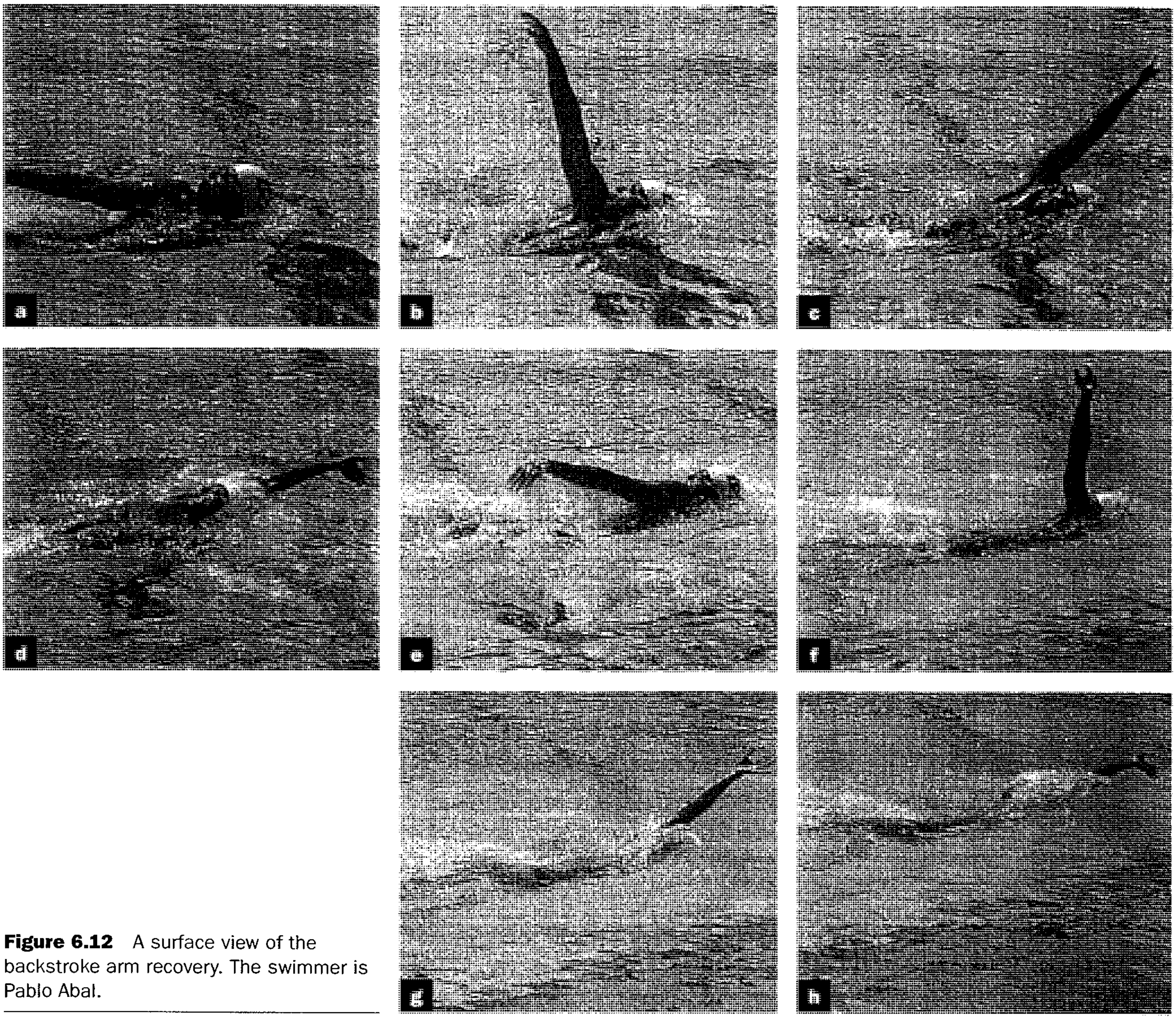


Figure 6.12 A surface view of the backstroke arm recovery. The swimmer is Pablo Abal.

(a) Swimmer's recovering arm (the right arm) leaves the water. Stroking arm is making downsweep. The body is rotated toward stroking arm.

(b) Recovering arm passes overhead. Stroking arm is executing the first upsweep.

(c) Recovering arm starts down for entry with palm turned out. Stroking arm is executing the second downsweep. The body should start rotating toward the entering arm.

(d) Recovering arm nears entry position. Stroking arm is completing the second downsweep. The body should be rotating toward the entering arm.

(e) The other arm (the left arm) leaves the water to begin its recovery. Stroking arm is executing its downsweep. The body is rotated toward the stroking arm.

(f) Recovering arm passes overhead with palm turning out. Stroking arm is executing the first upsweep.

(g) Recovering arm starts down for entry. Stroking arm is executing the second downsweep. Swimmer should be rotating his body toward the recovering arm.

(h) Recovering arm nears the entry position. Stroking arm is completing the second downsweep. Swimmer should be rotating toward the recovering arm.

arm passes overhead. This change of direction should be made quickly and be coordinated with the second downsweep of the stroking arm.

Two-Peak vs. Three-Peak Armstroke

The armstroke just described has three propulsive peaks. The traditional backstroke has two propulsive peaks, one during the first upsweep and the other during the second downsweep. Swimmers who use this style simply stop pushing back against the water and begin the recovery after they complete the second downsweep. World-class swimmers are presently using both styles, thus one cannot be recommended over the other based on performance. I believe the three-peak style has the potential to be more effective than the two-peak style. In the final analysis, however, the best style for a particular swimmer will be the one that produces the fastest race times.

Stroke patterns for the two-peak and three-peak styles are contrasted in figure 6.13. Both patterns are drawn from front views to emphasize the differences in the amounts of lateral and vertical arm movement in both styles.

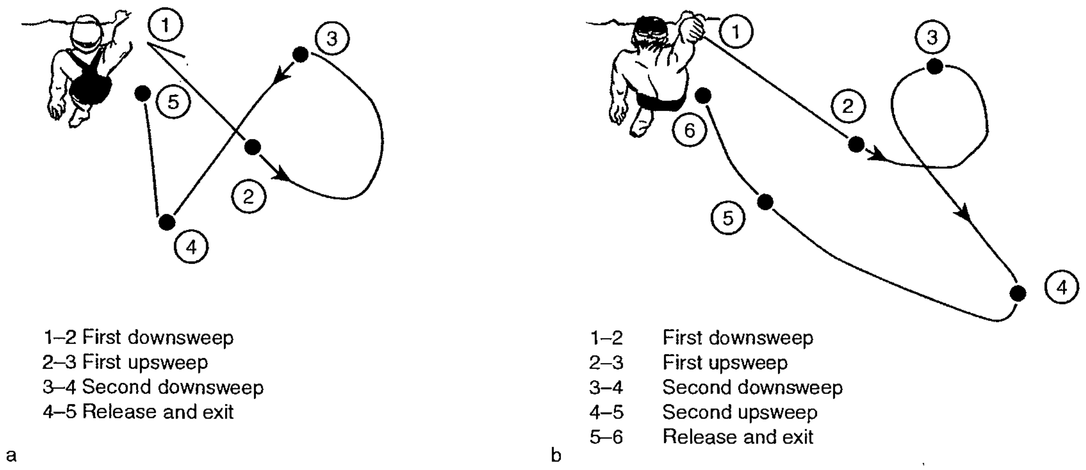


Figure 6.13 Front view stroke patterns for *(a)* two-peak and *(b)* three-peak backstroke swimmers.

Notice in the two-peak pattern, that the hand travels down a greater distance during the first downsweep, it travels up and in over a longer distance during the first upsweep, and it travels down and in during the second downsweep. Notice also that the hand travels almost directly upward as it leaves the water and that it does not travel upward for a very great distance. Conversely, the stroke pattern for the three-peak swimmer shows a shorter and somewhat wider first downsweep, a first upsweep that is also shorter, and a second downsweep that is directed downward over a longer distance and wider to the side. These arm movements are followed by a second upsweep that is directed back as well as up and in before the arm recovery begins.

There are two potential advantages to the two-peak style. Two-peak backstroke swimmers should have longer and more-propulsive upsweeps and, by finishing the second downsweep with the arm close to the body, they will only have to bring it up a short distance before it leaves the water.

Compared to the three-peak method, the two-peak style has the following disadvantages. By directing the arm in during the second downsweep, two-peak backstrokers will be pushing in as well as back during this phase of the stroke, which may decrease the propulsion they receive from it.

The second disadvantage of the two-peak style is that swimmers will not generate a third peak of forward velocity as they bring the hand toward the surface. This may reduce their average velocity per armstroke. The addition of a third propulsive peak increases the likelihood of applying propulsive force over a greater length of time during the underwater armstrokes. Of course, that depends on the size of those propulsive peaks. It is also possible for two-peak swimmers to have a longer application of propulsive force, however. Their longer first upsweeps and second downsweeps should generate more propulsive force than the corresponding sweeps of three-peak swimmers. Nevertheless, it seems reasonable to assume that swimmers might attain a faster average velocity per armstroke with three smaller peaks than with two larger peaks.

Perhaps the most significant advantage of the three-peak style is that it permits a faster turnover rate in races. Prior to the mid-1980s, most backstroke swimmers used a two-peak style and their stroke rates were in the range of 35 to 38 cycles/min in 200 races and between 44 to 48 cycles/min in 100 races (Craig et al. 1985). My own observations have revealed that many of the great backstroke swimmers in the 1990s were using stroke rates of 45 to 48 cycles/min in 200 events and 48 to 53 cycles/min during 100 swims (Maglischo 1998). Further, underwater videos of these swimmers during competition indicated they were using three-peak armstrokes.

A final advantage of the three-peak style may be that it encourages less fluctuation between the minimum and maximum forward velocities swimmers reach during each armstroke. This is principally because the period of deceleration between the end of one underwater armstroke and the beginning of the next can be reduced if a propulsive second upsweep is used. It generally takes approximately 0.10 sec for two-peak backstrokers to begin accelerating the body forward with one arm after the other has finished its propulsive phase. If they combine the stretch and the beginning of the downsweep of the entering arm with a propulsive second upsweep from the stroking arm, however, they can reduce that period of deceleration to approximately 0.05 sec. Consequently, they should decelerate less during this period and that, in turn, should contribute to a faster average velocity per armstroke.

Flutter Kick

The flutter kick in the back crawl is very similar to the kick used in the front crawl. It consists of alternating diagonal up and downsweeps of the legs. These are termed, for obvious reasons, the *upbeat* and *downbeat.* The major difference is that the upbeat rather than the downbeat is the propulsive phase of the backstroke flutter kick because swimmers are in a supine position. The sequence of photographs in figure 6.14 illustrates the underwater mechanics of the backstroke flutter kick.

Upbeat

The upbeat of the left leg is shown in figure 6.14, a through c. The upbeat of his right leg is pictured in figure 6.14, c through f.

The upbeat is the propulsive phase of the backstroke flutter kick. It is a whip-like extension of the leg that begins with slight flexion at the hip, followed by extension at the knee and ending with partial flexion of the foot (the toes kick upward through the surface).

As with the flutter kick of the front crawl, the beginning of the upbeat actually appears to be part of the preceding downbeat. Swimmers gently flex the leg at the knee as the foot passes below the body and then presses the thigh slightly upward to initiate the upbeat. At that time, the pressure of the water above the leg pushes the lower leg downward further into a flexed position while the thigh is actually moving upward. This gives the impression that the downbeat is still underway, but in actuality, it has ended and the upbeat has begun. The water pressing down on the top of the relaxed foot pushes it down and in so that it is plantar flexed and inverted (pointed with toes in) in a good position to apply backward force against the water when the leg is extended. This foot position can be seen best in figure 6.14e.

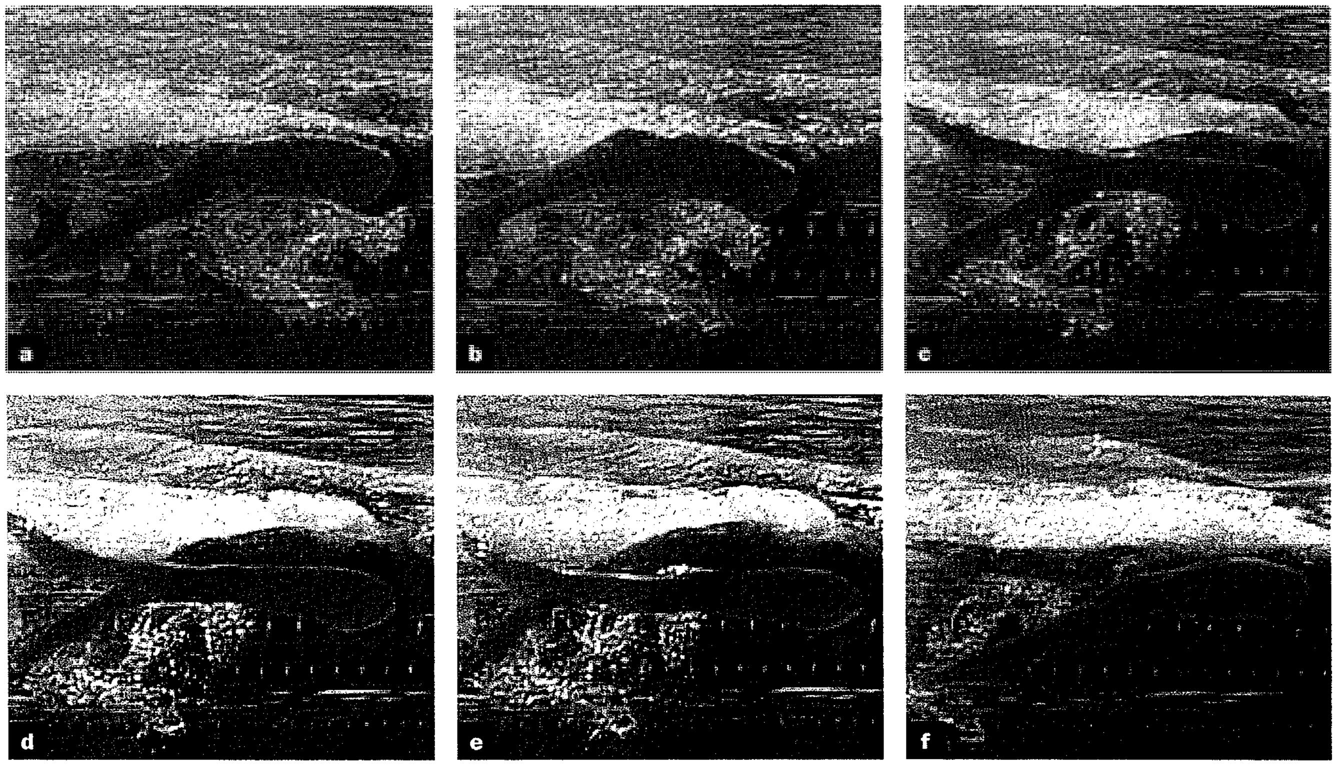


Figure 6.14 The flutter kick in the backstroke.

(*a*) End of upbeat with right leg. Start of upbeat with left leg.
(*b*) Hip flexion phase of upbeat with left leg. Downbeat with right leg.
(*c*) End of upbeat with left leg. Start of upbeat with right leg.
(*d*) Hip flexion phase of upbeat with right leg. Downbeat with left leg.
(*e*) Leg extension phase of upbeat with right leg. Continuation of downbeat with left leg.
(*f*) End of upbeat with right leg. Start of upbeat with left leg.

The thigh continues moving upward for a short distance until it passes above the hips, after which swimmers extend the leg rapidly, sweeping it diagonally up toward the surface, until it is completely extended and just below the surface of the water. The velocity of the lower leg should accelerate rapidly during the upbeat. The upbeat is completed by flexing the foot at the very end to add a small amount of additional propulsion. When the upbeat is performed correctly, the toes will come to the surface or actually break through the surface of the water as it is completed.

Backstroke swimmers will flex the legs more during the upbeat than in the corresponding downbeat of the front crawl stroke (approximately 10° more). This is because they are in a supine position where the lower leg can be flexed more without increasing drag.

The upbeat is probably most propulsive in the early stages of knee extension when the lower leg is traveling up and back and when the front of the lower leg and the instep of the foot are in position to push back against the water. The foot is probably the only propulsive part of the leg during the later stages of the upbeat because the lower leg will be pushing up against the water. Swimmers with good ankle extension ability have a distinct advantage because they keep the insteps of the feet pushing back against the water longer during the upbeat.

Downbeat

The downbeat is a rebound-like action of the leg that begins when the previous upbeat is nearing completion. The upward force of the extending lower leg starts the thigh of the same leg moving diagonally downward while the lower leg and foot are still traveling toward the surface. In this way, the upward inertia of the leg can be overcome smoothly and the downbeat can be initiated. The downbeat of the right leg can be seen in figure 6.14, a and b, while the downbeat of the left leg is shown in figure 6.14, c through f.

Once the previous upbeat is completed, a small amount of hip extension keeps the leg moving downward as the downbeat continues. The leg travels down until it passes below the body line, at which time swimmers flex the leg slightly and the next upbeat begins.

The leg should be maintained in an extended position and the foot in a natural position between extension and flexion throughout most of the downbeat. The pressure of the water pushing up from underneath the leg and foot will keep them in these positions if the leg is properly relaxed. The leg should be brought down gently, with just enough speed to reach the point where the upbeat can begin just as the other leg has completed its upsweep and is starting down.

Because the leg travels down and forward during the downbeat, this phase of the backstroke flutter kick is probably not propulsive. Its purpose is simply to place the leg in position for another upbeat.

Propulsion From the Flutter Kick

Backstroke competitions do not exceed 200 m. Thus, the legs can be used considerably more for propulsion than they are used in longer freestyle races without causing early fatigue. For this reason, backstroke swimmers almost universally use a vigorous six-beat kicking rhythm. This does not mean, however, that backstrokers should kick as hard as possible in their races. They should soften the effort of their kicks somewhat in the early portions of their races to save energy for the final sprint. This is particularly true for distances of 200 yd and 200 m.

Stablizing Role of the Flutter Kick

In addition to their propulsive contribution, the legs also play an important role in maintaining lateral and horizontal body alignment in backstroke swimming. Arm recoveries and the diagonal components of the underwater arm sweeps can disrupt these alignments. For this reason, the up- and downbeats of the backstroke flutter kick should be made not only in vertical directions but also in the direction that the body is rotating. In this way, the diagonal sweeps of the legs can facilitate body roll and cancel the tendency for arm movements to push the body up, down, and to the side.

Timing of the Arms and Legs

Backstrokers, almost without exception, use a six-beat kicking rhythm in their races. That is, they execute six kicks (six upbeats and six downbeats) with the legs during each stroke cycle. Three of these kicks are matched to each underwater armstroke in much the same way they were matched in the front crawl.

The legs move up and down as well as laterally during the backstroke flutter kick. But the extent of their diagonal motion is even greater in the backstroke than in the front crawl. In general, the legs tend to move in the direction the body is rotating during the upbeats and opposite that direction during the downbeats.

The six-beat timing of the arms and legs can be viewed in the sequence of photographs in figure 6.15. Beginning with the entry of the left arm, the left leg kicks up and out (and the right leg kicks down and out) during the first downsweep of the left arm, as illustrated in figure 6.15a. The left leg completes its upbeat as the left arm makes its catch (figure 6.15b).

The right leg completes its upbeat during the first upsweep of the left armstroke (figure 6.15c). The right leg begins kicking up and in during the first upsweep of the

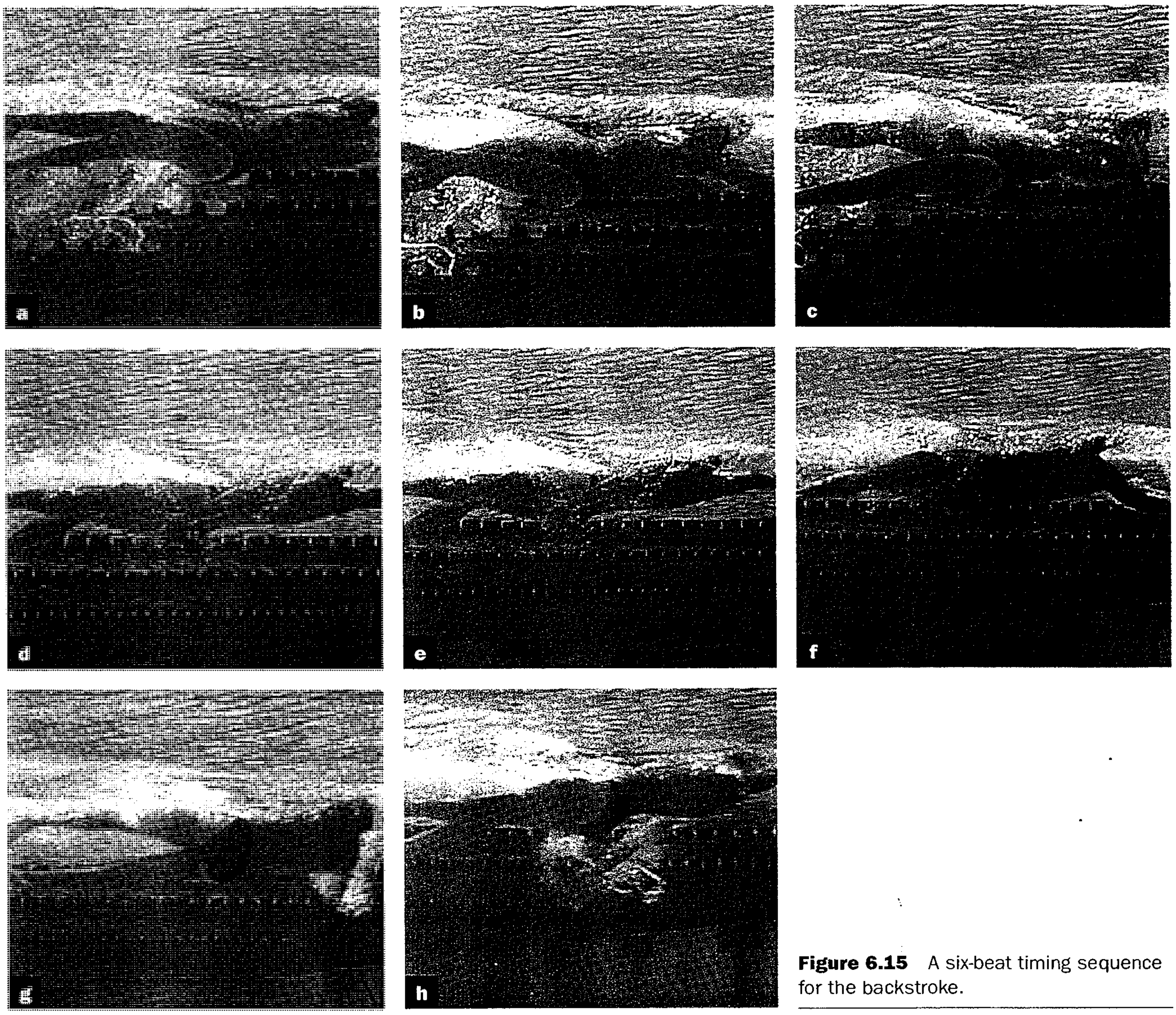


Figure 6.15 A six-beat timing sequence for the backstroke.

(a) Start of upbeat with left leg. First downsweep with left arm.
(b) Completion of upbeat with left leg. Catch with left arm.
(c) Upbeat with right leg. First upsweep with left arm.
(d) Upbeat with left leg. Second downsweep and second upsweep with left arm.
(e) Upbeat with right leg. Downsweep with right arm. Release with left arm.
(f) Completion of upbeat with right leg. Catch with right arm.
(g) Upbeat with left leg. First upsweep with right arm.
(h) Upbeat with right leg. Second downsweep and second upsweep with right arm.

left arm but finishes traveling, almost directly up near the end of this sweep as the body starts rolling toward the other side. At the same time, the left leg starts kicking down and in but finishes kicking straight down.

The left leg completes another upbeat during the second downsweep and the second upsweep of the left arm (figure 6.15d). The left leg kicks almost straight upward (and the right leg kicks downward) during the second downsweep of the left arm. Swimmers who use a three-peak style will make this kick during the final two sweeps of that armstroke. Two-peak swimmers will match the upbeat of the left leg to the second downsweep of the left arm. The timing is similar for the right armstroke.

The similarity between the timing of this stroke and the six-beat timing of the front crawl lends additional support to the theory that six-beat timing may be the most efficient method for both strokes, at least for distances of 200 m and less.

Body Position, Body Rotation, and Breathing

Backstrokers can reduce resistive drag by keeping the body nearly horizontal at the surface of the water. The body should not be perfectly horizontal, however, because a slight lowering of the hips is essential for effective kicking. They must also rotate the body from side to side in time with the up and down movements of the arm to keep the hips and legs from swinging out to the side. Because of their supine position in the water, backstrokers can inhale and exhale at will. Consequently, the mechanics of breathing are easier to master in this stroke than any other.

Body Position

The body position of backstroke swimmers has both horizontal and lateral components. Each of these is discussed in the following sections.

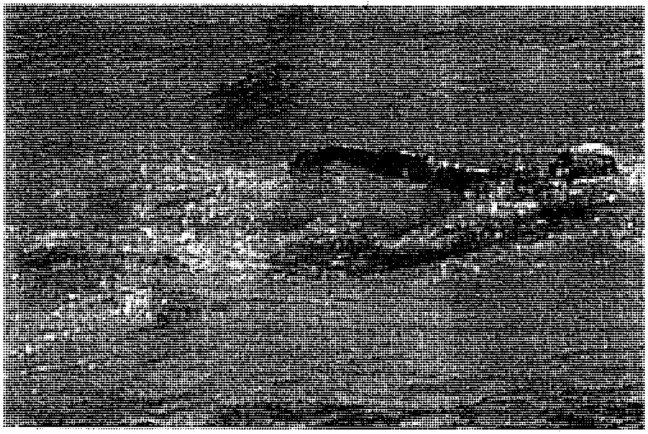


Figure 6.16 A side view of a backstroke swimmer showing horizontal alignment. Notice that his chin is tucked and that his hips are dropped slightly.

Horizontal Alignment

The body should be nearly horizontal with the surface, but with a slight pike at the waist, to keep the thighs from breaking through the surface of the water during the upbeat of the flutter kick. This bend at the waist should not be excessive, however. The head should be in a natural position on the spine with the chin tucked in and the eyes focused back and up. The back of the head should rest in the water, with the waterline passing just under the ears (the wake will cover the ears). This body position is shown from a side view in figure 6.16.

Lateral Alignment

Good lateral alignment is shown from a front underwater view in figure 6.7 (see pages 190–191). The hips and legs should remain within shoulder width at all times. Lateral movements of the arms during their recovery and underwater strokes will tend to move the suspended body from side to side, but this can be counteracted by rolling the body from side to side in time with the down and up movements of the arms.

Importance of Body Roll

The alternating movements of the arms in the back crawl cause one arm to move down while the other is traveling up and it is very important for backstrokers to roll the body in the same direction the arm is moving if they want to prevent the hips and legs from swinging from side to side. Any attempt to remain in a flat position while the arms and shoulders are sweeping down and up will cause countertorques that will throw the body out of alignment.

Although it is possible to roll too much, it is far more common for backstrokers to roll too little. Backstroke swimmers should roll approximately 45° to each side. They should roll to the left as the left arm starts down for the water after passing overhead in its recovery, and they should continue rolling to the left as that arm completes its entry, first downsweep, and most of the first upsweep. Swimmers should start rolling the body toward the other side during the transition between the first upsweep and second downsweep of the armstroke. This is when the recovering arm passes overhead and starts down. They should then continue rolling toward that side through the first half of the next underwater armstroke. At the same time, the legs should kick diagonally in the new direction to facilitate this roll. The proper sequence for body roll can be seen from a front view in the series of photographs in figure 6.7 (see pages 190–191).

If these rolling movements are timed properly, the body will stay in good lateral alignment. Any body part that fails to roll in sequence with the arms will be pulled out of alignment. The head is the only exception to this statement. Backstroke swimmers should keep the head in a stationary position during the entirety of each stroke cycle.

Backstrokers should be sure to bring their shoulder out of the water as they begin the recovery with each arm. This will help keep the arm clear of the water longer during the arm recovery. A swimmer is shown rolling his shoulder out of the water as he recovers his arm over the water in figure 6.12e (page 196).

Breathing

Because backstroke swimmers keep the face above the surface when they swim, there is no need for them to restrict their breathing. They can inhale and exhale at will. Nevertheless, some experts recommend inhalation during one arm recovery and exhalation during the other. It may not be necessary, or even wise, to teach this or any other breathing rhythm, however.

Stroking rates differ from one swimmer to the next, obviously, as they differ in 100 m and 200 m races. This means that backstroke swimmers might not breathe as often as they could or should if they have slow rates of turnover and/or when they are swimming longer races. According to McArdle, Katch, and Katch (1996), "rates as high as 60 to 70 breaths per minute have been measured in elite athletes during maximal exercise." As mentioned earlier, backstroke racers use stroke rates between 40 and 50 cycles/min. Consequently, taking one breath per cycle might limit the amount of oxygen they consume, particularly in 200 races where they tend to stroke slower. Therefore, it is probably best to allow backstroke swimmers to breathe at will. Through trial and error, they should develop an efficient breathing rate that is right for them and for the length of their races.

Underwater Dolphin Kicking

Most backstrokers can kick underwater faster than they can swim on the surface. This is probably due to a combination of three factors. The first is that they can execute a larger number of propulsive thrusts with the legs than they can with the arms. Most backstrokers kick at rates in excess of 150 cycles/min when they use the underwater dolphin kick whereas their stroke rates in 100 and 200 races vary between 70 and 100 strokes/min (35 to 53 cycles/min).

The second factor may be that there is less drag underwater than at the surface (Lyttle et al. 1998). The third is that backstrokers are probably not capable of generating as much propulsive force with the arms as swimmers in other strokes because the arms stroke out to the sides rather than underneath the body. Therefore, the majority may not be able to move as fast on the surface using the arms as they can move while kicking underwater (Arellano, Gavilan, and Garcia 1996).

Swimmers who use the underwater dolphin kick should be sure to execute it correctly. The sequence of photographs in figure 6.17 shows a backstroke swimmer doing the underwater dolphin kick.

The arms should be together, overhead, with one hand on top of the other, forming a V that allows streams of water to separate gradually over all four surfaces of the body as swimmers pass through it. The separation of water streams should start at the very

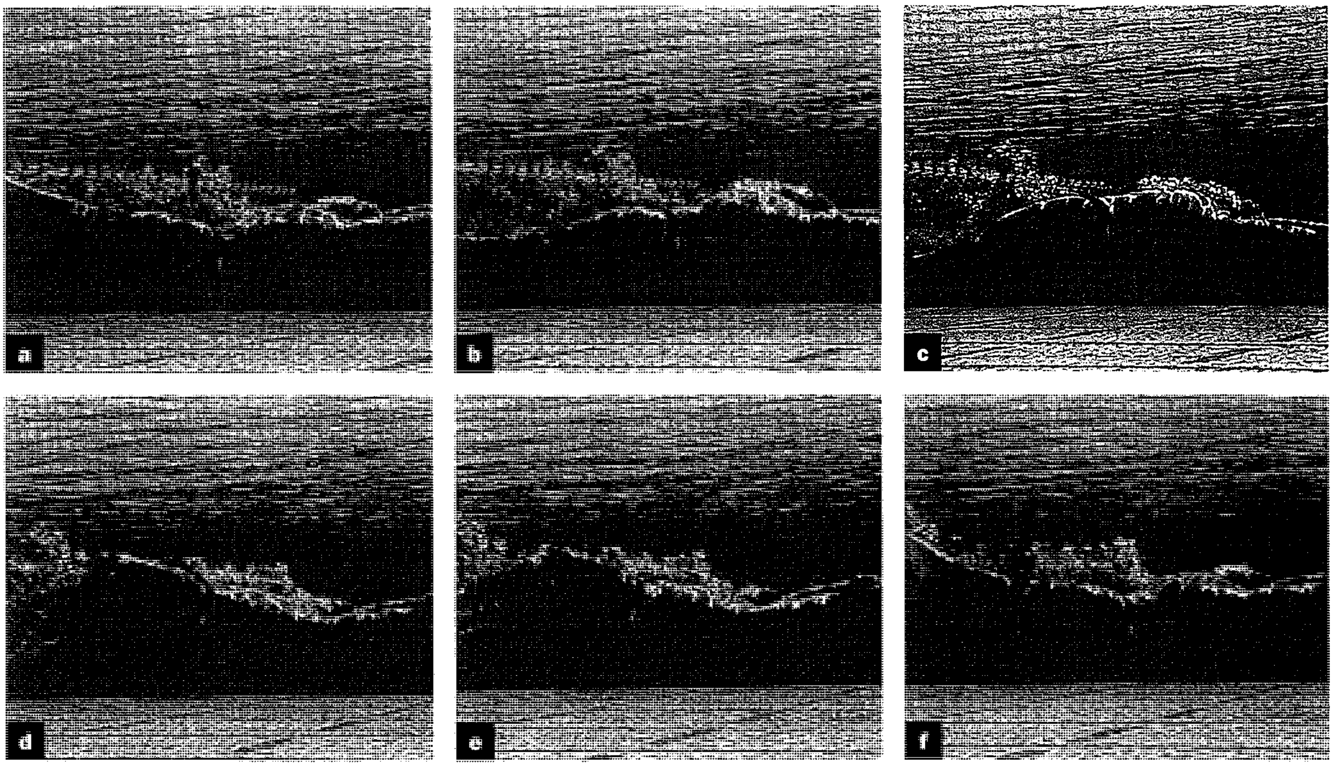


Figure 6.17 Sequence of photographs showing the mechanics of the underwater dolphin kick for backstrokers. The swimmer is Guillermo Diaz DeLeon, NCAA all-American from Arizona State University.

(*a*) End of upbeat.
(*b*) Straight-leg portion of downbeat.
(*c*) Start of next upbeat.
(*d*) Hip flexion phase of upbeat (notice horizontal position of the arm).
(*e*) Beginning of leg extension phase of upbeat.
(*f*) End of upbeat.

smallest surface of the fingertips and pass backward along the ever widening arms and trunk. The head should be between the arms, and the shoulders should squeeze the ears to achieve a very streamlined position as they kick down the pool. Swimmers should be 0.4 to 0.6 m (1.5 to 2 ft) underwater, where resistive drag is lower, when dolphin kicking (Lyttle et al. 1998).

The downbeat of the underwater dolphin kick is pictured in figure 6.17, a and b. It overlaps with the finish of the upbeat, in that the final upward snap of the lower legs will start the thigh moving downward in a rebound-like maneuver, as in figure 6.17a. From there, the legs continue sweeping downward until they are just below the body, where the next upbeat will start. The water pushing up from underneath the legs should maintain the body in an extended position during the downbeat. That water pressure will also push the feet up into a natural position, midway between extension and flexion, as seen in figure 6.17b, as they travel down.

The legs will travel down and forward during the downbeat, thus it is doubtful that this phase of the kick is propulsive. More likely, the primary purpose of the downbeat is merely to get the feet in position for another propulsive upbeat. For this reason, the downbeat should be made gently. It must also be made quickly, however, so that swimmers can maintain a kicking speed in excess of 150 cycles/min.

The upbeat of the underwater dolphin kick is shown in figure 6.17, c through f. The upbeat begins as the legs pass below the body during the preceding downbeat. It starts with swimmers flexing the thighs at the hips to start them moving upward. In the meantime, the water pushing downward will push the lower legs into a flexed position at the knees and will push the feet into an extended position at the ankles. This is in preparation for the whip-like upward extension of the lower legs that will follow soon thereafter, shown in figure 6.17d. Once the legs are flexed and the feet are facing back, the legs are extended at the knees. (Leg extension begins in figure 6.17e.) The legs should accelerate up and back at a rapid rate. Following that extension, the upbeat ends with the legs completely extended and slightly above the head, as in figure 6.17f.

Swimmers propel forward by pushing back against the water with the fronts of the lower legs and the insteps of the feet early in the upbeat. Later, they will push water up with the lower legs but can still direct some water back with the feet, if the ankles are flexible enough to allow them to remain extended and facing back until late in the upbeat.

The backstroke underwater dolphin kick, like the butterfly underwater dolphin kick, should include a certain amount of full body undulation that may permit the upward movements of the legs to propel swimmers forward with a reverse body wave. Consequently, the *body shimmy* is also used here in a manner similar to that described for butterfly underwater dolphin kicking. In this case, however, it will be the upbeat of the dolphin kick that pushes the hips and trunk forward through the water. This movement of the trunk can be translated to forward propulsion by manipulating the position of the head and arms in the following manner.

Swimmers should press up and forward slightly with the hands, head, and shoulders during the upbeat of the kick. This will change body direction from down to forward and allow the wave of undulation from the upbeat to push the body forward as it passes from the legs to the hips, on to the shoulders, and finally to the arms. Swimmers should then press the arms slightly downward during the downbeat of the kick to keep the body from being pushed upward unnecessarily by the movements of the legs.

Backstroke swimmers should utilize underwater dolphin kicking to the fullest extent possible in their races. At present, the rules for backstroke swimming permit kicking 15 m underwater after the start and after each turn. Most swimmers, however, are dolphin kicking underwater for the full 15 m only after the start. Even the best underwater dolphin kickers are only staying underwater for approximately 10 to 12 m after the turn in 100 races, whether those races are contested in yd or m. These same swimmers generally perform four to six dolphin kicks after each turn in 200 events. I suspect that, in time, more backstrokers will be staying underwater for the full 15 m of each length of 100 races and for the first 10 or 12 m of each length in 200 races.

One mistake many backstrokers make today is to stay too far underwater early in their races and then not enough later in those same races. I believe they would do better to select a reasonable underwater distance during each length and then kick underwater for that distance after the start and each turn of the entire race. In this way, they can delay fatigue early in the race and use the fast technique of underwater dolphin kicking to greater advantage later in the race.

Regardless of the amount of time they spend underwater during the early parts of races, another strategy I would recommend is for backstroke swimmers to train themselves to kick the full 15 m underwater on the last length of every race. The few swimmers I have observed using this strategy have been quite successful with it.

Another aspect of underwater dolphin kicking that is often overlooked is the technique of coming to the surface. A common mistake that swimmers make is to angle up too steeply toward the surface. This causes them to increase upward velocity at the expense of forward velocity during the transition from underwater to surface swimming. Swimmers should use the final two or three dolphin kicks to surface gradually. They should still be underwater when the final dolphin kick is taken, however. Then they should begin a flutter kick, taking one or two kicks, before they start the first armstroke. After the start and after each turn, that first armstroke should be taken just under the surface and should bring the body up through the surface at full stroking rhythm.

Common Stroke Mistakes

The common stroke faults in the backstroke are presented in the following order: armstroke mistakes, kicking mistakes, and body position mistakes.

Armstroke Mistakes

The most common mistakes swimmers make during each phase of the armstroke will be described in this section, beginning with the entry of the hand into the water.

Mistakes During the Entry

Some of the most common mistakes that swimmers make when they enter the hands into the water are (1) overreaching, (2) underreaching, (3) smashing the back of the hand into the water, and (4) placing the fingertips in the water before the arm.

1. When they overreach on the entry, swimmers swing the hand behind the head toward the opposite shoulder. Reaching behind the head for the entry will pull the hips out of alignment in the opposite direction and delay the catch.

2. When they underreach, backstroke swimmers put the hand in the water outside the same shoulder. Swimmers were actually taught to put the arm into the water this way during the period from 1930 to 1960. Today, however, we realize that entering the arm wide reduces the length of the propulsive phases of the armstroke.

To eliminate both underreaching and overreaching, swimmers should be coached to enter the hand somewhere between the middle of the head and the tip of the shoulder on the recovery side. A good teaching technique is for them to imagine that they are lying on the face of a clock with the head pointing at 12 o'clock and the feet pointing at 6 o'clock. The right hand should enter the water between 11 and 12 o'clock and the left hand should enter between 12 and 1 o'clock.

3. Smashing the back of the hand will increase pushing drag. The surface area presented to the water is considerably larger when the hand enters with the palm facing up rather than to the side. If the hand is pushed down and back forcefully as it enters, water will be pushed forward and forward velocity will decelerate considerably.

Backstroke swimmers should slice the hand into the water on its side with the palm facing outward so that the hand can slip into the water on its edge. Swimmers usually enter with the palm up because they fail to rotate the body toward the entering arm. They rotate too little or too late so that the body is still inclined in the other direction when the arm is entering the water. When the body is rotated away from the entering arm, swimmers cannot turn the palm out and, thus, have no choice but to put the hand into the water with the palm facing up. To correct this mistake, backstroke swimmers should be instructed to rotate toward the entering arm as it is traveling down for the entry.

4. The final mistake, usually made by novice swimmers, is entering the hand into the water before the arm. Probably a carryover from the front crawl where entry with fingertips first is desirable, this mistake is not only undesirable in backstroke swimming but also impossible to do without increasing drag and upsetting stroke rhythm.

Swimmers who make this mistake usually display a *hitch* during each stroke cycle. That is, they exhibit a hesitation in stroke rhythm just after the arm enters the water. This hesitation is caused by the need to straighten the arm and turn the palm out to the correct position before they can begin sweeping the arm down.

Mistakes During the First Downsweep

The most common mistake that swimmers make during this phase of the armstroke is trying to push back against the water before the arm is deep enough and wide enough to make an effective catch. This mistake can take two forms: (1) swimmers push water down or (2) they push water to the side.

1. The detrimental effect of pushing water down is illustrated by the swimmer in figure 6.18a. The shaded area on the inset of the stroke pattern shows that his arm is moving down during this phase of the underwater stroke. The arrows underneath his arm show that he will be pushing water down at this time. This will push his body up and decelerate his forward speed. The solid arrow above his head shows that the downward force from his armstroke will push his head and shoulders up. Swimmers who make this mistake usually bob up and down as each arm sweeps down. Backstroke swimmers should be cautioned to make the first downsweep gently to reduce the tendency of the arms to push the head and trunk up out of horizontal alignment.

Figure 6.18b shows a swimmer who is sweeping his arm down correctly. He moves it gently through the water and he waits until his hand and arm have traveled sufficiently downward to achieve a backward orientation before he attempts to apply force. As a result, the force he applies will displace water back, in the direction of the solid arrows, and propel his body forward.

2. Swimmers who sweep the hand out to the side for a shallow catch can make a similar mistake, except in this case, they will push water to the side and disrupt their

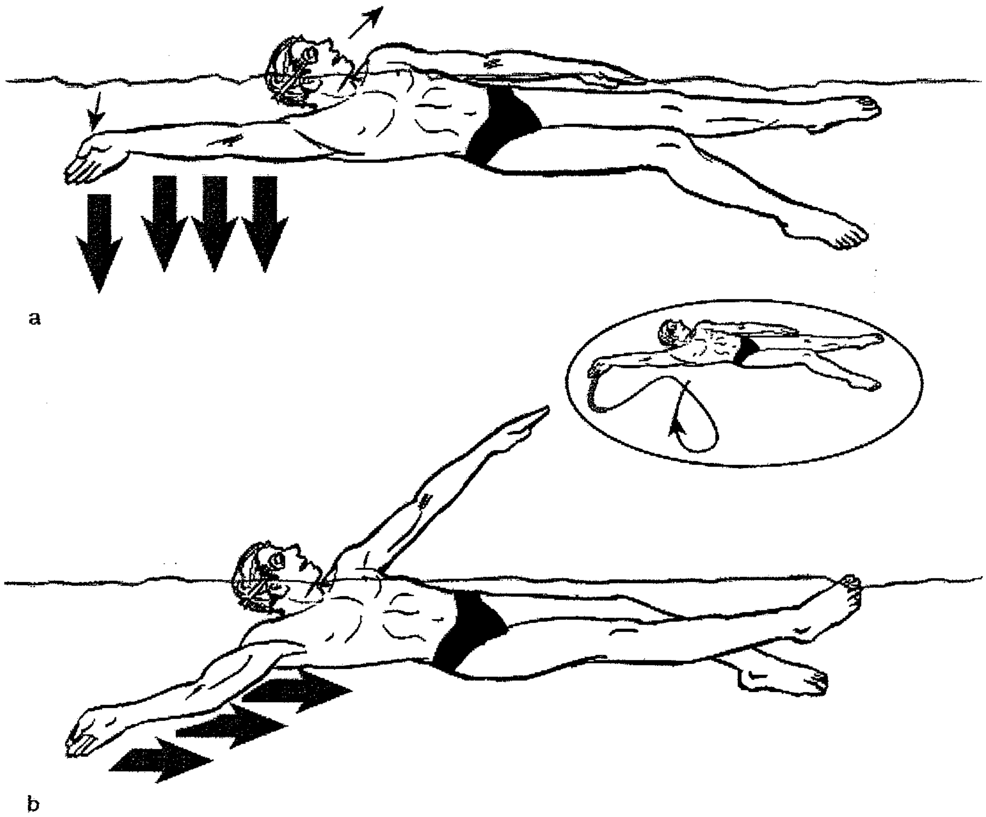


Figure 6.18 The effect of trying to apply force too early during the armstroke. The swimmer in *(a)* is trying to push against the water immediately after his hand enters. This causes him to push down and decelerate his forward speed. Swimmers should wait until the arm is deep enough to push water back, like the swimmer in *(b)* is doing.

lateral alignment. Many swimmers find it difficult to wait until the arm has traveled down and out to the side before making a catch. Understandably, they get in a hurry to apply force when they feel the hand entering. Consequently, they start pushing against the water almost immediately. Unfortunately, the force they apply only serves to increase resistive drag and decelerate forward speed.

These same swimmers are often fooled into thinking they are ready to push back because they flex the wrist and get the hand facing back soon after it enters the water. This gives them the mistaken impression that they are in position to push water back with the entire arm. The hand and arm are actually traveling down and out at this time, however, so they can only push water in those directions, despite the fact that the palm is facing back. Backstroke swimmers must learn to sweep the arm and hand gently down and out to the side until both are facing backward before they begin pushing against the water with them.

Mistakes During the First Upsweep

Some of the most common mistakes made during the first upsweep are (1) pulling with a straight arm, (2) sculling the hand vertically, and (3) pushing up against the water with the palm of the hand.

1. The most common mistake that novice swimmers make in this phase of the armstroke is to pull with a straight arm. This causes them to push water to the side for a good portion of the sweep. Swimmers must learn to bend the arm during the first downsweep so that they can execute the first upsweep with a flexed arm.

2. The most common mistake that more experienced swimmers make is to scull the hand almost vertically upward. This mistake is also more likely to occur if swimmers make the catch with an extended or nearly extended arm. Making the catch in this manner and then flexing the arm during the first upsweep encourages them to scull vertically. The problem with this technique is that the arm may fail to press sufficiently backward against the water while it is sculling upward. More often, the backward velocity of the upper arm is slowed to nearly 0 and they sweep the hand and forearm up around it.

3. Another mistake that both experienced and inexperienced backstroke swimmers make is to push up against the water with the palm of the hand during the first upsweep. The effect of this error is illustrated in figure 6.19.

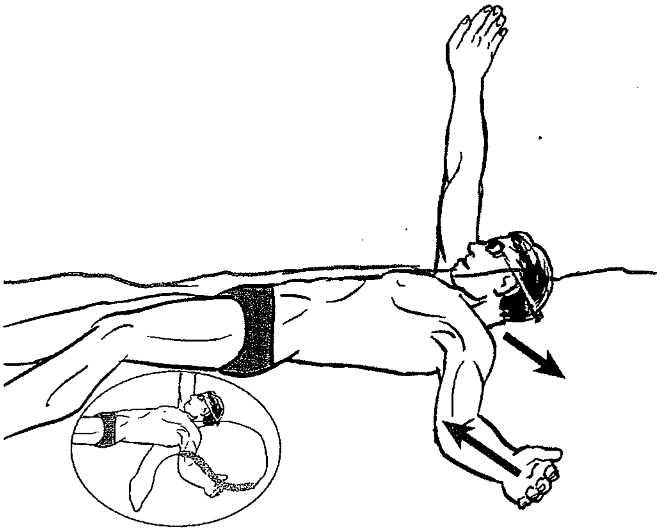


Figure 6.19 The effect of pitching the hand up too much during the first upsweep.

This swimmer has his hand pitched up so much that it is nearly perpendicular to the direction it is moving. At this angle of attack, he will push water up much more than back and will gain very little propulsion. One indication that swimmers are making this mistake is that they pull the shoulder down into the water when they sweep the hand upward. The hand should be in alignment with the forearm during the first upsweep and both should be facing back and pushing back against the water as the hand sweeps up and back.

Mistakes During the Second Downsweep

The two most common mistakes swimmers make during this phase of the underwater armstroke have already been described. The first is to sweep the hand back and in toward the thigh. The second is to perform the second downsweep with the fingertips pointing up rather than to the side. Swimmers are more likely to push down with the hand when the fingers are facing up, and they are certain to push down with the forearm when the hand is in this position during the second downsweep. By contrast, swimmers will be more likely to maintain a backward orientation with the palm and forearm for a longer time during this stroke phase when the fingertips remain pointed toward the side.

Mistakes During the Second Upsweep

Swimmers who use this phase of the armstroke for propulsion are prone to commit three mistakes. They may (1) pitch the hand up, instead of back, (2) press against the water too long as the arm travels toward the surface, and (3) pitch the hand in rather than back. The effects of the first two of these mistakes are illustrated in figure 6.20.

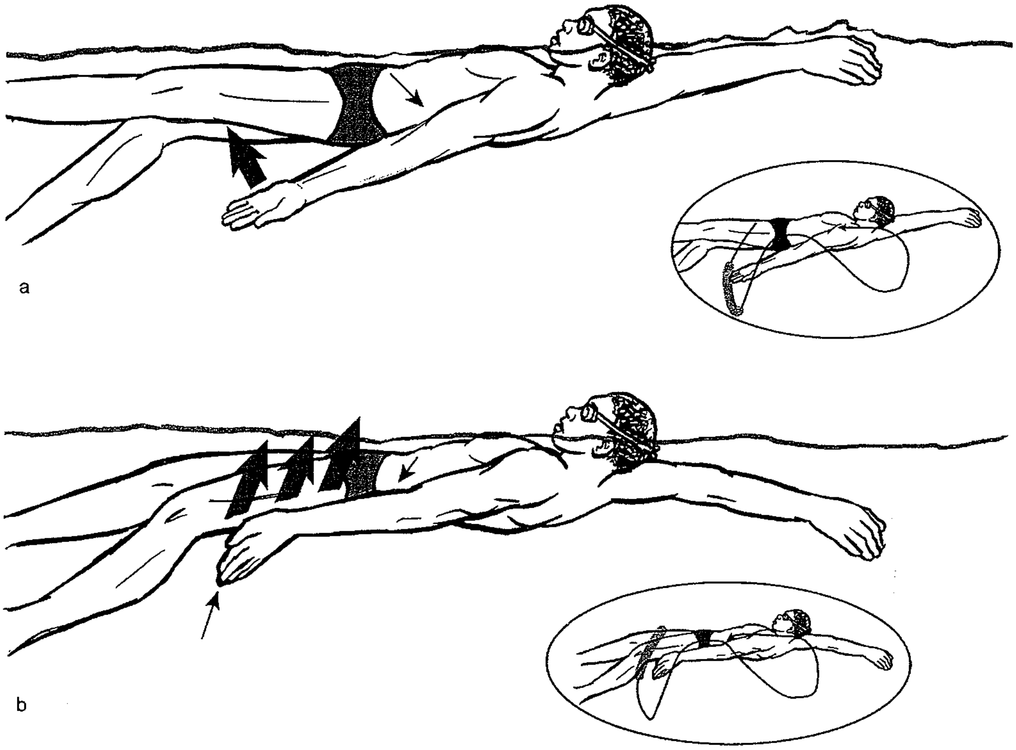


Figure 6.20 The effects of *(a)* pitching the hand too far upward during the second upsweep and *(b)* continuing that motion for too long a distance.

1. Figure 6.20a shows a swimmer who is pushing upward too much with his hand. His palm is facing up, almost perpendicular to the direction it is moving. With his hand in this position, he can only push water up, in the direction of the arrow above his hand. In addition to sacrificing potential propulsion, the hips will be submerged by this error and his forward speed will be reduced. Swimmers should keep the hand (and the forearm) facing back during the second upsweep.

2. The swimmer in figure 6.20b is using the second upsweep over too long a distance. He is trying to apply propulsive force all the way to the surface of the water. This will also be counterproductive because he cannot avoid pushing up with his hand and arm as they near the surface. The second upsweep should end when the hand approaches the rear of the thigh. Even if swimmers keep the palm of the hand facing back

after it passes the thigh, they will still be pushing up too much with this arm if they try to continue the second upsweep beyond this point.

Another reason swimmers must release pressure on the water before the hand passes the leg is because the last portion of the underwater armstroke must be used to overcome the backward inertia of the arm and start it forward into the recovery smoothly and without delay. This is done by releasing pressure on the water and directing the arm up and forward during the last portion of its sweep to the surface. This change of direction is assisted by rolling toward the other side so that the shoulder of the releasing arm pulls it up and forward out of the water. The point where the arm starts moving forward while still underwater is shown in the stroke pattern inset of figure 6.20. The hand will no longer be an effective propulsive agent when it starts moving forward, thus it is time to stop pushing against the water and move it smoothly into the recovery.

Mistakes During the Release and Recovery

There are many mistakes swimmers can make during these phases of the armstroke. Some of these increase resistive drag while others can disrupt the rhythm of the stroke. The mistakes that swimmers make frequently are to (1) bring the arm out of the water with the little finger up and the palm facing out, (2) bring the hand out of the water with the palm facing down, (3) initiate recovery by lifting the hand rather than rolling the shoulder up, and (4) swing the arm low and to the side.

1. Turning the palm outward will twist the humerus (the long bone of the upper arm) in its socket at the shoulder and cause unnecessary tension during the recovery. You can demonstrate this for yourself by standing with your arm hanging down at your side, with your palm facing in. Rotate your palm back and out and then lift it to the front until it is at shoulder height. You should feel a twisting motion that produces some tension in your shoulder. Now try lifting your arm overhead with your palm turned in. The tension should be gone.

2. There is a greater likelihood of increasing pushing drag when swimmers bring the hand out of the water with the palm facing down. This is because they may push water up with the back of the hand as it is leaving the water. It is possible to recover in this manner without increasing drag very much if swimmers slip the hand up and forward out of the water while flexed at the wrist. It is far easier to reduce drag during this time if the hand is on its side, however.

   The hand should leave the water thumb first, with the palm facing in so that resistive drag will be reduced as the hand travels its last few inches before leaving the water. The first half of the arm recovery should be made with the palm facing in, and the palm should not be turned out until the arm passes overhead.

3. Perhaps the most frequent mistake swimmers make is to initiate the arm recovery by lifting the hand from the water rather than rolling the shoulder up. Lifting the hand out of the water may submerge the shoulder on that side and cause the arm to drag through the water longer during the recovery.

   The hand and arm should be relaxed after the release takes place and swimmers should allow the body roll to do as much of the work of bringing the arm to the surface and over the water as possible. The recovery motion should be one of lifting and shrugging the shoulder. This action will start the arm moving forward. With the body rolled to the side and the shoulder above the water, the arm will remain clear of the water for a longer time during the recovery. In fact, the arm should not push forward through the water until the hand is almost ready to enter.

4. Another common mistake during the recovery is to swing the arm low and to the side. This sideward arm movement will pull the hips out to the side in the same direction. This, in turn, will create a counterforce on the legs that will cause them to swing

outside the body in the opposite direction. Consequently, swimmers will travel down the pool with the hips and legs swinging from side to side. This will increase form drag because the legs swing outside the width of the shoulders. It will also increase pushing drag because of the sideward force produced by the leg swings. Backstrokers should recover the arms high and directly overhead with a minimum of sideward movement.

Kicking Mistakes

The mistakes that swimmers make most often are to (1) pedal the legs and (2) kick too deep. In addition, swimmers who lack ankle flexibility will not be fast kickers.

1. The detrimental effects of pedaling were described in chapter 3. Swimmers who make this mistake usually lift the thighs too much during the upbeat of the flutter kick and they extend the legs by pushing them forward, rather than extending them upward, in the manner of pedaling a bicycle. When the knees rise above the surface of the water during the kick, you can be sure that backstrokers are pedaling rather than kicking the legs. The primary problem is that they push the thighs upward and forward against the water during the upbeat and this produces pushing drag that slows forward speed. Swimmers should be instructed to keep the knees underwater and to straighten the legs completely on the upbeats of the backstroke flutter kick.

2. Two things can happen when the kick is excessively deep, both of which reduce forward speed. The first of these detrimental effects will be an increase of form drag, which occurs because the cross sectional area taken up by the body will increase due to the depth of the legs. The proper depth for the kick is approximately 45 cm (18 in). The second effect is that the hips and trunk will be pushed up if the thighs push down below the body during the downbeat, which will disrupt horizontal alignment and reduce forward velocity. The thighs should not travel down below the hips during a downbeat. The lower leg may drop below the body when swimmers flex the hip during the upbeat, but this is not a stroke defect.

Swimmers who kick too deep tend to kick by simply extending and flexing the leg at the knee with little or no involvement of the thigh and hip. The most serious problem is that they generally flex the leg during the downbeat and, in so doing, push the lower leg forward against the water. The legs should be kept straight on a downbeat, and they should not bend until the pressure of the water forces them into a flexed position during the first portion of the next upbeat.

Body Position Mistakes

The most common mistakes made with regard to body position are (1) swimming with the head too high and (2) piking excessively at the waist.

1. Swimmers who hold the head too high generally have the body inclined down too much from head to feet. This will increase form drag. In addition, they will need to use the arms and legs to support this high head position, which will increase pushing drag and reduce propulsion because they will be pushing down with the arms and kicking too deep during the first downsweep.

2. Some backstrokers swim with the hips too low in the water. This is particularly true of young swimmers when they are first learning this stroke. The effect of this mistake is illustrated in figure 6.21.

Figure 6.21a shows a swimmer with good horizontal alignment. His body is inclined down only slightly from head to hips, his head is comfortably back in the water in line with his trunk, and he is not kicking too deep. Poor horizontal alignment is illustrated by figure 6.21b. This swimmer's hips are too deep, her head is too high, and she is kicking too deep.

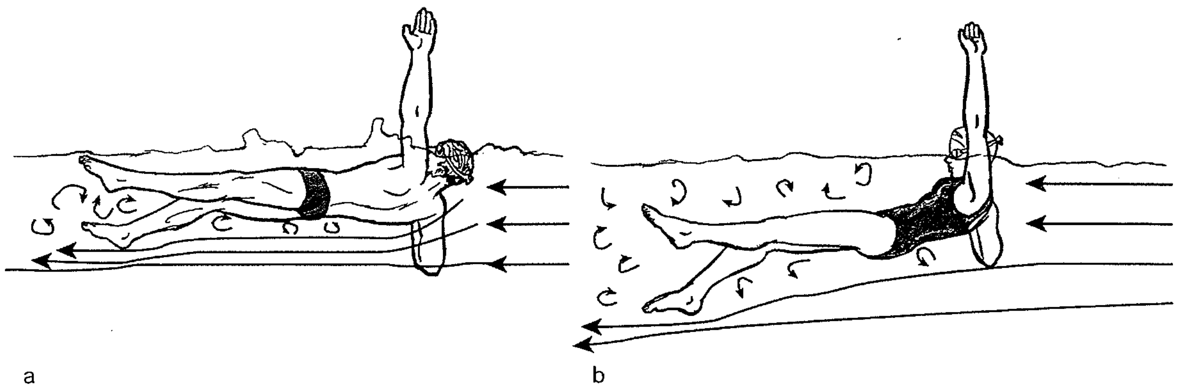


Figure 6.21 Good and poor horizontal alignment in the backstroke. The swimmer in *(a)* shows good horizontal alignment, while the swimmer in *(b)* has her head too high and her hips too low.

Stroke Drills

Some of the best drills for improving the armstroke, kicking, timing, and body position of backstroke swimmers are included in this section. I will begin with drills for the armstroke.

Armstroke Drills

Descriptions of ten drills are included in this section. Some of these are for the underwater armstroke and others are for the arm recovery.

STROKE PATTERN DRILL

Tracing an imaginary S on its side with the hand is a good way to learn the correct sweeps for a two-peak backstroke underwater armstroke. Figure 6.22a illustrates a backstroke arm pattern that has been drawn relative to the moving body. The S pattern, evident in the illustration, is the type of pattern that a two-peak backstroke swimmer would use. The first curve of the S corresponds to the first downsweep, the second curve represents the first upsweep, and the third curve represents the second downsweep. The dotted line that continues the stroke pattern represents the arm recovery.

In figure 6.22b, I have added an extra tail to the S pattern. This tail represents a propulsive second upsweep that is used by many three-peak backstrokers. With the tail added, the pattern could actually be likened to a letter W rather than an S.

The first curve of the W corresponds to the first downsweep, the second curve to the first upsweep, the third curve to the second downsweep, and the fourth curve to the second upsweep. Once again, the dotted

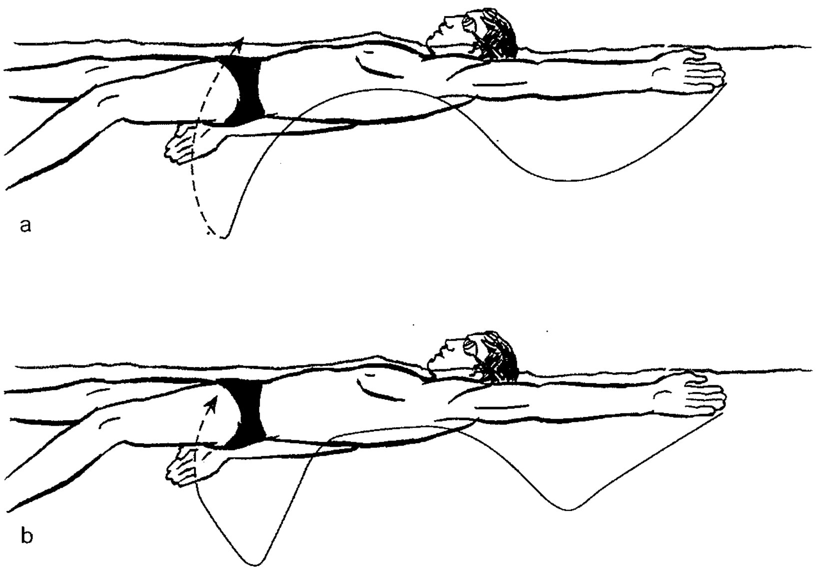


Figure 6.22 Stroke patterns for the backstroke drawn relative to the moving body. Drawing *(a)* shows the traditional S pattern used by two-peak backstroke swimmers. A less-traditional W stroke pattern, shown in *(b)*, is used by swimmers who have a three-peak velocity pattern.

line that continues the pattern to the water surface represents the release and the first part of the arm recovery.

Depending on the style they prefer, swimmers should trace one of these patterns with the hand during each underwater armstroke. They should try to keep the underside of the forearm and the palm of the hand oriented back against the water during each propulsive portion of the S or W to apply propulsive force effectively.

ONE-ARM SWIMMING DRILL

In this drill, athletes swim repeats, stroking with one arm and keeping the other arm at the sides. This is a good drill for the armstroke because swimmers can concentrate on the movements of one arm at a time. It is also a good drill for teaching swimmers to roll the body properly. After the arm enters the water, they should roll the body toward it until the opposite shoulder comes up out of the water. They should roll toward the opposite side during the second downsweep and second upsweep of that armstroke until the shoulder of the stroking arm breaks the surface leading into the arm recovery. This can be done as a pulling drill or kicking drill.

A variation on this drill is swimming with the nonstroking arm stretched overhead and underwater. This variation encourages better streamlining during the latter stages of the underwater armstroke, but it also discourages body rotation.

HALF-SIDESTROKE DRILL

This drill helps swimmers learn to make a correct catch and to use the first upsweep of the underwater armstroke effectively. The half-sidestroke drill, shown in the sequence of photographs in figure 6.23, is performed one arm at a time with both arms remaining underwater.

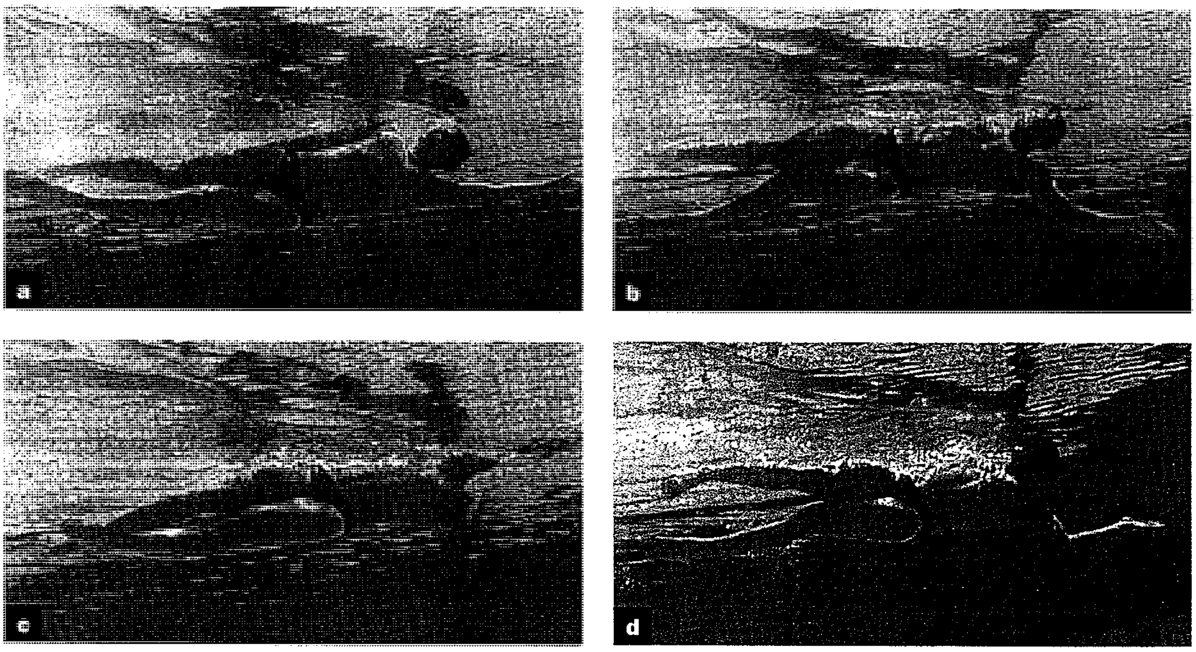


Figure 6.23 The half-sidestroke drill.

(*a*) Forward stretch with left arm.
(*b*) Catch position with left arm.
(*c*) Adduction with left arm to the side.
(*d*) Underwater recovery of left arm before another stroke.

Swimmers should be on their sides in the water with one arm stretched overhead and under the water. The other arm should remain back at the side in a position similar to the glide position of the sidestroke (figure 6.23a). They should take a half-stroke with the overhead arm by sweeping it down and out to the catch (figure 6.23b) and then adducting it up and back toward the side (figure 6.23c). The stroke ends when the first upsweep is completed. Then they should recover the arm (figure 6.23d) underwater and back to the starting position before executing another half-stroke. Swimmers should take several strokes with one arm before changing sides when doing this drill.

SIDESTROKE DRILL

This drill, pictured in the photos of figure 6.24, is used to practice the underwater armstroke. It can be done with one arm only or by alternating armstrokes.

Swimmers start on their sides, rotated toward the stroking arm. That arm should be extended over the head and underwater and the other arm should be down at the side, as in figure 6.24a. Swimmers slide the stroking arm down and out until they get the water behind it at the catch position, as in figure 6.24b. Then they execute an underwater armstroke, shown in figure 6.24, c and d. They remain on the side facing toward the stroking arm during the first upsweep. Then they rotate toward the other side while they complete the final two sweeps. When finished, they again extend the same arm overhead for another stroke. The non-stroking arm should remain underwater while doing the drill.

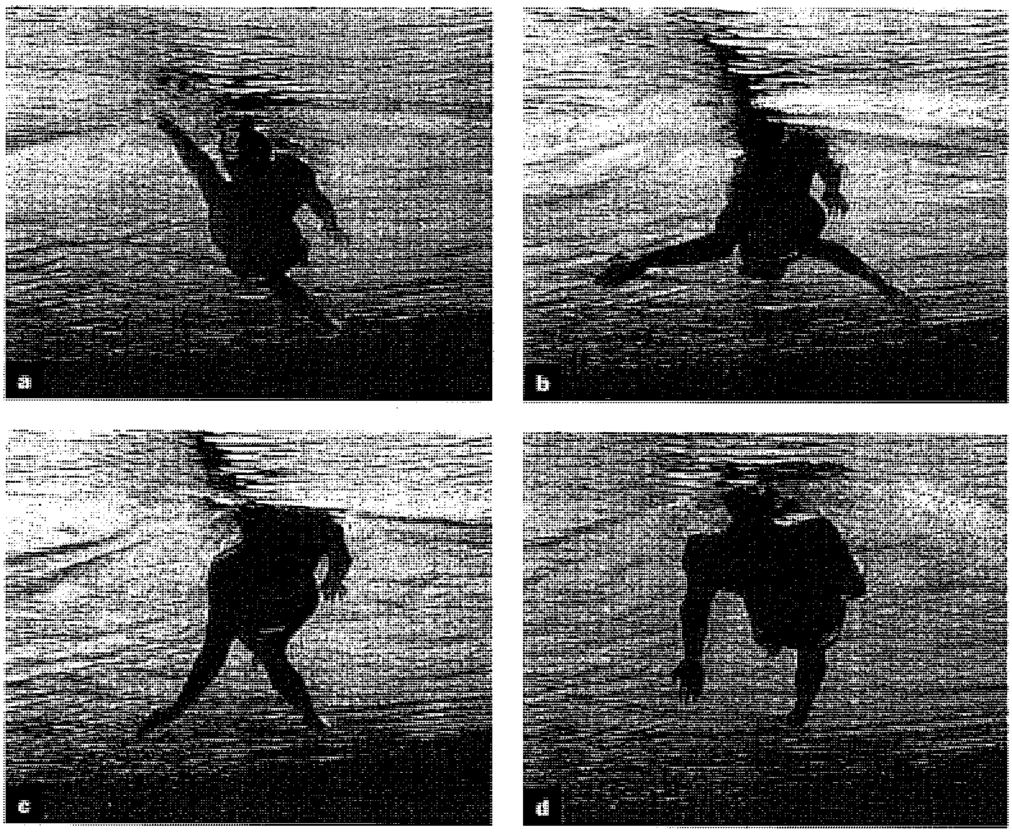


Figure 6.24 The sidestroke drill.

(a) Starting position with left arm stretched overhead (notice right arm remains at his side).
(b) Catch with left arm.
(c) Second downsweep with left arm.
(d) Second upsweep with left arm.

This drill can also be performed by alternating armstrokes. In this case, after completing one armstroke, swimmers would slide the other arm overhead, keeping it underwater. Then they would complete an identical underwater stroke with that arm before starting the cycle over again.

This drill can be done with arms only or while kicking.

UPSWEEP DRILL

This drill is used for swimmers who want to develop a three-peak underwater armstroke. They can also learn to use the second upsweep for propulsion.

This drill can be performed with both arms simultaneously or with alternating armstrokes. Swimmers lie on their backs with both arms at the sides. All arm recoveries are made underwater, as in the previous two drills. They begin by sliding the hands up underwater until they are opposite the chest. The arms should be flexed and positioned as though the swimmer had just completed a first upsweep. Then they sweep the arms down and up in the same manner they would when performing a second downsweep and second upsweep. Swimmers should do this as a pulling drill so that they can feel themselves being propelled by their armstrokes.

FIST SWIMMING DRILL

Swimmers perform this drill by swimming with the hands closed in a fist. Helpful for learning to use the arms for propulsion, fist swimming drills can be done in a variety of ways. Backstrokers can swim the full stroke with both hands made into fists. They can also do the drill making a fist with the hand of only one arm, which they use for stroking, while the other rests at the side. Or, they can swim the full stroke but with the hand of the dominant arm in a fist and the other hand open. Swimming with the hand of the dominant arm in a fist encourages swimmers to use the nondominant arm more effectively in this stroke, just as it did in the front crawl and butterfly.

Recovery Drills

I can recommend four drills to improve the arm recovery, body rotation, and lateral alignment.

HESITATION DRILL

Backstrokers swim a normal backstroke but with one exception: They stop the arm for an instant midway through its recovery and turn the palm from in to out (once or some other specified number of times). Swimmers should concentrate on stopping the arm straight above the shoulder so that they turn the palm out at the proper time. The purpose of this drill is to teach a vertical recovery with a clean entry.

DOUBLE-ARM BACKSTROKE DRILL

This drill is for swimmers who tend to overreach. They should swim the backstroke while simultaneously stroking with both arms. It is impossible to overreach when swimmers recover the arms simultaneously. Therefore, this drill may teach them the feeling of placing the arms in the water directly in front of the shoulders. It is also an excellent drill for teaching swimmers to use the four sweeps properly if they focus on the underwater sweeps of the arms.

IN-OUT DRILL

This drill is useful for swimmers who recover the arms too low and laterally. It combats the tendency to swing the arms out to the sides during the first half of the recovery and then in during the second half. This is learned by exaggerating the arm recovery motions in the opposite sequence. That is, they recover each arm up and in during the first half of the recovery and swing it out as it passes overhead and down for the entry.

LANE SWIMMING DRILL

This is another good drill for teaching a vertical recovery. Athletes swim down the pool with one shoulder next to the lane line. This forces them to recover the arm vertically, because it will get caught under the lane if they try to swing it out to the side as it is leaving the water. Backstrokers should swim the same side of the lane so that they can practice the drill with the left and right arms on alternate lengths.

Kicking and Body Rotation Drills

There are five drills swimmers can use to develop both the lateral and vertical movements of the legs when they kick.

SIDE KICKING DRILL

Kicking on the side with one arm stretched overhead and underwater and the other arm at the side is an excellent way to improve diagonal kicking and body rotation. Swimmers should practice this drill with the body rotated toward the arm that is stretched overhead. Swimmers should complete six, eight, or any specified number of kicks in this position before changing sides.

A side kicking variation can be used to practice the six-beat kicking rhythm. Swimmers should start out lying on one side with the arm on that side stretched overhead and underwater and with the other arm at the opposite hip. They should kick twice to each side before rotating to the other side and they should change the position of the arms when they change sides. When rotating to the other side, they should kick twice while on one side, twice more during the rotation, and then twice again on the other side so that they are executing an exaggerated six-beat kicking rhythm. At first, the drill should be done with no regard to stroking with the arms, except to change their position with each rotation. Swimmers can focus on correct stroking after they have become proficient at timing their kicks and body rotation.

BACK KICKING DRILL

This drill is a good one for improving kicking endurance and power. It is also excellent for teaching swimmers to maintain a horizontal body position. Swimmers can perform this drill with arms at the sides or stretched overhead and underwater. Kicking with the arms at the sides is a good method for improving body position if swimmers roll the shoulders from side to side as they kick. Kicking with the arms at the sides is also the easier way to do the drill and can be used with novice backstroke swimmers and those who have extremely weak kicks. Kicking with the arms overhead is more difficult. But it helps swimmers to maintain a horizontal body position, particularly if they tend to sit too deep in the water. The arms should be stretched overhead and underwater, with the palms up and fingers interlocked, while they kick.

ONE HAND OUT DRILL

In this drill, swimmers kick down the pool on their sides with one arm out of the water and extended directly above the shoulder. The other arm should be underwater at the side. Swimmers should have the body rolled toward the arm at the side so that the shoulder of the extended arm is also out of the water. They can change sides after any specified number of kicks. This drill is excellent for improving the endurance and power of the flutter kick because the kick must support the weight of the arm overhead.

BOARD KICKING DRILL

This is a good drill to correct a pedaling motion in the kick. Swimmers kick while holding a kickboard lengthwise over the thighs. If the board bounces, they are pedaling and hitting it with the thighs and knees. The board will stay still if swimmers are kicking correctly.

SPONGE DRILL

This drill is used for training backstroke swimmers to keep the head still. They place a small sponge on the forehead and swim down the pool while trying to keep the sponge from falling off. If a sponge is not available, coins or diving rings will work. Diving bricks are not recommended, however.

Underwater Dolphin Kicking Drills

Swimmers who plan to dolphin kick on their backs during a portion of their races need to learn the correct technique, and they need to train themselves to stay submerged for as much of the allowable 15 m per pool length as possible. Following are some drills that will help develop these skills.

25, 50, AND 75 UNDERWATER SPRINTS

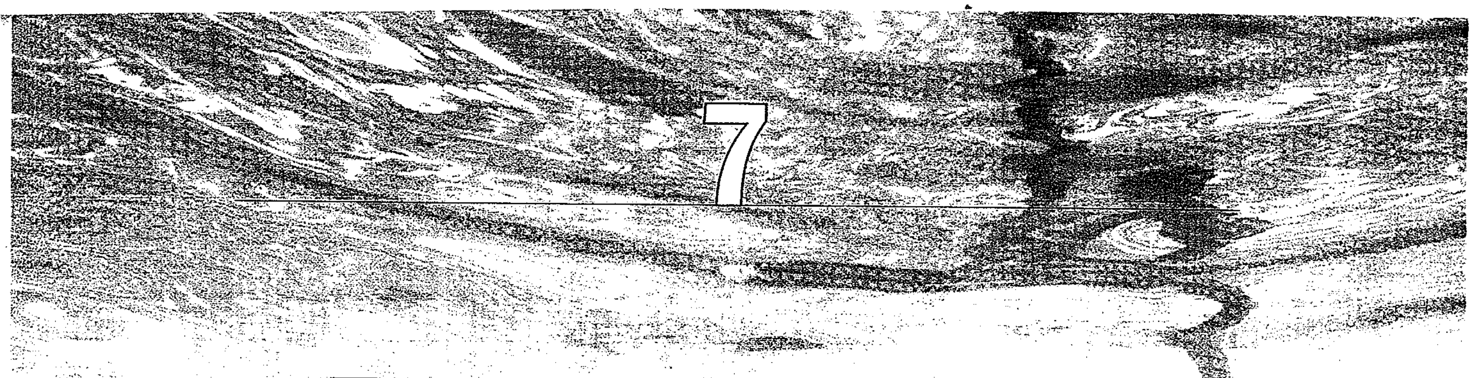
These drills can be performed with and without fins. Fins are a good aid initially. They help swimmers develop the small, quick kicks and body shimmy movements that are so important to speed in the underwater dolphin kick. They also make it easier to stay underwater longer. Once the skills are mastered with fins, swimmers should perform these drills without them so that they can build a bridge to actual competition kicking. Ten to twelve 25s, six to eight 50s, and three to four 75s are ideal for this purpose. The rest periods between repeats should be 1 to 5 min to allow swimmers sufficient recovery time to complete succeeding sprints with good quality.

BREAKOUT DRILL

Repeats of any distance can be done in this drill. Swimmers dolphin kick underwater for 15 m of each length and then come to the surface with a flutter kick, using that kick to complete the remainder of the length. They should concentrate on using the last two or three underwater dolphin kicks to rise gradually to the surface, and they should start the flutter kick just before they break through the surface. They should try to surface in such a way that they do not feel any noticeable break in rhythm beyond the loss of speed that naturally exists between dolphin kicking and flutter kicking.

SURGICAL TUBING DRILL

This is an excellent drill for improving the ability to stay underwater longer in races. A piece of surgical tubing is tied across the lane at the midpoint of a 25 yd or m course. Athletes should then swim sets of repeats, of 50 to 100 m, dolphin kicking underwater on each pool length until they pass the tubing.



7

Breaststroke

New in this edition:

- A description of the armstroke and kick based on drag-dominated propulsion
- A discussion of the undulating style of the breaststroke

The breaststroke has a rich competitive history. It was the first stroke used in competition after the Dark Ages and all of the remaining competitive strokes developed from it. At one time, the rules permitted swimmers to race underwater in breaststroke events. That proved to be too dangerous, however. There are many recorded cases of athletes passing out from staying underwater too long in breaststroke races. The rules were changed in the late 1950s to ensure that the majority of these races would be swum on the surface. Presently, breaststroke swimmers are permitted to stay underwater only during one stroke cycle after the start and after each turn. After that, some part of the body, usually the head, must appear above the normal flat surface of the water once during each stroke cycle. Breaststroke swimmers use a short, semicircular armstroke and a kick that goes by various names, although it is most commonly called a *whip kick.*

The breaststroke is the slowest of the competitive strokes because of the large fluctuations in velocity that occur within each stroke cycle. Although breaststrokers generate large forces during the propulsive phases of each stroke cycle, they also decelerate markedly each time they recover the legs in preparation for the next kick back. Swimmers in the other competitive strokes lose only about one-third of their forward velocity during recovery periods in their stroke cycles, whereas many breaststroke swimmers almost come to a complete stop when they recover the legs forward. Thus, breaststrokers must exert more force than swimmers in other strokes simply to accelerate the body back to racing speed during each stroke cycle and this makes the stroke a very rigorous one to swim.

In the past, most experts believed that the breaststroke should be swum with a flat body position. That is, the body should remain horizontal at the surface during the entire stroke cycle. An undulating style of breaststroke introduced in the 1970s involved moving the body in a dolphin motion somewhat like the butterfly during the kick. This style, called by many names including the *dolphin breaststroke* and the *European breaststroke* but now commonly called the *wave breaststroke,* was slow to catch on. Recently, however, the rule change that permits swimmers to drop the head underwater during portions of each stroke cycle has accelerated its adoption because swimmers have found that they can improve streamlining during the kick by lowering the head between the arms. They have also found that they can utilize the wave action of the water for propulsion while recovering the arms and legs.

Flat and Wave Breaststroke Styles

The two styles of breaststroke are contrasted in the series of drawings in figure 7.1. The flat style of breaststroke is characterized by a horizontal body position in which the hips remain at or near the surface throughout the entire stroke cycle. Swimmers breathe by lifting and lowering the head so that the flat position of the trunk is not disturbed. In the wave style, the head and shoulders rise out of the water when swimmers breathe and the hips are lowered during the forward leg recovery.

The major differences between the two can be seen in figure 7.1, c and d. The flat style swimmer's shoulders remain underwater, his hips near the surface when he breathes, and he remains horizontal during the time he recovers his legs forward. Conversely, the shoulders of the wave style swimmer are out of the water, his hips are down, and his body is inclined down from shoulders to knees when he breathes and recovers his legs forward. Body positions are very similar for the two styles in all other phases of the stroke. Both swimmers remain horizontal and streamlined during the propulsive phase of their armstrokes, as shown in figure 7.1, a and b. They are also horizontal during the propulsive phase of their kicks, as shown in figure 7.1e. The only other difference between the two can be seen in figure 7.1f. In the wave style, breaststrokers tend to press the hips up slightly more with the kick, perhaps in order to produce a reverse body wave. I will have more to say about the reverse body wave later in this chapter.

Proponents of the flat style support their preference with the argument that form drag is reduced and less energy is used because breaststrokers don't make extraneous up and down movements when they swim. Forward velocity tracings of swimmers' centers of mass have shown that this argument is invalid, however. Instead of creating more resistance to motion, form drag is actually reduced significantly when swimmers raise the head and trunk out of the water in the wave style. Indeed, they create less pushing drag with the legs and they reduce form drag by assuming a more streamlined shape during most of the arm and leg recoveries. In addition, as will be discussed in the section on forward velocity tracings, they receive a third propulsive phase from wave propulsion when they raise the head and shoulders out of the water.

Figure 7.2 on page 222 illustrates why flat style breaststrokers create more drag and wave style breaststrokers less drag during leg recovery. The flat style swimmer, on the left, produces a considerable amount of pushing drag during his leg recovery because he pushes his thighs down and forward against the water. This deceleration is depicted on the graph by the large valley at the end of his leg recovery. Velocity measurements of many flat style breaststrokers have shown that their forward speed decelerates markedly when they recover the legs in this manner. In fact, many come to a dead stop during this phase of the stroke cycle (Maglischo 1999).

The wave style swimmer, on the right, reduces pushing drag by lowering his hips when he recovers his legs and bringing his lower legs forward without pushing his thighs downward. The lower legs are smaller and move forward behind the trunk, therefore, recovering the legs in this way produces less resistive drag than pushing water forward with the larger thighs. The velocity graph for the wave style breaststroker illustrates that he decelerates less and for a shorter period of time when he recovers his legs forward. Notice that the flat style swimmer decelerates to a velocity of 0.20 m/sec while the swimmer on the right decelerates to only 0.80 m/sec.

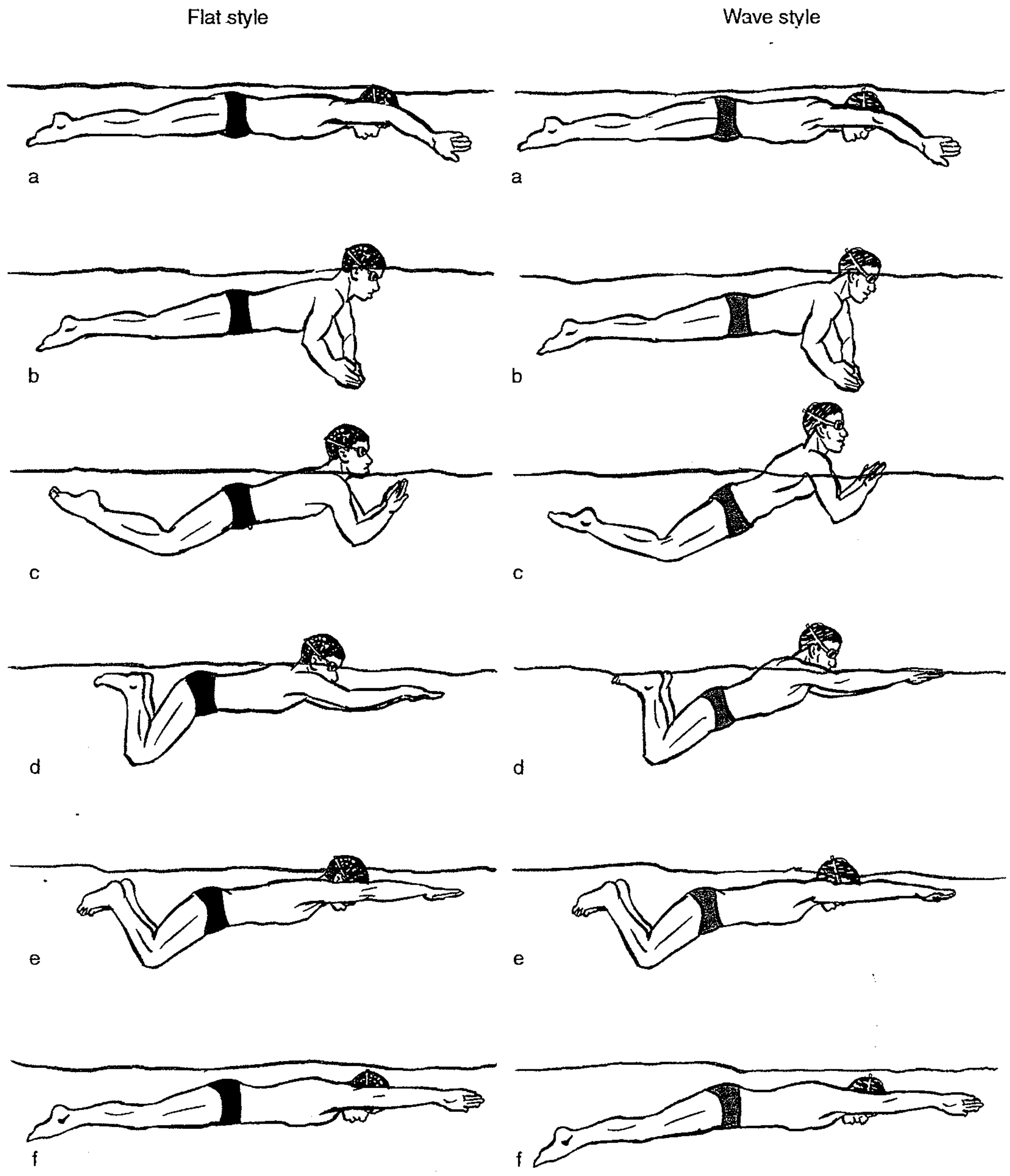


Figure 7.1 A comparison of the flat and wave styles of breaststroke.

Wave style breaststrokers also encounter less resistive drag because they maintain a tapered shape with the trunk and legs during the leg recovery. The body is inclined slightly downward from the head to the knees so that the streams of water can change directions gradually as the body and legs pass through them. This is indicated in figure 7.2 by the arrow under the swimmer's body depicting the relative direction of water flow. His head and shoulders must be raised in order to lower the hips and achieve this tapered body position, which may partially explain why many skilled breaststrokers bring the shoulders out of the water when they recover the legs. On the other hand, in the flat style of breaststroke, the legs form a flat wall-like surface to the oncoming water that will cause considerably more turbulence. Contrary to popular belief, swimmers who recover the legs by lowering the hips will not increase form drag by dropping the knees deeper into the water.

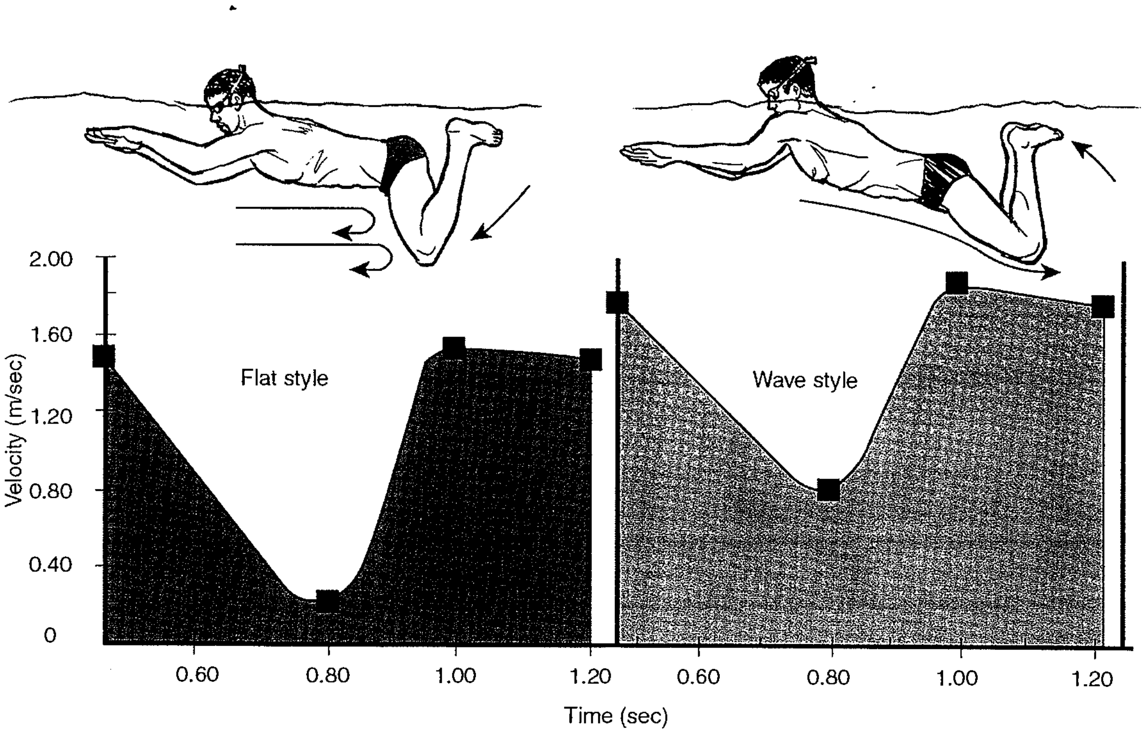


Figure 7.2 A comparison of resistive drag produced by leg recoveries in the flat and wave styles of breaststroke.

You may be thinking that swimmers could reduce resistive drag even more by using a flat body position and recovering the legs without pushing the thighs forward. This compromise is not possible, however. The feet would come out of the water if breaststroke swimmers tried to recover the legs while remaining flat. If the hips remain near the surface, breaststrokers cannot keep the feet underwater when they recover the legs forward unless they push the thighs down and forward. On the other hand, in the wave style, breaststrokers are able to keep the feet underwater without pushing the thighs down and forward because they lower the hips.

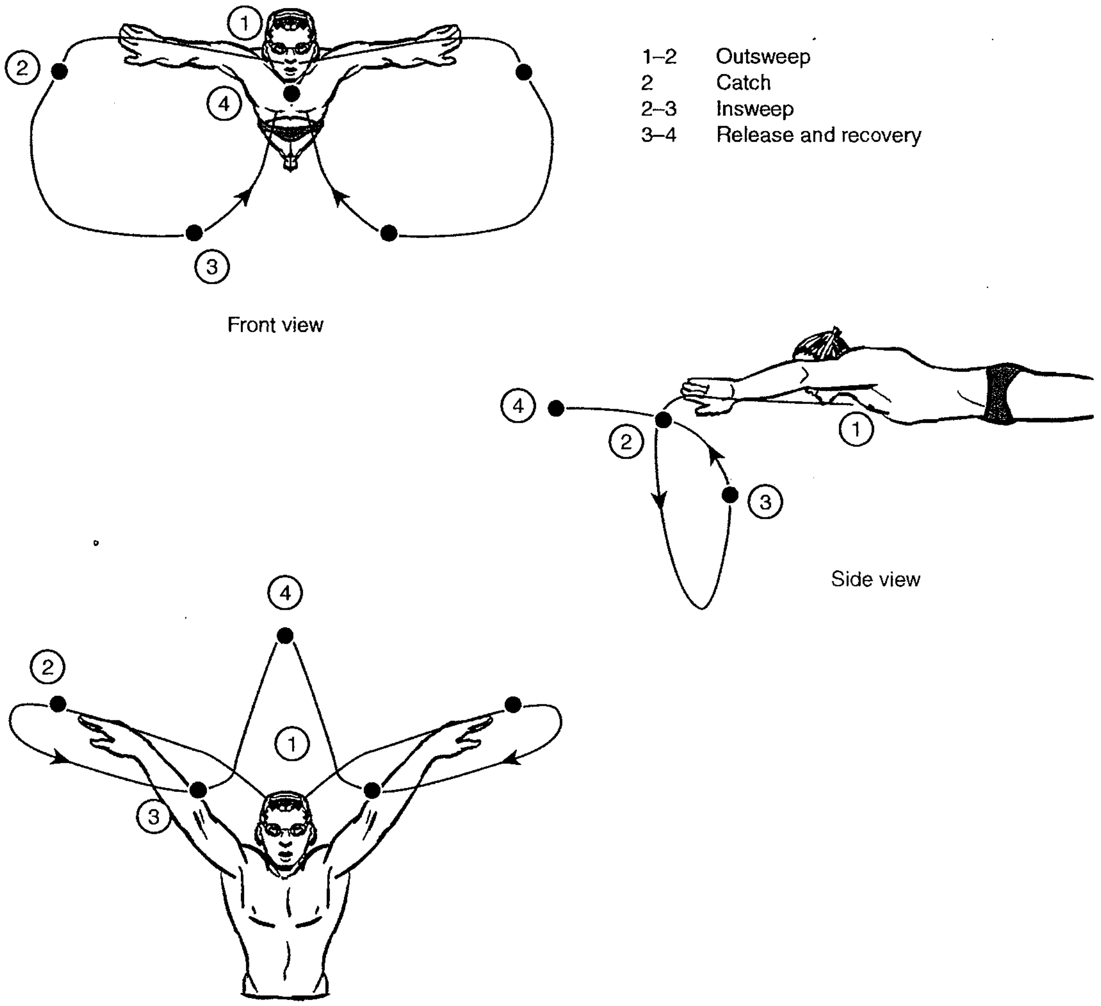
Stroke and Velocity Patterns

The first topic of this section is the armstroke patterns used by breaststrokers. This is followed by a discussion of kicking patterns. Forward velocity and hand velocity patterns will be described next and, because of their importance to propulsion, velocity patterns for the legs will also be described.

Armstroke Patterns

Typical front, side, and underneath armstroke patterns for the breaststroke are presented in figure 7.3. These patterns were drawn relative to the water. For purposes of description, the armstroke has been divided into four phases: the outsweep, the catch, the insweep, and the release and recovery.

Breaststrokers sweep the arms out and forward during the outsweep. Some swimmers also direct the arms slightly upward. This is particularly true of those swimmers who undulate the body when they swim breaststroke. The catch takes place as the arms travel outside the shoulders, where they can achieve a backward orientation. The insweep is a semicircular movement where the hands are brought in under the body. The arms continue traveling out in the first part of the insweep in order to overcome inertia gradually as they also start back and down. The arms continue moving out and down until they complete the first half of the insweep, at which time their direction



Front view

Side view

Underneath view

Figure 7.3 Front, side, and underneath stroke patterns for the breaststroke.

changes to back, up, and in. The propulsive phase of the insweep ends when the backward direction of the hands changes to forward as they are coming together under the shoulders. From there, the arms continue up, in, and forward until they reach the surface, at which time they are extended forward for the next stroke.

I want to draw your attention to three important aspects of these stroke patterns shown in figure 7.3.

1. The underneath view shows that the hands begin sweeping out before they are completely extended. There is no glide. Although the glide has traditionally been taught, it is not used by the majority of world-class breaststroke swimmers. There is a rest period for the arms, however, that takes place as they stretch forward and out to the catch. Swimmers keep the hands moving from the recovery into the outsweep in order to overcome their forward inertia as they change direction to outward.

2. The front view pattern shows that the hands sweep up slightly during the outsweep. This upward direction is deceptive. It is not really as great as it appears here. This is because stroke patterns are drawn by tracing the movements of the middle fingers of the hands. The middle fingers will naturally travel upward as the hands turn out during the outsweep, which gives the appearance that the arms have traveled up more than they actually have.

Most breaststroke swimmers sweep the hands directly out to the side. But those swimmers who tend to undulate the body will sweep the hands up somewhat during the outsweep. This is because the hands are pushed down somewhat as the hips undulate upward. Consequently, they slide them up as well as out during the outsweep to make the catch near the surface.

3. The front and side view stroke patterns show what, to some, may be a surprisingly large amount of downward motion during the first half of the insweep. Swimmers sweep the hands down nearly 60 cm (approximately 2 ft) during this phase of the armstroke. This downward motion serves two purposes: It brings the arms underneath the shoulders where they can be recovered forward with minimal pushing drag, and it aids in elevating the head and shoulders so that the legs can be recovered with a minimum of pushing drag.

Armstroke Variations

There seem to be two distinct styles of arm pulling in use by world-class swimmers today (Thayer et al. 1986). Some sweep the hands out and forward during the first portion of the armstroke and then in and back during the final portion. This is the pattern shown in figure 7.3. It usually results in one large surge in forward velocity during the armstroke.

The second style is almost the direct opposite of the one just described. The hands are swept out and back during the outsweep and in and forward during the insweep. This pattern, illustrated on the right hand side of figure 7.4, also results in one large

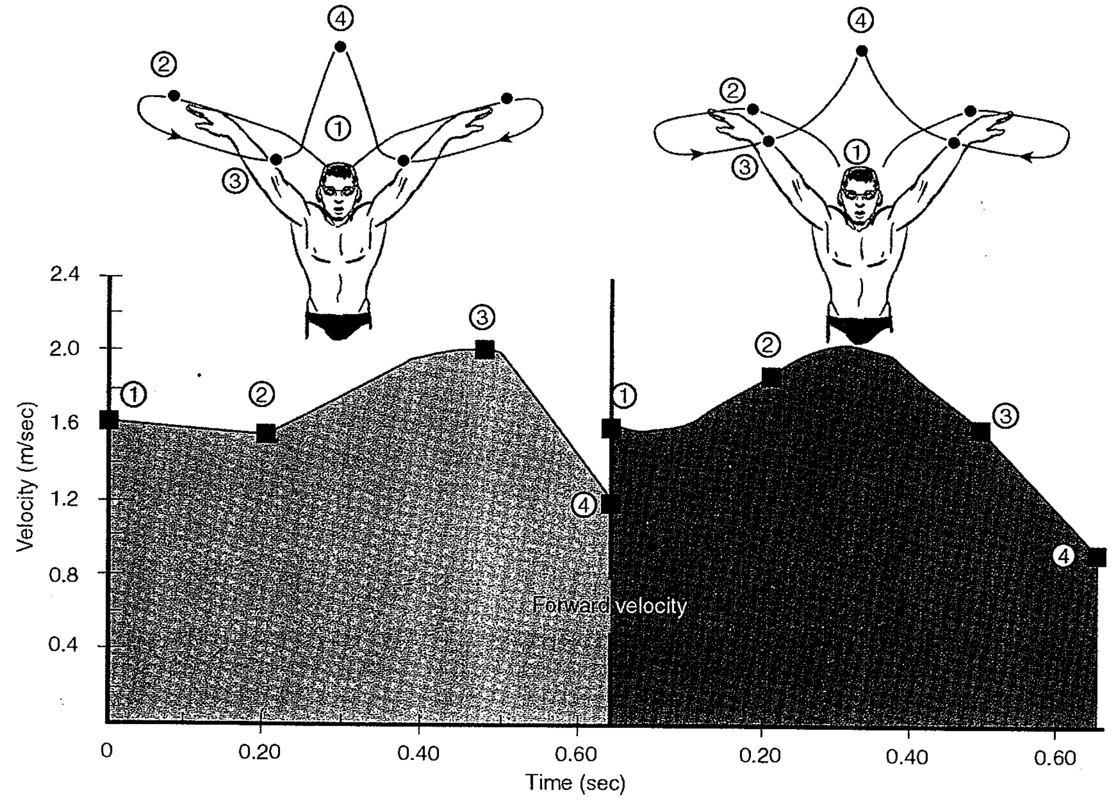


Figure 7.4 Propulsion during two types of breaststroke armstrokes. The graph on the left shows the pattern of sweeping the hands out during the outsweep and back during the insweep. The graph on the right depicts another common pattern of sweeping the hands out and back during the outsweep and in and forward during the insweep.

surge of forward velocity. In this case, however, the surge comes much earlier in the armstroke, during the last part of the outsweep and the first part of the insweep.

The velocity graphs in figure 7.4 show how swimmers accelerate the body forward with each of these contrasting styles. The graph on the left shows what happens to forward velocity when the arms travel forward and outward during the outsweep and back and in during the insweep. The body begins to accelerate forward late in the outsweep and continues accelerating forward throughout the insweep.

The graph on the right shows the effect on forward velocity when swimmers sweep the hands out and back during the outsweep and in and forward during the insweep. The body will begin accelerating forward earlier in the armstroke, but that acceleration will also end earlier. As shown in the graph, forward velocity accelerates most during the latter portion of the outsweep and the very first portion of the insweep, while the arms are pushing back against the water. Forward velocity decelerates during most of the insweep, however, after the hands start moving forward.

Where propulsion is concerned, the differences between the two styles shown in figure 7.4 are the following:

1. The outsweep is nonpropulsive for the swimmer on the left because his hands are moving forward as well as out. The entire insweep is propulsive, however, because the swimmer keeps his hands moving in and back until they are inside his shoulders.
2. The second half of the outsweep is propulsive for the swimmer on the right because he begins moving his hands back during that phase of his armstroke. This propulsion continues for a small portion of the insweep but terminates very early because his hands start moving forward.

Both of these methods can be effective. Indeed, they have proven to be so because they have been used by various world-class swimmers. Nevertheless, I believe that the stroke pattern illustrated on the left has the potential to be the more effective of the two. This is because swimmers reach maximum forward velocity just before the armstroke ends and the legs begin to recover forward. Because the leg recovery is the most potent retarding movement in this stroke, it follows that forward velocity may decelerate to quite the same extent during this phase of the stroke cycle if swimmers are traveling faster when it begins. By the same token, forward velocity will probably drop to a much lower level if swimmers have already begun decelerating before they begin to recover the legs forward.

Having said this, I should also mention that most swimmers prefer the style illustrated by the stroke pattern on the right. I suspect that these swimmers sweep the hands in and forward because of the emphasis coaches have placed on training them to get the hands forward quickly during the recovery. This emphasis has caused many swimmers to sweep the hands forward almost immediately when they start sweeping them in. I believe this is a serious technical error that causes many swimmers to lose velocity and distance per stroke. Swimmers would be better advised to sweep the hands in and back during the insweep so that they can maintain propulsion during this phase of the armstroke. This additional propulsion should more than compensate for the propulsion they lose during the outsweep. In addition, pushing the hands forward against the water during the insweep will only cause them to decelerate more than they otherwise might. The body should be traveling forward at peak velocity at the end of the insweep so that they will not decelerate as much when they recover the legs forward.

Kick Patterns

The directions the feet move during the breaststroke kick are drawn from front, side, and underneath views in the kick patterns shown in figure 7.5. The phases of the kick are the recovery, the outsweep, the catch, the insweep, and the lift and glide.

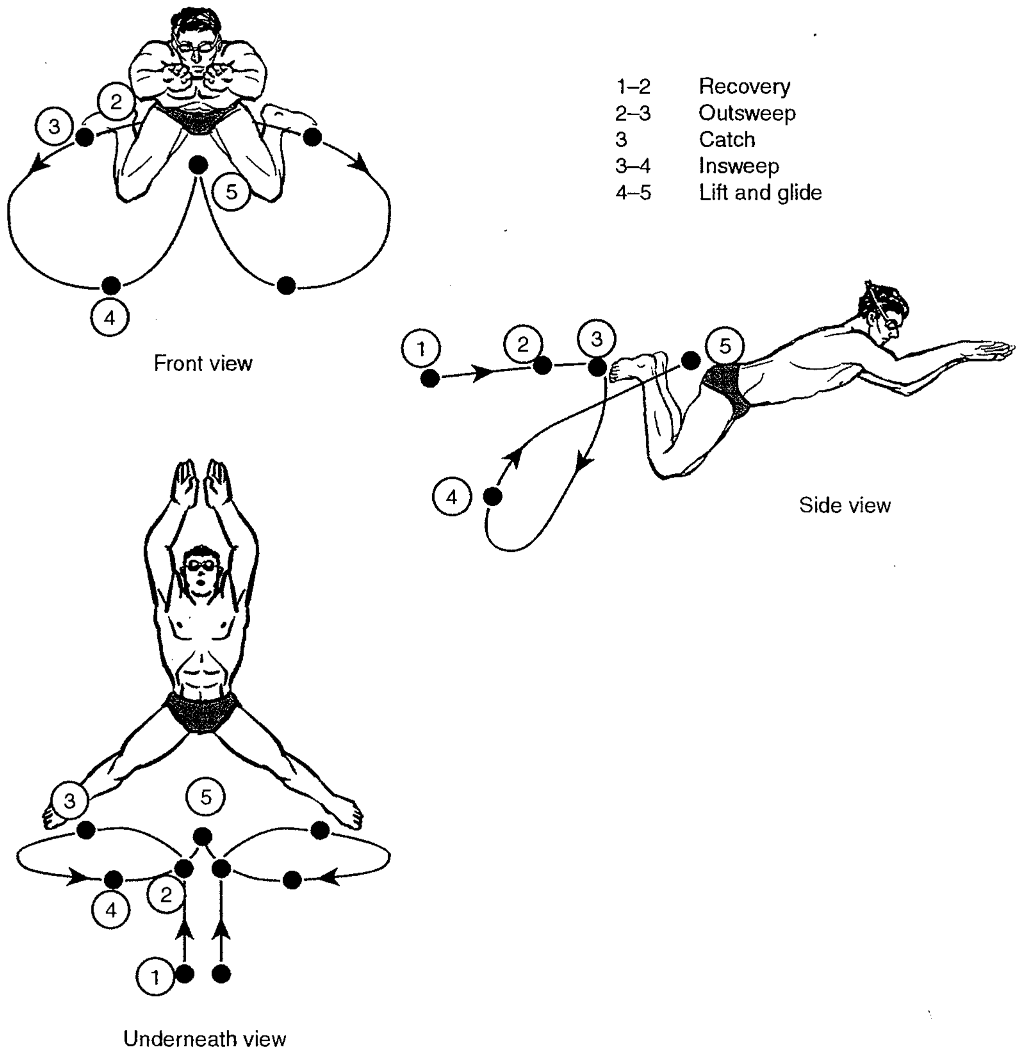


Figure 7.5 Typical side, front, and underneath view patterns of motion for the breaststroke kick. These patterns were drawn relative to the water.

The kick cycle begins as the feet and lower legs are recovered forward. As they approach the buttocks, the feet are swept outward as well as forward until they are outside the shoulders and facing back. This is where the catch takes place and swimmers begin to apply propulsive force. The front view pattern shows clearly that the propulsive phase of the breaststroke kick is a circular movement. From the catch, swimmers sweep the legs out, back in, and then down until they are completely extended at the knees and nearly together. From there, the legs move up into alignment with the body and are held in a streamlined position while the propulsive phase of the armstroke is executed.

Three important technical points are illustrated by these kick patterns. The first concerns the amount that the legs sweep downward during the insweep of the kick, approximately 50 to 60 cm (20 to 24 in). This directional component is deceptive, however. While the legs do travel downward during the insweep, the distance is only about half of what it appears to be in these patterns.

The legs seem to move down more than they actually do because the kick pattern is drawn by tracing the path of the big toe. With the legs flexed at the knees and the feet turned out and pulled forward at the ankles, the toes will be almost at the surface when the insweep begins. The feet will then rotate down as the legs are extended back. Therefore, depending on the size of a particular swimmer's feet, 15 to 30 cm (6 to 12 in) of the distance the legs appear to travel down will simply be due to the fact that the feet are rotated down during the insweep.

The second misleading technical feature of these patterns has to do with the small amount that the legs appear to travel back during the insweep. We might expect to see the legs move back more during the insweep if pushing water back was the primary source of forward propulsion. I cannot explain with certainty why the legs do not move back more. I can, however, offer one possible reason.

The most obvious of these reasons may be that the forces of lift and drag contribute almost equally to the propulsive force of the breaststroke kick. Figure 7.6 illustrates how propulsion from the breaststroke kick may be a result of nearly equal production of lift and drag forces. The vector analysis of that portion of the insweep between the two horizontal bars shows that a considerable amount of propulsive force could be produced, even though the feet are moving down more than back during this phase. While the lift force produced combines with drag to form a fairly sizable forward propulsive force, it also constitutes a sizable upward force on the hips. This may explain why many breaststrokers appear to pike at the hips slightly during this phase of the breaststroke kick.

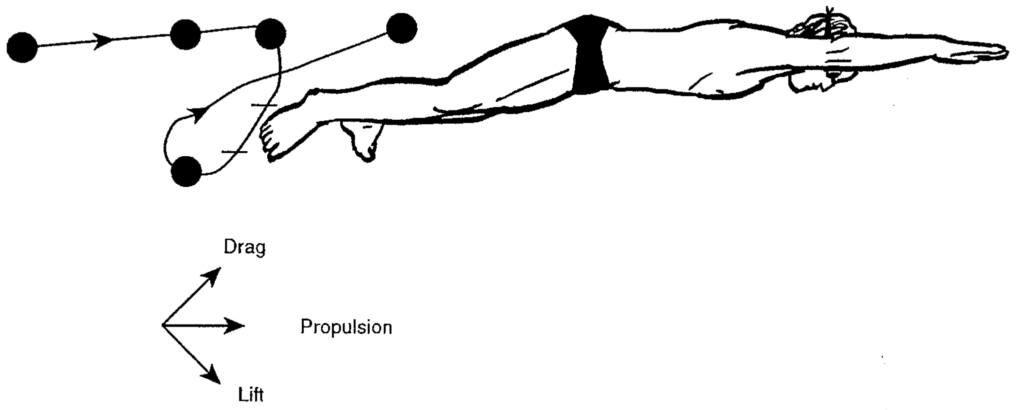


Figure 7.6 The illustration shows how propulsion may be generated by a combination of lift and drag forces during the insweep of the kick.

The final technical feature of these kick patterns that I want to comment on is the slight difference between the movements of the right and left legs. Underneath kick patterns show that swimmers' right legs have a longer and wider pattern of motion than their left. Asymmetry of this type is typical of most breaststroke swimmers (Czabanski and Koszczyc 1979). Just as all swimmers seem to have one arm that is more effective than the other, so do the legs differ in propulsive efficiency. The left leg is usually the inferior limb (Czabanski 1975).

The three most logical explanations for leg asymmetry in breaststroke are (1) less strength in one leg relative to the other, (2) differences in the size of the two legs, and (3) greater range of motion in one leg relative to the other. Research indicates the latter explanation is the more likely of the three. Czybanski (1975) found that two groups of swimmers, with good and poor breaststroke kicks, did not score differently on tests of leg strength. On the other hand, Nimz and associates (1988) reported differences between the right and left legs in measures of knee joint flexion and eversion (turning the feet out). The latter group of researchers did not find any significant differences in measures of leg length, width, or circumference, however. These data suggest that exercises to increase the range of motion in the knee and ankle joints might improve kicking speed.

Hand, Foot, and Forward Velocity Graphs

The graphs in figure 7.7 show typical forward, hand, and foot velocity graphs for a competitive breaststroke swimmer. I will describe each of these, beginning with forward velocity.

Forward Velocity Graphs

The forward velocity of a breaststroker's center of mass is shown during one complete stroke cycle in the lower graph in figure 7.7. He was swimming at 200 m speed when these data were collected. The graph begins at 0 sec on the timeline. That is the point where his arms start to sweep out after he has recovered them forward. The swimmer is traveling forward at approximately 1.60 m/sec at that time. His forward speed comes from the final portion of his kick as his legs are coming together. After completing the propulsive phase of his kick, his speed drops off slightly, to 1.30 m/sec, while he sweeps his arms out to the catch position. He makes his catch at approximately 0.18 sec.

After the catch, he sweeps his arms out, down, and in. His forward velocity reaches a high of approximately 1.70 m/sec just before he releases pressure on the water at the end of the insweep with his arms. The propulsive phase of the insweep occurs when he is approximately 0.55 sec into his stroke cycle. After the insweep, his forward velocity decelerates for a short time as he recovers his arms up to the surface and his legs begin to recover forward. Notice, however, that his forward velocity increases, once again, shortly after he begins to recover his limbs and continues to increase until he is approximately 0.90 sec into his stroke cycle. This increase is due to wave propulsion.

He decelerates sharply when the wave effect dissipates and his forward velocity drops to 1.00 m/sec as his arms move forward and his legs flex even more during their recovery. This deceleration takes place when he is approximately 1.10 sec into his stroke cycle. The rate of deceleration is quite rapid and pronounced because he is pushing

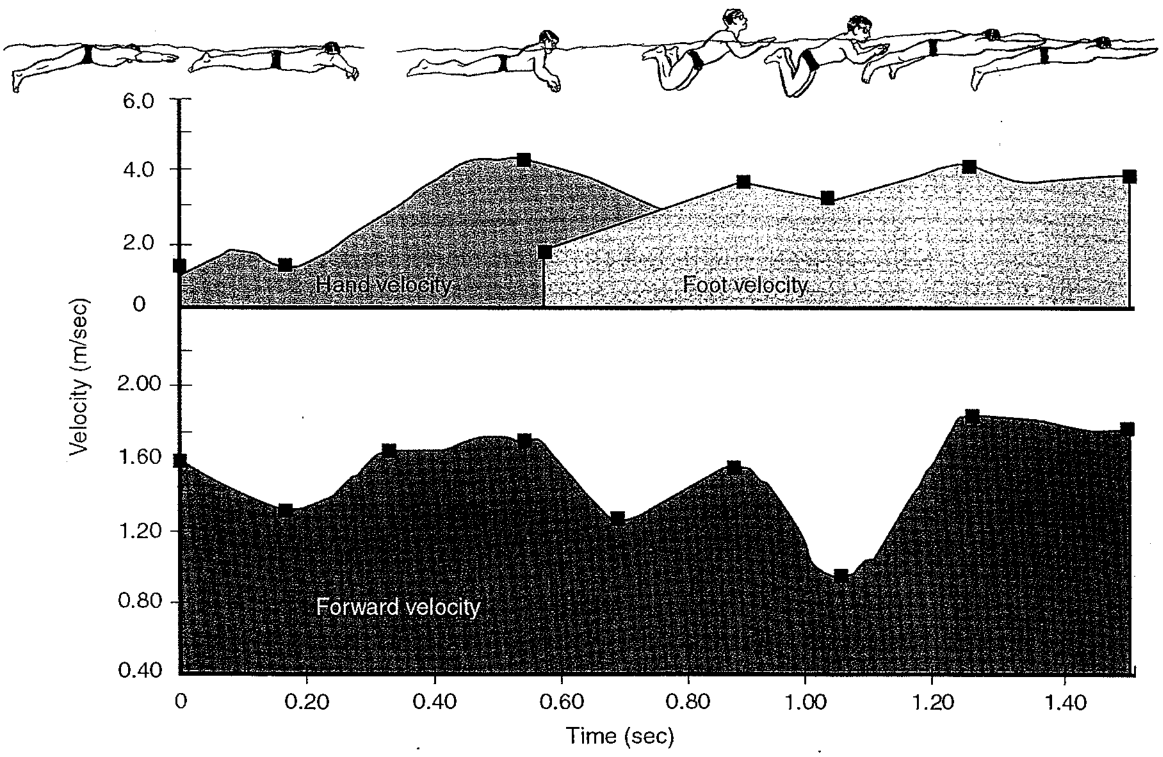


Figure 7.7 Typical forward, hand, and foot velocity patterns for breaststroker Glenn D. Mills.

both legs and arms forward through the water. Most world-class breaststrokers decelerate to speeds of approximately 1.00 m/sec during this time (Thayer et al. 1986). Less-skilled breaststrokers, however, actually stop moving forward for an instant near the end of the leg recovery (Craig, Boomer, and Skehan 1988).

The swimmer in figure 7.7 accelerates very rapidly from this valley of deceleration once the propulsive phase of his kick begins. He reaches his peak velocity of approximately 1.80 m/sec about midway through the insweep of his legs and he maintains nearly that same velocity until he stops pushing back against the water with his feet at the end of their propulsive phase. He stops pushing back approximately 1.49 sec into his stroke cycle.

Most world-class breaststrokers reach similar peak velocities with the arms and legs. They accelerate their bodies forward for a longer time with their arms than they do with their legs, however. Nevertheless, the kick is clearly the dominant propulsive agent in this stroke. This swimmer's forward velocity increases nearly 0.90 m/sec during the kick. It increases only 0.40 m/sec during the armstroke. Thus, swimmers do not accelerate the body forward as much with the arms as they do with the legs, even though peak velocities are similar during both phases of the stroke. That is because propulsion from the kick begins when forward velocity is at its lowest point in the stroke cycle, whereas they begin to accelerate the body forward with the arms when they are already traveling much faster.

Two observations about the forward velocity pattern in figure 7.7 provide important information concerning the techniques of breaststroke swimming. The first is the valley of deceleration during the leg and arm recoveries. One of the most important differences between world-class and less-successful breaststrokers can be attributed to this phase of the stroke cycle. World-class breaststroke swimmers decelerate less and they spend less time in this valley. The best swimmers do not decelerate much more than 1 m/sec during this time and they do not spend more than 0.30 sec in that valley. Less-skilled breaststrokers will often decelerate 1.50 m/sec or more and they will spend 0.40 to 0.60 sec in the valley before completing the leg recovery.

The second observation concerns the third, or middle, propulsive phase during the stroke cycle, the one that results from wave propulsion. During the armstroke, swimmers will be pushing the body forward against a large wall of water and will also be pulling some water forward with them in the wake. When forward velocity decelerates quickly at the end of the armstroke, that water will fill in behind and the wake will surge forward, accelerating the body forward as it does so. The acceleration of forward velocity due to wave propulsion is usually similar in magnitude to forward acceleration from the armstroke, although it is not maintained for the same length of time.

Only wave style breaststrokers gain the magnitude of wave propulsion illustrated in figure 7.7. Breaststroke swimmers who use the flat style will not experience the same magnitude of wave propulsion during arm and leg recoveries, as described earlier.

Obviously, wave propulsion can be a great benefit to breaststroke swimmers. For one thing, adding a large, third propulsive phase will significantly increase average velocity per stroke cycle. For another, wave propulsion, because it takes place while swimmers are recovering the arms and legs, reduces both the time they spend decelerating and the extent to which they decelerate during the arm and leg recovery. Finally, wave propulsion is quite economical. In a sense, it is free propulsion because it does not require any muscular effort.

Another velocity pattern that shows the effect of wave propulsion is provided in figure 7.8. The swimmer is Silke Horner, former world record holder in the 100 m breaststroke. Notice when the wave propulsion takes place during the stroke cycle. It is just after she starts recovering her arms and legs forward. This is when her upper body is at its highest point out of the water and before her arms begin pushing forward through the water. The wave propulsion is marked by the dark shaded area on the velocity graph. The position of her body during this phase is shown in the inset.

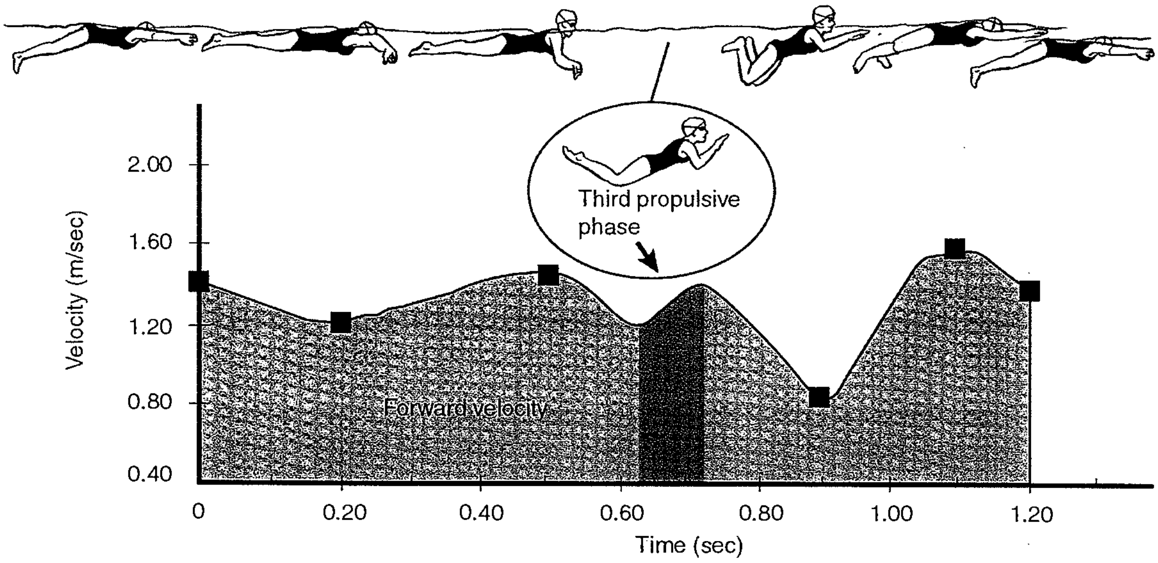


Figure 7.8 A velocity pattern for a world-record holder in the breaststroke. The swimmer is Silke Horner, former world-record holder in the 100 m breaststroke.

Adapted from Mason, Patton, and Newton 1989.

The timing of her wave propulsion shows clearly that it is not caused, as some believe, by swimmers lunging forward when they extend the arms during their recovery. Her forward acceleration took place before that time and she is already decelerating before she extends her arms forward. It is possible that lunging forward may reduce the extent to which swimmers decelerate as they extend the arms forward. Horner's acceleration in forward speed from wave propulsion is caused by other mechanisms, however, most likely waves of water from her wake that surge forward as she begins to decelerate after the propulsive phase of her kick ends.

Hand and Foot Velocity Graphs

Hand velocity is represented by the dark shaded graph at the top of figure 7.7 (see page 228). The swimmer's hands are traveling at approximately the same speed as his body when they begin the outsweep at 0 sec on the timeline. They accelerate slightly during the outsweep and then slow until they are, once again, traveling at the same speed as his body when the catch is made, approximately 0.20 sec into his stroke cycle. Thus, this swimmer apparently moves his hands slowly through the outsweep and allows them to come almost to a complete stop at the catch before initiating the insweep. Once the catch is made, his hand speed accelerates rapidly throughout the insweep phase of his armstroke until he stops pushing back against the water at approximately 0.55 sec into his stroke cycle.

The maximum velocity the swimmer's hands reach during the insweep is more than double their speed at the catch (1.30 vs. 4.00 m/sec). Hand speeds start decelerating when he begins to recover his arms forward and they continue to decelerate until the catch is made for the next stroke cycle. As was the case with the other competitive strokes, increases and decreases in hand velocity mirror changes in his forward velocity during his armstroke.

The velocity of the swimmer's feet is illustrated by the light shaded graph at the top of figure 7.7. His legs were gliding motionless during the armstroke, as indicated by the fact that they were being pulled forward at the same velocity his body was moving during that time.

He begins his leg recovery immediately after the propulsive phase of his armstroke is completed, at approximately 0.55 sec into his stroke cycle. He recovers his legs forward rather rapidly. They reach a speed of approximately 3 m/sec just before they start sweeping out to make their catch. Their speed decelerates during the outsweep until the catch is made at approximately 1.08 sec into the stroke cycle. The swimmer accelerates his legs rapidly once the propulsive phase of the kick begins. They continue to accelerate during the backward and downward portion of their insweep, reaching a velocity of approximately 4 m/sec when his legs are completely extended and just before they start sweeping in toward one another.

The velocity of his feet decelerates slightly while they change directions from out to in, after which they accelerate once again until the insweep is nearly completed at approximately 1.48 sec into the stroke cycle. Once the propulsive phase of his kick has been completed, the swimmer's legs will decelerate while they are lifted toward the surface to their streamlined glide position.

The most surprising aspect of this foot velocity pattern is how fast the swimmer moves his feet during the recovery. He, undoubtedly, did this to shorten the deceleration period while he recovered his legs and arms. Recovering his legs fast probably increased their pushing drag somewhat and, in doing so, reduced his forward velocity more than it might have otherwise been reduced. Regardless, breaststrokers, apparently, prefer to reduce forward velocity rapidly for a short time by recovering the legs quickly rather than to reduce it less rapidly for a longer time by recovering the legs slowly. The trade-off must be a good one where average velocity per stroke cycle is concerned. Otherwise they would not recover the legs so rapidly.

It should be emphasized, however, that breaststrokers should try to reduce the pushing drag from the legs as they recover them. In this respect, they should slip the legs forward in the most streamlined position possible, even though they are bringing them forward quite rapidly.

Another important aspect of the foot velocity pattern involves the timing of the leg recovery. Notice that the swimmer does not begin to recover his legs forward until the propulsive phase of his armstroke has been completed. This does not mean that he waits until his arms are stretching forward along the surface before he recovers his legs. The propulsive phase of his armstroke will end when his hands are coming together inside his shoulders. This is when he should begin to recover his legs forward so that the delay between the end of his arm propulsion and the beginning of propulsion from his legs will be as short as possible.

While some swimmers wait too long after the arm propulsion ends before they begin recovering the legs forward, there are others who don't wait long enough. Many swimmers believe, mistakenly, that they can reduce the deceleration period between the propulsive phases of the armstroke and kick if they start recovering the legs while the arms are still accelerating them forward. What they fail to realize is that the recovery movements of the legs will cause pushing drag that will reduce the forward velocity they can attain with the armstroke. The result may be that lower forward velocity during the armstroke will reduce average velocity for the entire stroke cycle more than it would have been reduced by a slight delay between the end of the propulsive phase of the armstroke and the propulsive phase of the kick. Apparently, this is the case, because all of the world-class breaststroke swimmers we have studied prefer to wait until the propulsive phase of their armstrokes is completed before they recover the legs (Thayer et al. 1986).

Armstroke

The armstroke has been separated into four phases: (1) the outsweep, (2) the catch, (3) the insweep, and (4) the recovery, for the purpose of describing it. The sequence of photographs in figure 7.9 show the armstroke from a side view while a front view of the armstroke is presented in figure 7.10.

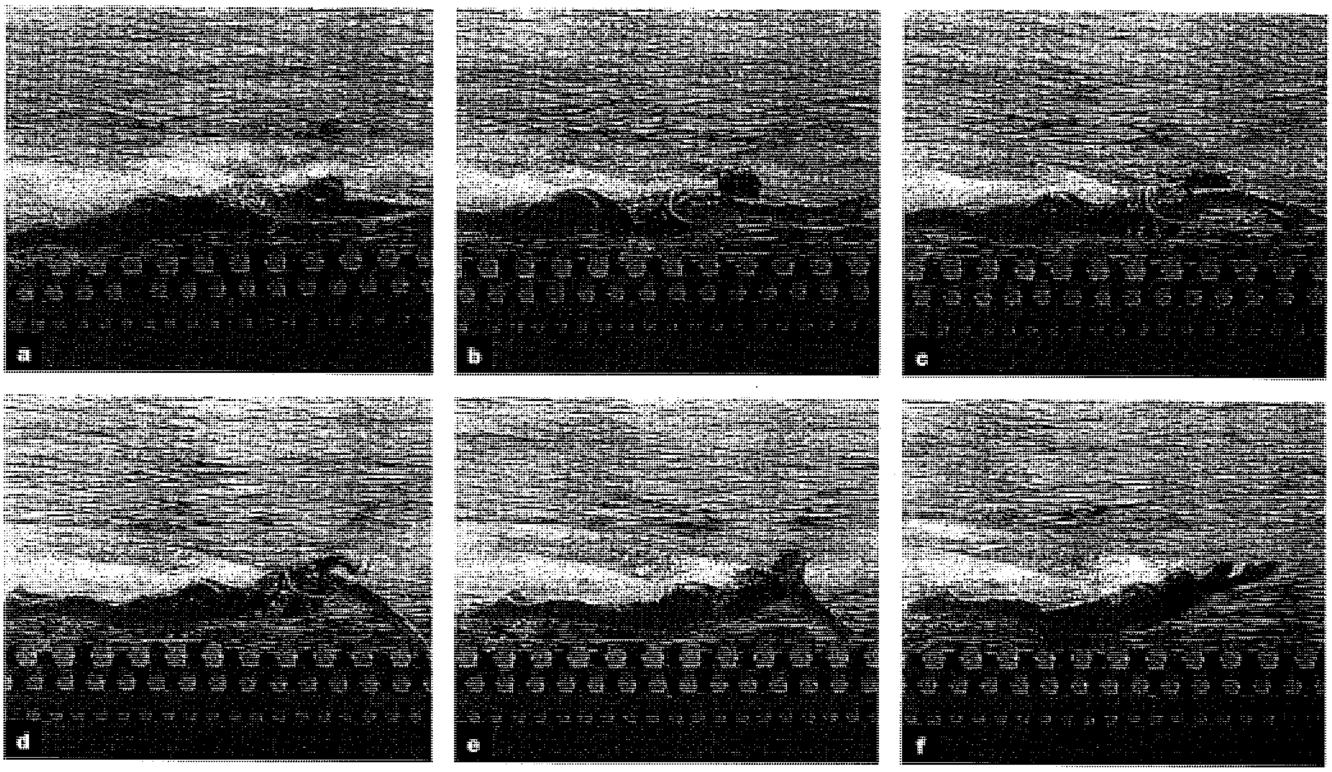


Figure 7.9 A side underwater view of the breaststroke. The swimmer is Anita Nall, former world-record holder for the 200 m breaststroke.

(a) Start of stroke cycle. Completion of insweep of the kick. Start of outsweep with arms.
(b) Lift with legs to streamlined position. Continuation of the outsweep with arms. Start of head lift toward surface.
(c) Catch with arms. Start of insweep.
(d) Mid-insweep of armstroke
(e) Start of recovery with arms and legs. Inhalation.
(f) Arms reach surface. Wave propulsion phase takes place.

Outsweep

The outsweep is pictured in figures 7.9 and 7.10, a through c. Swimmers begin the outsweep by sliding the arms out and forward as they near complete extension at the end of the recovery. The hands should trace a semicircular path, sweeping out, forward, and slightly up until they pass outside the shoulders where the catch is made. While sweeping them out, swimmers should flex the arms at the elbows in order to place them in a backward-facing position as soon as possible during the outsweep. The outsweep is not a propulsive phase of the stroke. Its main purpose is to place the arms in position to accelerate the body forward during the insweep that follows.

Swimmers should not glide after they extend the arms forward. This will only cause them to decelerate longer between the end of the propulsive phase of the kick and the beginning of the propulsive phase of the armstroke. Propulsion from the arms does not begin immediately when swimmers start moving them to the side. Forward velocity actually continues to decelerate during the outsweep until the arms and hands are in position, outside the shoulders, to begin pushing back against the water. Thus, when swimmers extend the arms forward and out without gliding, they will reduce the length of deceleration time after the legs have stopped accelerating the body forward.

The hands should be facing down when the outsweep begins and remain so until they travel outside the shoulders. They travel on edge, with little fingers leading, so that a smaller surface area is presented to the water. Once the hands pass outside the

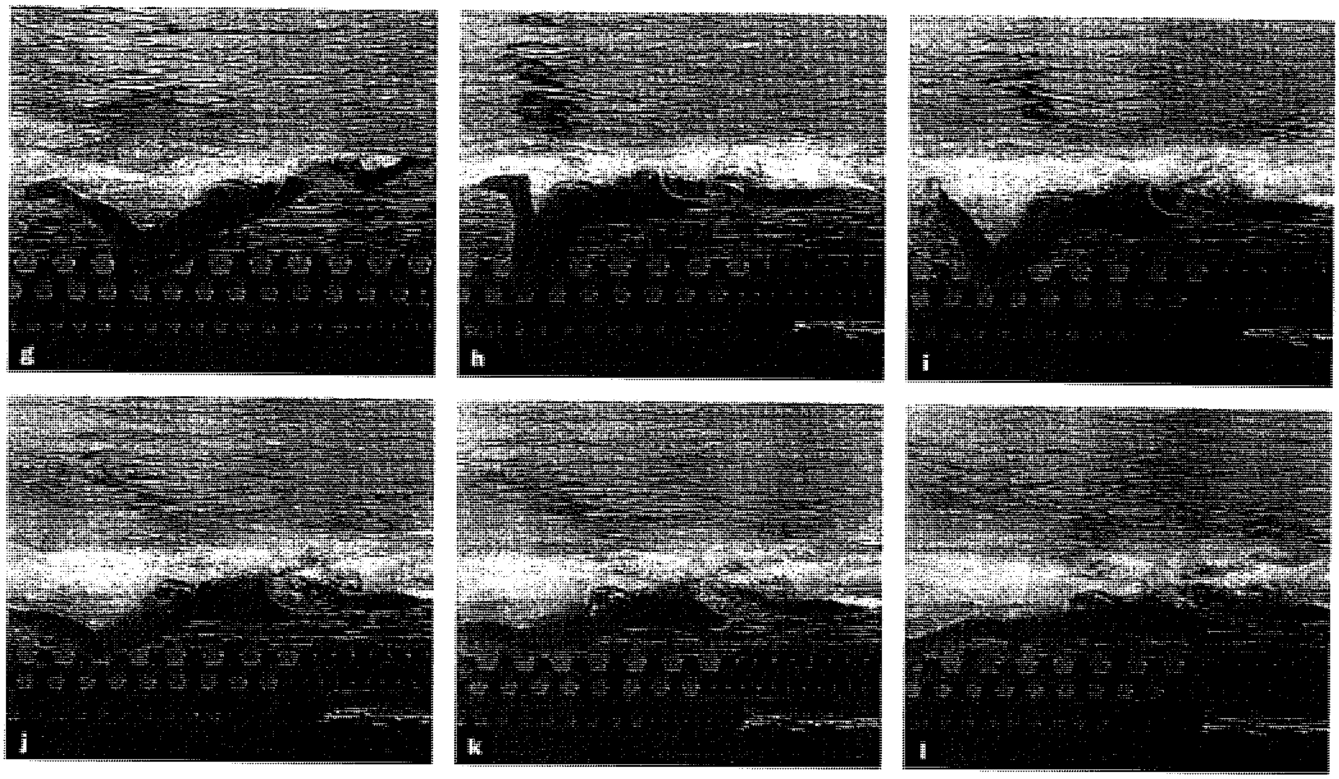


Figure 7.9 *(continued)*

(g) Palms turn flat and begin extending forward along the surface. Head drops toward surface, and hip flexion phase of leg recovery begins. Wave propulsion phase is over.
(h) Arms extend forward. Continuation of leg recovery, with legs sweeping out to catch.
(i) Outsweep of legs, with Anita pushing water back and out. Her arms remain extended with head down in streamlined position.
(j) Outsweep of kick ends and insweep begins. Arms remain extended with head down in streamlined position.
(k) Insweep of legs continues. Arms remain extended with head down in streamlined position.
(l) Propulsive phase of leg kick ends. Leg lift begins. Outsweep of arms continues.

shoulders, swimmers should begin flexing the arms at the elbows and rotate the palms of the hands outward to face them out and back when they reach the catch position. Although swimmers may flex the wrists during the early portion of the outsweep, the hands and forearms should be aligned when the catch is made.

The hands will be traveling somewhat faster than the body during the transition from recovery to outsweep, but then they should gradually decelerate during the outsweep until they are almost motionless when the catch is made.

Catch

The catch is shown in figures 7.9c and 7.10c. It takes place when the hands and arms are outside the shoulders and facing back. The elbows should be flexed approximately 90° at this time.

Insweep

The insweep is shown in figures 7.9 and 7.10, c and d. The insweep, the only propulsive phase of the armstroke, begins when the catch is made with the arms outside the shoulders. Then swimmers should execute a large, semicircular sweep in which they sweep the arms and hands back, down, in, and up until the arms are behind the shoulders and the hands are passing under the shoulders.

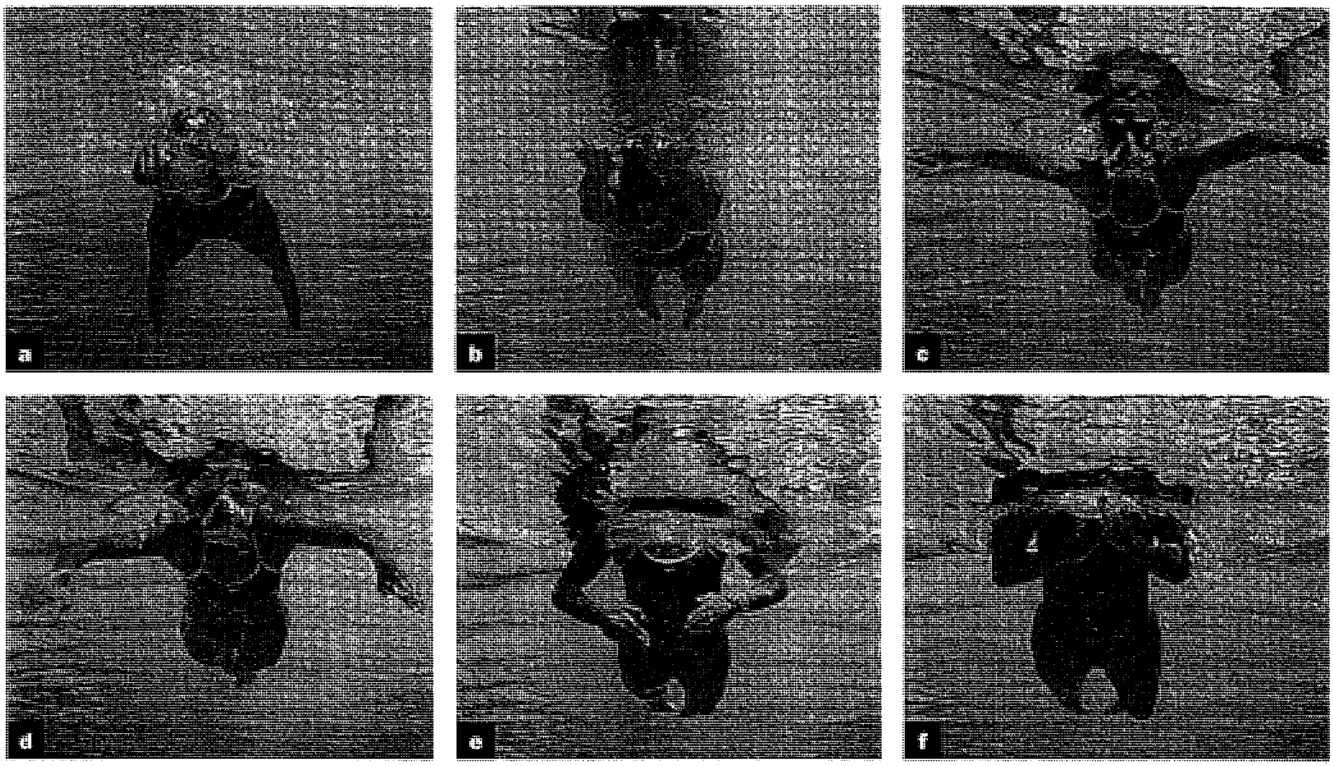


Figure 7.10 A front underwater view of the breaststroke. The swimmer is Anita Nall.

(*a*) Start of stroke cycle. Completion of insweep of the kick. Start of outsweep with arms.
(*b*) Lift with legs to streamlined position. Continuation of the outsweep with arms. Start of head lift toward suface.
(*c*) Catch with arms. Start of insweep.
(*d*) Mid-insweep of armstroke.
(*e*) Start of recovery with arms and legs. Inhalation.
(*f*) Arms reach surface. Wave propulsion phase takes place.

This statement goes against traditional tenets of the breaststroke armstroke. For decades, swimmers have been cautioned to prevent the hands and arms from traveling back behind the shoulders during the insweep. The belief is that the arms will get stuck under the body, causing a hesitation in the transition from the propulsive phase of the armstroke and the arm recovery when swimmers will decelerate markedly. Many believe that sculling the hands directly inward during the insweep will provide as much propulsion as possible during this phase of the stroke without causing a hesitation during the transition from pull to recovery. I disagree, however. I believe swimmers should sweep the arms diagonally back under the body during the insweep and that they should press back against the water with the hands and arms as they do so. Figure 7.11 illustrates the way, I believe, swimmers apply propulsive force during the insweep of the breaststroke.

As indicated, the catch takes place when the undersides of the arms and the palms of the hands have traveled out sufficiently to achieve a backward orientation to the water. The arms will be outside the shoulders, near the surface, and they will be flexed at the elbows when the catch is made. From that point, swimmers should push back against the water with the undersides of the arms and the palms of the hands until the arms are back behind the shoulders and moving in toward the ribs. The hands will be under the body and inside the shoulders at this time.

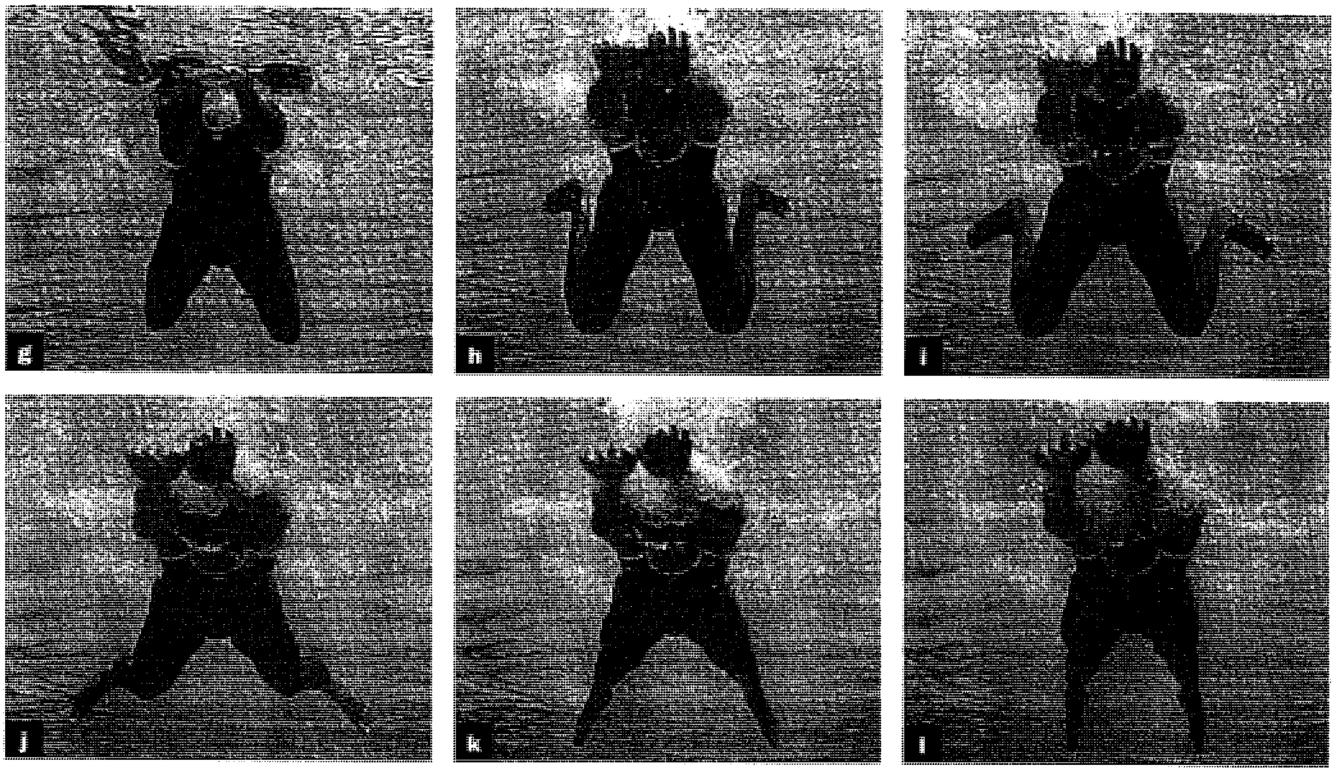


Figure 7.10 *(continued)*

- *(g)* Palms turn flat and begin extending forward along the surface. Head drops toward surface. Hip flexion phase of leg recovery begins. Wave propulsion phase is over.
- *(h)* Arms extend forward. Leg recovery continues.
- *(i)* Outsweep of legs continues, with Anita pushing water back and out. Her arms remain extended with head down in streamlined position.
- *(j)* Outsweep of kick ends. Arms remain extended with head down in streamlined position.
- *(k)* Insweep of kick is underway. Arms remain extended with head down in streamlined position.
- *(l)* Legs sweep in. Arms begin outsweep.

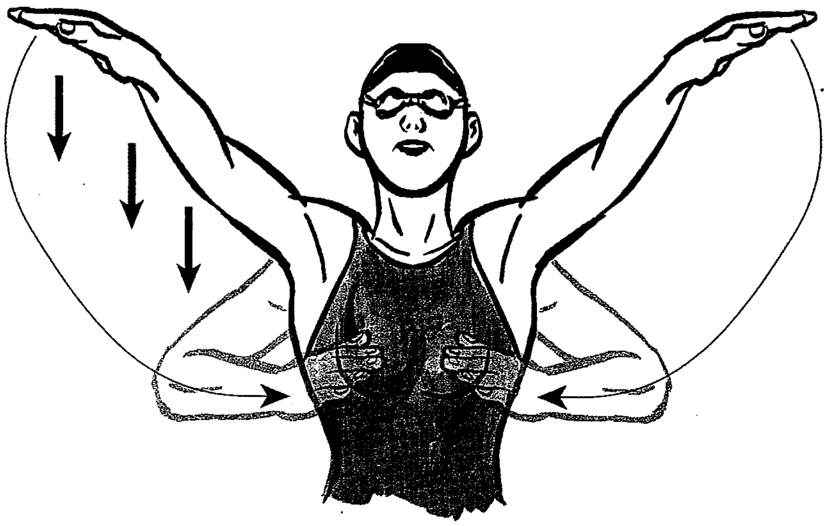


Figure 7.11 The insweep of the breaststroke.

The palms of the hands, which were facing out and back at the catch, will be facing in and up at the end of the insweep. Swimmers should not rotate the hands in at the wrists to accomplish this, however. The palms should stay in alignment with the rest of the arms so that they are facing out early in the insweep when the arms are sweeping out, as in figures 7.9d and 7.10d. They will be facing in late in the insweep when the arms are traveling inward, toward the sides. Swimmers should accelerate the velocity of the arms from the catch throughout the insweep.

This sweep is more difficult to describe than it is to do. To simplify, swimmers should make the catch with the arms in the position described earlier. From there, they should press the arms back, down, and in, toward the ribs, until the hands are nearly together and inside the shoulders.

Recovery

The arm recovery is shown in figures 7.9 and 7.10, e through h. The arm recovery should begin when the hands have passed inward under the shoulders. At that time, swimmers should stop pushing back against the water and squeeze the arms down and in under the shoulders. This elbow squeeze will overcome the backward inertia of the hands and start them moving upward and forward into the recovery.

The hands should continue moving up and forward until they are at the surface of the water just in front of the face. They should reach the surface together, palms facing somewhat upward, as figures 7.9f and 7.10f. Swimmers should then turn the palms down and bring the forearms to the surface before sliding the arms forward, as shown in figures 7.9g and 7.10g. Swimmers should then slide the arms forward along the surface until they are almost completely extended in front. Moving the arms forward along the surface will reduce pushing drag as compared to pushing them forward through the water.

Swimmers should not stop the arms in an extended position at the end of the recovery. Instead, they should begin sliding the arms out to the sides as they near an extended position overhead. This will help overcome the forward inertia of the arms and start them moving outward into the outsweep of the next stroke cycle with a minimum of effort.

The arms have the potential to create a considerable amount of pushing drag as they are recovered forward. Therefore, swimmers should slide them forward quickly, but gently, in a very streamlined manner.

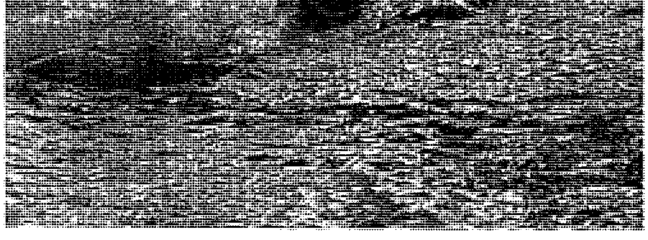


Figure 7.12 A swimmer recovering her arms over the water. Notice the turbulence around her forearms, which are being pushed forward against the water.

Controversial Aspects of the Recovery

The techniques swimmers use to recover the arms forward are, perhaps, more controversial than any other phase of the breaststroke. Some experts advise swimmers to recover the arms over the water. Others recommend that they should not turn the palms up. Still others suggest that swimmers should lunge forward as they recover the arms.

What I have just written concerning reducing pushing drag might lead some readers to think that breaststroke swimmers should recover the arms over the water. I do not recommend this technique, despite the fact that it has been used by some very successful breaststroke swimmers. The breaststroke swimmer in figure 7.12 is recovering her hands over the water.

This method is not recommended because breaststroke swimmers cannot really eliminate or even reduce pushing drag by recovering the arms over the water. The rules require that the elbows remain underwater during each stroke and that the forearms push forward through the water, even though the hands are out of the water. Because of their poor streamlining, any attempt to recover the arms over the water will create more pushing drag than simply sliding them forward along the surface in a more streamlined position.

Coaches often debate whether swimmers should rotate the palms up during the recovery. Although rotating the palms up is not, in itself, propulsive, it is a natural follow-through action that indicates the insweep was performed correctly.

If the insweep is done properly, as it nears completion, the palms will be rotating in and up very rapidly. Consequently, the inertia of the hands will cause the palms to continue rotating up through the first portion of the recovery in a natural follow-through motion that will continue until the palms are actually facing up when the hands reach the surface. This is what should happen if swimmers are maximizing propulsive force during the final portion of the insweep. The only way swimmers could change the rotational direction of the palms from up to down after their recovery begins would be to decelerate the velocity of the arms during the final portion of the insweep. This would, of course, reduce the propulsive force produced at that time. The palms will, and should, turn up during the recovery. But they should again be turned down at the surface before swimmers start sliding them forward.

Many swimmers are being taught to accelerate the hands forward during the recovery in a style that has been characterized as a *lunge*. Although I have not seen the effect on forward velocity for swimmers who use this technique, data collected on breaststroke members of the 1984 U.S. Olympic swimming team show that they do not accelerate their arms during this phase. I suspect that swimmers appear to lunge forward because they begin the propulsive phase of the kick as they stretch the arms out. They do not really accelerate the arms forward because this would increase pushing drag during the arm recovery.

Alternate Arm Pull

The change of limb direction from out to in during the insweep is very difficult for many breaststroke swimmers to negotiate without dropping the elbows and pushing downward on the water. Breaststrokers who perform the insweep as a shoulder-adducting movement should have fewer problems than most. Swimmers who have been taught the breaststroke armstroke as a sweep out and a sweep in, however, tend to initiate the change of direction from out to in by turning the palms down and pushing down on the water. This, of course, will decelerate their forward speed. Swimmers who make this mistake can still be successful if they execute a short, backward push with the arms before they start the insweep.

This method results in two smaller peaks of forward acceleration instead of the one large peak with the method described earlier. This two-peak armstroke is illustrated by the graph in figure 7.13. The three illustrations at the top of the graph show a swimmer who is pushing water back at the beginning of the insweep, pushing down through the middle, and then pushing it back, once again, during the final portion of that sweep.

Swimmers accelerate the body forward for the first time by pushing back and out against the water at the end of the outsweep. This is followed by a deceleration of forward velocity as they push downward while changing the direction of the arms from out to in, after which they accelerate forward for the second time during the final portion of the insweep. The series of photographs in figure 7.14 show a side view of a swimmer who is using a two-peak armstroke. Once her arms are outside her shoulders and facing back, she achieves the first propulsive peak by pushing back with them for a short distance. Then she slides her hands down, below her arms, until her elbows are

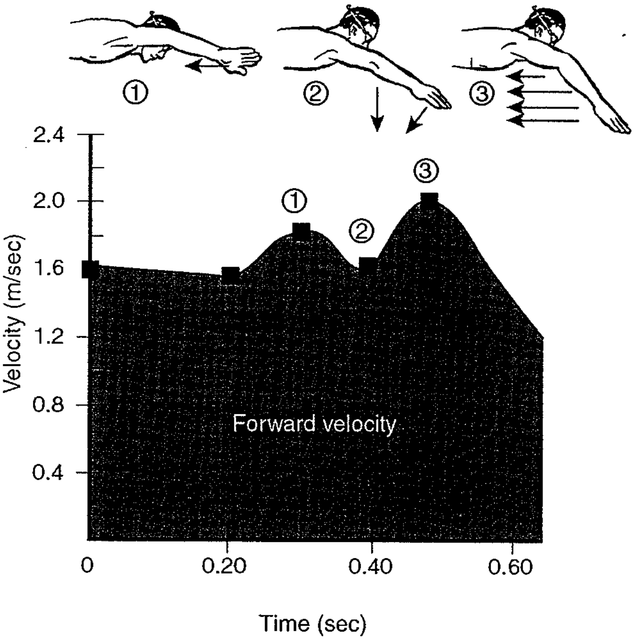


Figure 7.13 A two-peak forward velocity pattern for the breaststroke armstroke.

Figure 7.14 A swimmer doing a two-peak armstroke. Notice how she executes the first propulsive peak by pushing out and back with her arms in photo *(a)*. Then she slides her arms into a high elbow catch position in photos *(b)* and *(c)*, after which she will adduct them backward, creating the second propulsive peak.

above them in a classic high elbow position. After that, she adducts her arms toward her sides to achieve the second propulsive peak.

I believe that the one-peak shoulder-adducting arm pull described earlier is, by far, superior to this two-peak style because swimmers who use the former method will not decelerate during the middle of a short insweep. Having said this, however, I should also say that many world-class breaststroke swimmers have used the two-peak style quite successfully.

Breaststroke Kick

Before 1960, the breaststroke kick was taught as a *wedge* action. Swimmers extended the legs back and out to the sides in an inverted V shape and then attempted to squirt a wedge of water backward as they squeezed them together. Counsilman (1968) demonstrated the fallacy of the wedge kick when he showed that colored water placed between swimmers' legs was not squirted back when they squeezed them together but instead was simply diverted to the side. Coach James Counsilman and breaststroke swimmer Chet Jastremski then revolutionized the breaststroke kick by introducing a narrow whip-style leg action that is used by most breaststrokers today. It has become known as the *whip kick.*

The whip kick style used by most present-day world-class breaststrokers is really a diagonal and semicircular backsweep of the legs in which the feet travel out, back, down, and in until they come together. The soles of the feet are the primary propulsive surfaces, and swimmers use them like paddles to push water back. The mechanics of the breaststroke kick can be seen from a side view in figure 7.9 and from a front view in figure 7.10 (see pages 232–235). For the purpose of describing it, the kick has been separated into five phases: (1) the recovery, (2) the catch, (3) the outsweep, (4) the insweep, and (5) the leg lift and glide.

Recovery

There are two phases to the recovery: a knee flexion and a hip flexion. After completing the propulsive phase of the armstroke, swimmers should flex the legs at the knees and bring the lower legs up and forward while riding the wave of propulsion caused by the sudden deceleration of the body as the arms and legs are recovered forward. This phase of the leg recovery, shown from a side view in figure 7.9, e and f (see page 232), continues until the arms are extended forward and the head is dropped toward the surface. At that point, swimmers flex the legs at the hips to complete the recovery. They continue to bring the feet up until they are close to the buttocks, and then they rotate the feet out and sweep the legs outside shoulder width to the catch position. The hip flexion phase of the kick is pictured in figure 7.9, g and h (see page 233).

Let me make it clear that the leg recovery begins when swimmers release pressure on the water during the insweep of the armstroke, not when the arms reach the surface. Swimmers must begin recovering the legs immediately when they lose propulsion from the arms in order to reduce the period of deceleration between the end of the propulsive phase of the armstroke and the beginning of propulsion from the kick. The feet should travel almost directly forward, staying within the confines of the hips, until they are near the surface. The toes should be pointed back (feet extended) and held close together, and the lower legs should remain inside shoulder width throughout their recovery to help reduce resistive drag.

Swimmers should separate the knees somewhat when they recover the legs forward. This will enable them to keep the lower legs and feet inside the confines of the body as the lower legs come forward. They should not separate the knees more than shoulder width, however, or resistive drag will be increased.

Swimmers must drop the hips and incline the body down from head to hips during the knee flexion phase of the leg recovery so that they can keep the legs underwater during the recovery without flexing at the hips. Swimmers will experience an acceleration of forward speed from wave propulsion during the first part of the recovery if they bring the legs up without flexing at the hips. But they will actually decelerate if they flex the legs at the hip joints from the very beginning of the time they begin bringing the legs up behind them. Flexing at the hips will cause an abrupt and significant reduction in forward velocity because they will be pushing the thighs down and forward through the water.

The body should be inclined downward approximately 45° from the surface during the early stages of the leg recovery. This degree of inclination is accomplished by allowing the downward component of the armstroke during the insweep to elevate the head, shoulders, and a portion of the trunk above the surface, while at the same time allowing the hips to drop down from the surface.

The legs should move fairly fast through the recovery to reduce the period of deceleration between the end of the propulsive phase of the armstroke and the beginning of propulsion from the kick. Regardless of speed, the legs should be slipped forward gently and in the most streamlined position possible. The feet should begin sweeping out as they approach the buttocks, signaling the beginning of the first propulsive phase of the kick, the outsweep.

This hip flexion phase of the leg recovery may seem to contradict my earlier recommendation to recover the legs without flexing at the hip. It does not, however. Why should swimmers flex the legs at the hips when it slows forward speed so much? Because flexing the legs at the hip joints as well as the knees will provide greater force when they extend the legs during the next phase of the kick. Underwater films and videos show that nearly all world-class breaststroke swimmers flex the thighs at the hips during the outsweep, even though this action causes them to decelerate. The tradeoff is probably a good one because they gain relatively more forward speed during the succeeding insweep with the legs than they lose during the outsweep. This is because they can use two large groups of muscles, rather than one, to apply force during the insweep: the muscles that extend the legs at the knees and those that extend the thighs at the hip joints. Only the knee extensors would be used if swimmers did not also flex the legs at the hip joints.

Although some hip flexion is essential for a powerful insweep, it is neither necessary nor desirable to pull the thighs upward too much under the hips during the outsweep in preparation for the propulsive phase that follows. Belokovsky and Ivanchenko (1975) reported that more force was delivered when the backward thrust of the legs began with the hips flexed 40° than when flexed at angles closer to 90°. They also reported that the range of hip flexion for wave style breaststrokers was approximately 34° to 50°. Sanders (1996) reported a range of hip flexion between 54° and 68° for a group of international-level breaststroke swimmers from New Zealand.

Before going on, let me make it clear that swimmers should not push the thighs down and forward while bringing the legs forward during the recovery, or they will decelerate much more. They can reduce the amount of deceleration that occurs because of hip flexion by waiting until they begin the outsweep before bringing the thighs down under the hips. In other words, breaststrokers should add hip flexion to the movement as they sweep the legs out and not before. By waiting until the outsweep before flexing at the hip, swimmers can make the catch and begin accelerating the body forward before the action of flexing the hips has slowed their velocity to nearly a standstill.

Catch

Swimmers should begin sweeping the legs outward as the feet approach the buttocks. The feet should sweep out to the sides until they are facing back, where they can push water back. This is when the catch is made.

The feet should be flexed (dorsiflexed) and rotated out (everted) at the ankles as they sweep outside the shoulders to the catch position in order to achieve a backward orientation at the earliest possible time during the outsweep. The catch takes place when the feet have traveled out, and in some cases back, enough to face backward against the water. The legs will be flexed approximately 40° to 50° at the hip joints. They should also be flexed between 60° and 70° at the knee joints.

The legs should be flexed as much as possible at the knees so that they pass very close to the buttocks as they are circled outward during the outsweep. Ideally, swimmers should circle the feet directly outward to the catch position without pushing back with them. This will enable them to make what is known as a *high catch*. That is, they will be able to begin applying propulsive force with the feet when the legs are forward and nearly opposite the hips.

Outsweep

The outsweep is a backward and somewhat outward extension of the legs at the hip and knee joints. This phase of the kick is pictured in figures 7.9 and 7.10, i and j (see pages 233 and 235). The feet begin rotating down and in as the legs near extension and the next phase of the kick, the insweep, begins.

Insweep

Swimmers should rotate the legs downward and turn the soles of the feet toward one another as they complete the leg extension. Then they should sweep the feet inward across the water until they are inside the shoulders. The insweep of the kick is pictured in figures 7.9 and 7.10, j, k, and l (see pages 233 and 235). The soles of the feet are rotated down and in until they are pitched inward and they should remain flexed at the ankles until the insweep has been completed.

The insweep ends when the legs are completely extended and coming together. At that point, the legs and feet stop pushing back against the water and swimmers allow the momentum of the insweep to carry the legs upward, toward the surface, as they come completely together. The legs should be almost motionless at the catch, after which they should accelerate rapidly until the propulsive phases of the kick are completed. The feet will reach velocities between 4 and 5 m/sec during the outsweep and insweep of the kick.

One of the major mistakes that swimmers make during this phase of the kick is to extend the feet at the ankles before the insweep ends. This causes them to push water up, instead of back, during the latter part of the movement. In a study of 178 swimmers, Vervaecke and Persyn (1979) found that swimmers with the best breaststroke kicks maintained their feet in flexed and outwardly rotated positions longer than those with poor kicks. The poor kickers extended their feet much earlier during the insweep. Thus, swimmers should keep the feet flexed at the ankles and they should turn them inward (invert them) to gain the last bit of propulsive force as the legs are passing inside the shoulders near the end of the insweep. The drawings in figure 7.15 illustrate the effect of this mistake.

Leg Lift and Glide

The leg lift is another example of a follow-through motion. Once the insweep has been completed, swimmers use the inward inertia of the legs to change their direction gradually from down to up. They do this by circling the legs up during the final few inches before they come together. Once the change of direction has been effected, they continue sweeping the legs up toward the surface until they are just beneath the surface of the water and slightly above the body.

This upward movement of the legs should take place while they are sweeping the arms out, after which they should hold the legs in this

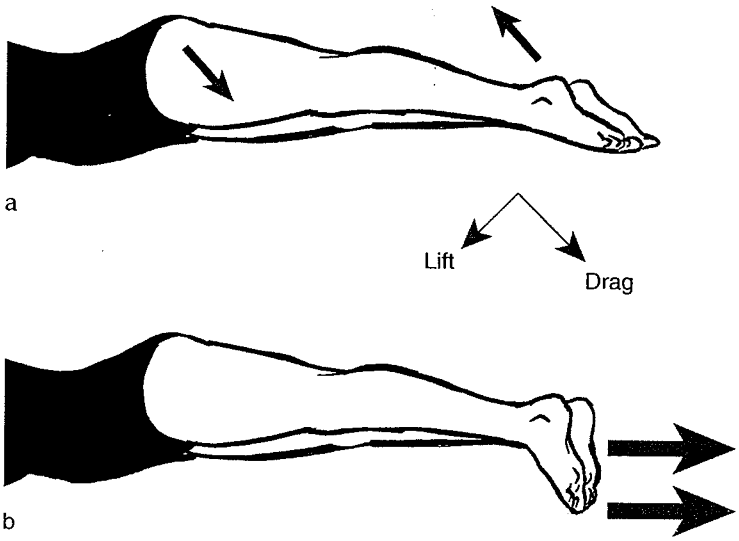


Figure 7.15 The finish of the insweep. The swimmer in *(a)* is making the common mistake of extending her feet at the ankles as she finishes the insweep of her kick. This causes her to push water upward with her feet. The swimmer in *(b)* is finishing the insweep correctly. She keeps her feet flexed at the ankles so that she can direct the water back as her legs are coming together.

streamlined position so that they do not produce extra drag during the remainder of the armstroke. The leg lift and glide phases can be seen from side and front views in figures 7.9 and 7.10, b through d (see pages 232 and 234).

When gliding, the legs should be completely extended from hips to toes with feet extended back at the ankles. They should be held close together and in line with the trunk but inclined upward. The speed of the feet should decelerate during the lift until the legs are simply being pulled along by the armstroke at the same speed as the body.

Although some expert will disagree, I don't believe that the leg lift is a propulsive phase of the kick. The side view kick pattern in figure 7.5 (see page 226), which is typical of the breaststrokers I have studied, shows that the legs move not only up but forward as they are being lifted toward the surface. It is doubtful that the legs could produce any significant amount of forward propulsion while traveling up if they are also moving forward. Sweeping the legs up forcefully at this time should only force the hips down without accelerating them forward.

The vector diagram in the top illustration of figure 7.15 also shows that both the lift and drag forces would be directed downward during the lift. The drag force would be aimed down and back, which would tend to submerge the hips, and the lift force would be aimed down and forward, which would also tend to submerge the hips. Even if some propulsive force could be achieved form this combination of forces, it would be greatly negated by both the backward and downward components of the parent forces, which would be of considerably greater magnitude. Consequently, I suggest that swimmers slip the legs to the surface gently and in a tightly streamlined position to reduce resistive drag as much as possible during this time.

Ankle and Hip Flexibility

Several aspects of hip and ankle flexibility are essential to a good breaststroke kick. Breaststroke swimmers need good flexibility in several joints in order to rotate the feet and lower legs out to make a catch while the legs are flexed at the knees. They must have better than average ability to rotate the thighs in at the hip joints and to rotate the lower legs out at the knee joints. They must also be able to pull the feet up (dorsiflex them) and turn them out (evert them) much more than the average person.

Unfortunately, many swimmers, including some world-class breaststroke swimmers, are not above average in these ranges of motion. Therefore, they have to sweep the legs out and back a short distance before they can get them oriented back against the water. Breaststroke swimmers can improve the kick considerably by doing exercises that improve flexibility of the hips and knee joints in the directions indicated.

Sore Knees

Coaches and breaststroke swimmers know what a serious problem sore knees can be. At the very least, valuable training time will be lost when the condition becomes acute. At worst, injuries to the knees can end a breaststroker's career.

Sore knees are generally caused by chronic inflammation of the medial collateral ligaments and medial menisci located within these joints. An enlarged view of these structures is illustrated in the inset drawing of the knee joint in figure 7.16.

The medial collateral ligament connects the femur (the long bone in the upper leg) to the tibia (a bone in the inner lower leg). The medial meniscus is attached to the medial collateral ligament and runs between the femur and tibia. It is composed of cartilaginous connective tissue and cushions the articulation between these two bones.

The outsweep and the first part of the insweep of the breaststroke kick exert a considerable amount of stress on these structures because the range of outward rotation of the lower legs at the knee joints is so limited as to be almost nonexistent. In fact, it is only possible when the knees are bent and then only through a very small range. Con-

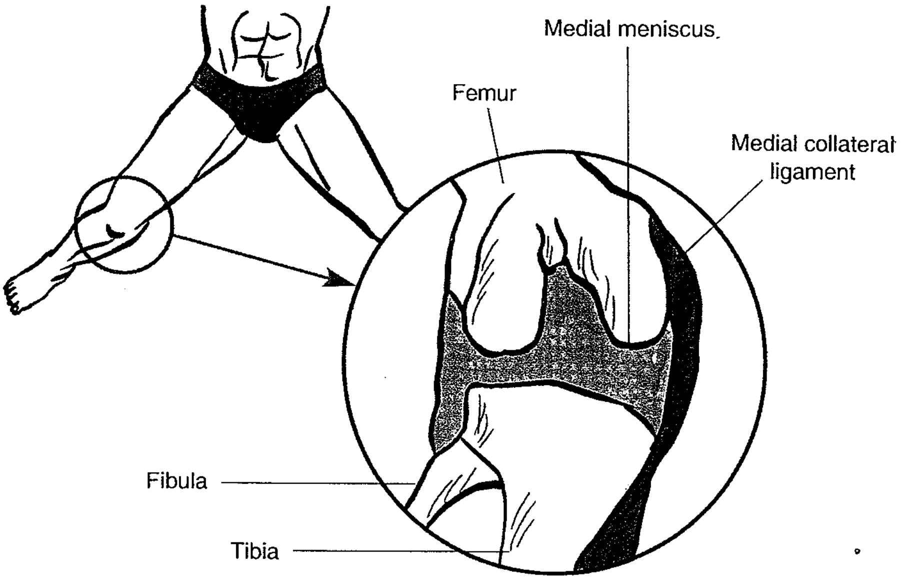


Figure 7.16 A drawing of the knee joint showing the medial collateral ligament and medial meniscus.

sequently, when breaststroke swimmers attempt to rotate the lower legs out, the head of the femur pushes in and the head of the tibia pulls out against the medial menisci and the medial collateral ligaments. Over time, constant pulling can cause these structures to become irritated and inflamed, which will cause pain whenever breaststrokers try to kick. In very severe cases, the medial collateral ligaments may be torn. At the same time, the medial menisci may be compressed to the point that they are pulled away from the medial collateral ligaments. Anita Nall is shown in figure 7.10i (see page 235) rotating her lower legs out for the catch. This is the phase of the kick when the strain on these tissues is most likely to occur.

The dilemma facing breaststroke swimmers is that outward rotation of the lower legs at the knee joints is very important to a good kick, yet the potential for injury is great because of the limited range of motion in these joints. Those swimmers who can perform the kick without soreness and injury are lucky. The others must curtail their kicking at the first sign of pain until that pain subsides. There is something this latter group can do to reduce the incidence of sore knees, however.

Breaststrokers who are susceptible to sore knees can modify the kick in certain ways to remove some of the strain on the medial collateral ligaments and medial menisci. One way is by reducing the width of the outsweep. They can push the legs back more and out less during this phase. Doing so will reduce strain on the knees, but it will also take these swimmers longer to get the feet in position for the catch. This, unfortunately, will shorten the insweep and reduce the propulsive potential of the kick. Nevertheless, it will enable them to train more effectively with their strokes if sore knees tend to be a problem.

There is yet another technique that can be used to reduce the incidence of sore knees and this one may not reduce the propulsive effectiveness of the kick as much. It involves recovering the legs with the knees spread slightly wider apart than I recommended earlier. With the knees wider, swimmers will be able to rotate the thighs in more at the hip joints, which in turn will permit them to rotate the lower legs out wider with less strain at the knee joints. This method will increase form drag somewhat during leg recovery, but it is better than enduring the pain of sore knees. Obviously, swimmers should not widen the knees any more than necessary to perform the outsweep effectively and without pain.

Timing of the Arms and Legs

Three general styles of breaststroke timing have been advocated by various swimming experts. They are known variously as *continuous, glide,* and *overlap* timing. When continuous timing is used, swimmers start the arms out immediately after the legs come together. With glide timing, there is a short interval between the completion of the kick and the beginning of the armstroke while swimmers are coasting or gliding along with arms and legs extended in a streamlined position. With overlap timing, swimmers start sweeping the arms out before the legs come together. This latter method is the one used by most world-class breaststroke swimmers today (Miyashita 1997). Glide timing is the method recommended by most coaches and teachers of swimming, however. Let me explain why overlap timing should be superior to both the glide and continuous methods.

With glide timing, the resistance of the water will cause swimmers to decelerate markedly while they are gliding along, no matter how streamlined the position of the body. Contrary to what some believe, the propulsive phase of the kick ends before the legs come together and the propulsive phase of the armstroke does not begin when the arms start apart. Consequently, swimmers decelerate not only while they are gliding but also while the legs are coming together and while the arms are sweeping out to the catch. Gliding can increase the time they decelerate between stroke cycles from approximately 0.20 sec to between 0.30 and 0.40 sec. The effect of glide timing on forward velocity is illustrated by the graph in figure 7.17.

Notice the loss of velocity that takes place in the dark shaded area while the swimmer is gliding. That is the period after his kick has been completed and he is gliding, before he begins to sweep his hands out to the sides. His velocity declines from 1.60 m/sec to approximately 1.22 m/sec during this phase. His forward velocity, then, decelerates even further to 1.18 m/sec while he sweeps his arms out to the catch. Taking the time for the glide and the outsweep into consideration, in this example, the time interval between the end of the propulsive phase of his kick and the beginning of the propulsive phase of his armstroke is nearly 0.40 sec.

Continuous timing, as it is commonly taught, is merely another example of glide timing with the glide phase shortened. Swimmers are taught to wait until the legs come together before they begin sweeping the arms out. This eliminates the glide phase,

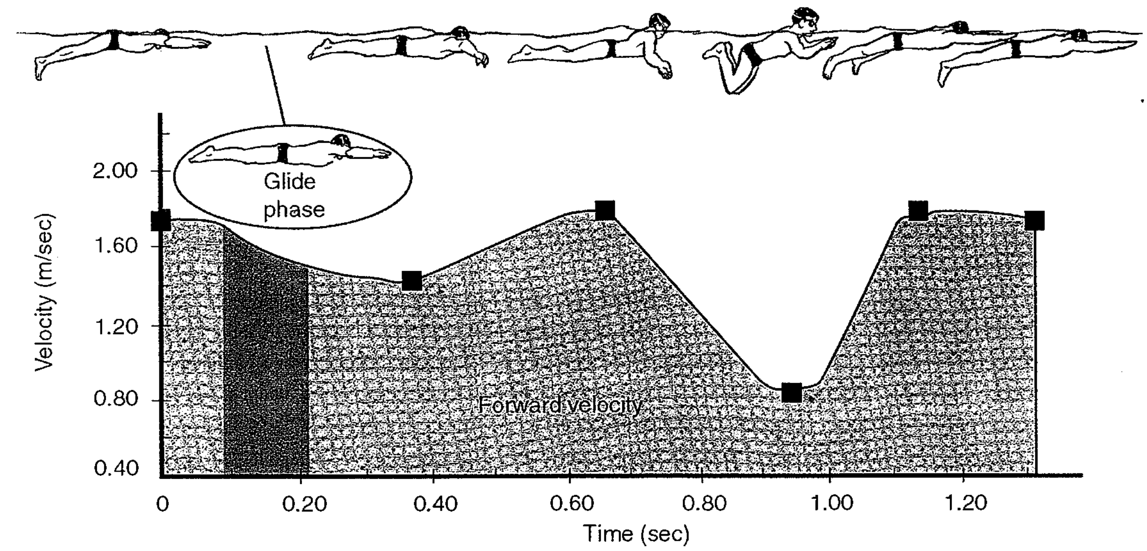


Figure 7.17 A forward velocity chart for a swimmer who is using glide timing.

but swimmers still decelerate for a longer time than necessary between stroke cycles. That is because the interval between the time the propulsive phase of the kick ends and the arms sweep out to the catch will still be longer than it needs to be.

The best way to reduce this deceleration period between the end of the propulsive phase of the kick and the beginning of the propulsive phase of the armstroke is to use overlap timing. The velocity graph in figure 7.18 illustrates the effect of overlap timing on a swimmer's forward velocity from one stroke cycle to the next. The interval between the end of propulsion from the kick and the beginning of propulsion from the armstroke has been shortened considerably because the swimmer begins sweeping his arms out at the instant he completes the propulsive phase of his kick. In other words, he sweeps his arms out as his legs are coming together. This is why I have termed this *overlap* timing. By doing so, he reduces the time interval between the end of propulsion from the legs and the beginning of propulsion from the arms to less than 0.20 sec as it should be. In this way, he should decelerate less and for a shorter time during the outsweep.

One thing I would like to make clear about overlap timing is that swimmers should not start the arms out while the legs are still accelerating them forward. If they start sweeping the arms out while the kick is propelling them forward, they will increase form drag and lose some of the velocity they might have otherwise attained from that kick. Most swimmers stop accelerating forward when the legs pass inside the shoulders during the insweep. Consequently, that is the time they should begin sweeping the arms out to the side.

Breaststroke swimmers whose kicks are weaker than most may need to use more overlap than those whose kicks are more effective. This is because swimmers with weak kicks generally stop accelerating forward earlier during the insweep with the legs. Therefore, they will need to start sweeping the arms out a little earlier in order to get them to the catch before they lose too much forward velocity. This will increase the rate of turnover and increase energy cost. Nevertheless, it should be faster to maintain a higher average velocity per stroke cycle by taking more strokes per min than it would be to save energy and lose velocity by stroking slower.

The major argument against overlap timing is that swimmers will save energy if they remain streamlined after finishing the propulsive phase of the kick. This argument assumes that saving energy is more important than preventing a large loss of

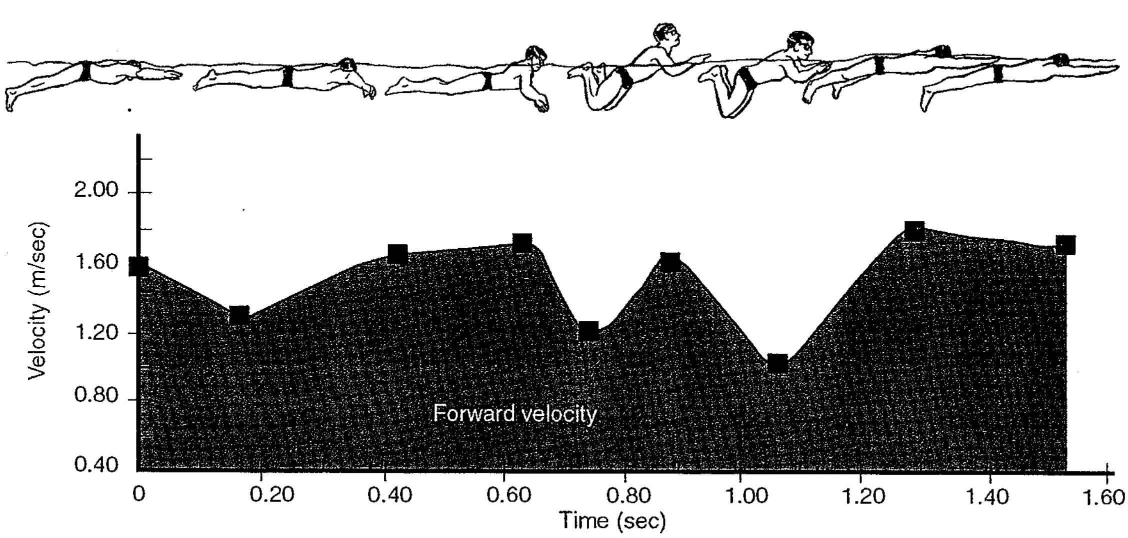


Figure 7.18 An example of overlap timing.

forward velocity while they are gliding. But I believe that it is more important to prevent a large loss of forward velocity. What we have learned from other competitive strokes about the importance of maintaining a nearly continuous application of forward propulsion certainly supports that belief. By the same token, overlap timing will not significantly increase the energy cost of swimming the breaststroke if swimmers sweep the arms out in a relaxed and gentle manner. They can be resting the arms during this time, just as they would if they were gliding.

Body Position and Breathing

Most swimmers and coaches now agree that the flat style of breaststroke is passé. Breaststrokers are advised to allow the head and trunk to rise out of the water when they breathe to encourage wave propulsion and reduce drag during the leg recovery. They disagree, however, as to whether or not breaststrokers should use body undulation to enhance propulsion. Opponents believe that body undulation will create additional form drag, while those in favor believe that forward propulsion can be enhanced by body undulation. There are good arguments on both sides of this question.

Dolphin Motion: Good or Bad?

If a body wave and reverse body wave can increase propulsion in the butterfly, there is good reason to believe that they could do the same for breaststrokers. The body wave, created by reaching down with the hands, followed sequentially by downward undulation of the head and shoulders and upward undulation of the hips, may create a summation of forces that could provide additional propulsive force during the insweep of the breaststroke kick. Sanders, Cappaert, and Devlin (1995) showed this force summation during the dolphin kick in the butterfly. I doubt that the body wave is a propulsive reality in the breaststroke, however, just as I doubted its validity in butterfly swimming.

I do think that the reverse body wave contributes to propulsion in the butterfly and that it could contribute to propulsion in a similar manner during breaststroke swimming. In the breaststroke, a reverse body wave allows the force of gravity to assist in maintaining forward velocity at a higher level after the propulsive phase of the kick has ended and the hips pass the peak of their upward movement and travel down.

On the other hand, it could be argued that undulation should be minimized when the body is underwater. The major component of the propulsive phase of the breaststroke kick is a backward push against the water. The opposite is true of the dolphin kick in which the legs travel down much more than back. Consequently, it may be neither necessary nor advisable for breaststrokers to undulate the hips upward as they kick back. Those who argue against undulation would say that more propulsion can be generated by the arms and legs if swimmers remain horizontal. They would argue, further, that undulation increases form drag.

The belief that undulation can increase propulsion in the breaststroke is probably tied to acceptance of the body wave or the reverse body wave as propulsive mechanisms. Because I think there is a high probability that the reverse body wave contributes significantly to propulsion, I recommend an undulating style of breaststroke swimming. The sequence of photographs in figure 7.19 shows a breaststroker who is using an undulating style.

To set the stage, breaststroke swimmers should kick down somewhat as they extend the legs back to undulate the hips up to, or just above, the surface of the water. At that time, they should reach forward and down slightly with the arms. The head should be between the arms and they should be looking down. The swimmer is doing this in figure 7.19a. As the hips pass the peak of their upward undulation and start down, swimmers should look up and raise the arms up to a horizontal position so that the

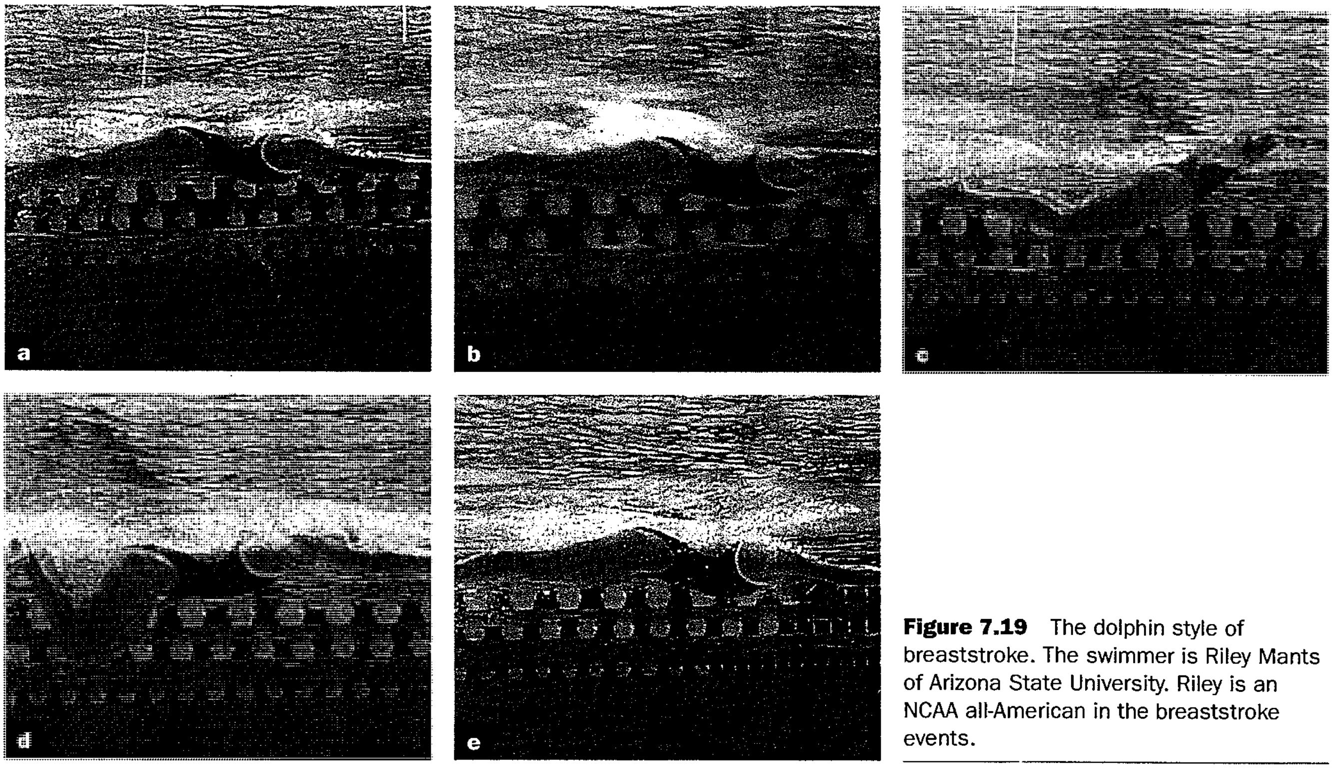


Figure 7.19 The dolphin style of breaststroke. The swimmer is Riley Mants of Arizona State University. Riley is an NCAA all-American in the breaststroke events.

(a) Completion of the insweep of the kick (notice the hips are somewhat piked).
(b) Rise with legs to streamlined position.
(c) Wave propulsion phase of stroke cycle (notice the head and shoulders are elevated above the water, the hips are dropped, and the legs are beginning to flex at the knees).
(d) Return to a streamlined position (notice the arms extended overhead and the head down between the arms in preparation for the propulsive phase of the kick).
(e) Completion of kick with a dolphin motion.

downward velocity of the hips and trunk may be translated into forward velocity for the body, as shown in figure 7.19b. As in other styles of breaststroke, swimmers should be in a horizontally streamlined position during the propulsive phase of the armstroke (figure 7.19b) and the kick (figure 7.19d). They should also be in an inclined position with the head and shoulders elevated above the water when they begin the leg recovery in order to make use of wave propulsion, as shown in figure 7.19c.

A word of caution is in order about undulating too much. The amount of body undulation should be considerably less than that used by butterfly swimmers. This is because, as stated earlier, the breaststroke kick is most effective when swimmers push the legs back against the water, not when they push them down. Exaggerating the downward movement of the legs simply to produce a large upward undulation of the hips would only reduce propulsion from the breaststroke kick. Breaststrokers should concentrate on kicking back, allowing the natural downward movement of the legs to produce the proper amount of upward hip undulation. They should not try to enhance the upward movement of the hips.

The hips will and should drop when breaststroke swimmers raise the head and shoulders out of the water as they breathe. The reasons for doing this were discussed earlier in this chapter. It reduces frontal drag and enhances wave propulsion during the leg recovery. This upward motion of the head and shoulders as well as the downward motion of the hips can also be overdone. The following six guidelines should provide some help in determining whether swimmers are undulating too much or too little both when they kick back and when they raise the head and shoulders out of the water as they breathe.

1. Undulation is excessive when the head and shoulders go up and down more than forward. Swimmers should never arch the trunk back when they come out of the water. Sanders (1996) reported trunk angles of 39° to 46° from the horizontal among a sample of international-level New Zealand breaststroke swimmers when their trunks were elevated above the surface for a breath. It was not unusual for their heads to be raised 46 to 64 cm (18 to 25 in) above the surface and for their shoulders to be elevated 32 to 50 cm (13 to 20 in) at that same time. Until more data is available, these numbers probably represent the range for proper trunk, shoulder, and head elevation during breaststroke swimming.

2. Undulation is excessive if the hips rise more than a few inches above the surface of the water as breaststrokers kick back. The downsweeps of the legs should push the hips up to or slightly above the surface, but no higher. The amount of hip undulation should be no greater than approximately 14 to 17 cm (5 to 7 in) (Sanders 1996).

3. Undulation is excessive if the hands and head go more than a few inches underwater as breaststroke swimmers stretch the arms forward. Swimmers who dive the hands and head too deep as they kick back will waste time and energy bringing them back to the surface. Swimmers should drop the head only slightly below the surface and they should extend the arms primarily in a forward direction with only a slight amount of downward inclination so that both are in line with the inclination of the trunks and legs.

4. Undulation is inadequate if the shoulders and a portion of the trunk do not come out of the water when breaststrokers breathe. When they reach their highest point during the breathing cycle, the water line should be at the lower back when viewed from behind, and just under the chest when viewed from the front.

5. Breaststrokers are undulating too little if the hips do not reach the surface during the completion of the insweep of the kick.

6. Undulation is inadequate if the entire body, including the head, is not underwater during the insweep of the breaststroke kick.

Breathing

Breaststroke swimmers should breathe once during each stroke cycle, regardless of the race distance. Breathing is such an integral part of the timing of this stroke that it aids, rather than interferes, with propulsion. Swimmers seem to lose their rhythm when they do not breathe. Furthermore, they need to elevate the head and trunk in order to recover the legs properly. The proper breathing sequence can be seen from the surface in the series of photographs in figure 7.20.

Swimmers should have the head underwater and be looking down at the bottom of the pool while extending the legs back during the propulsive phase of the kick, as shown from the surface in figure 7.20a. They should then begin looking up as they sweep the arms out and should continue moving the head and shoulders toward the surface as they begin the insweep with the arms. The head and shoulders should be out of the water as they complete the insweep of the armstroke and they should breathe as they bring the hands toward the surface during the recovery (figure 7.20b). Then they should lower the head back under the water as they extend the arms forward (figure 7.20c).

Swimmers should make certain that they continue to move forward while they are breathing. For this reason, they should not lift the head up and back to bring it above the surface. The head should remain in a natural position on the spine with the chin tucked and they should raise the shoulders and trunk to bring the face out of the water to breathe. A good teaching technique is for swimmers to keep the eyes focused down on the water directly in front of them as they bring the face out of the water for a breath (see figure 7.20b).

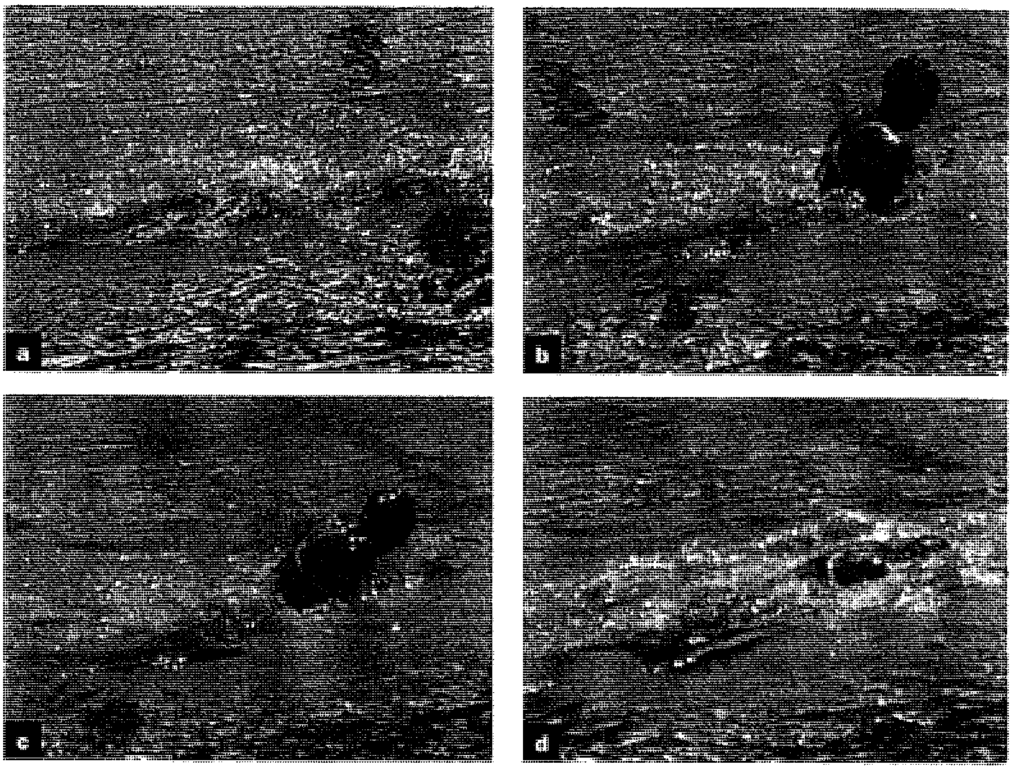


Figure 7.20 A surface view of breaststroke breathing. The swimmer is Anita Nall.

(a) Completion of the propulsive phase of the kick (notice the entire body is submerged in a stream lined position).

(b) Wave propulsion phase. A breath is taken as the arms come to the suface during their recovery. The head and shoulders are elevated above the surface and the hips are down as leg recovery begins.

(c) Arms extend forward as head and trunk drop toward the surface. Leg recovery continues. Wave propulsion phase is over.

(d) Arms near full extension and legs are ready to begin their propulsive phase.

The head, shoulders, and trunk should rise to the surface on a gradual diagonal so they move as much forward as upward when the head is rising above the surface for a breath. Swimmers should not arch the back, extend the chin forward, or extend the head back on the neck as they bring the head out of the water.

Another technique swimmers use to keep moving forward once they have reached the surface is shrugging the shoulders forward as they begin to extend the arms forward. In addition to maintaining forward movement with the trunk, this technique also improves streamlining as breaststrokers return the shoulders into the water.

The interrelationship between the leg recovery and dropping the head is very important to success in the wave breaststroke. Swimmers can reduce drag considerably during leg recovery by dropping the head and shoulders slowly toward the surface while they are recovering the legs. This allows them to keep the hips submerged so that they can recover the legs forward with less hip flexion for a slightly longer time. This, in turn, should increase the length and magnitude of the wave propulsion during this phase of the stroke cycle.

Some swimmers like to dive down and forward as they recover the arms and legs. They have no choice but to flex at the hips and push the thighs down and forward against the water when they do this, however, and wave propulsion will be terminated when that happens. The drawings in figure 7.21 demonstrate how swimmers can remain more streamlined during arm and leg recoveries.

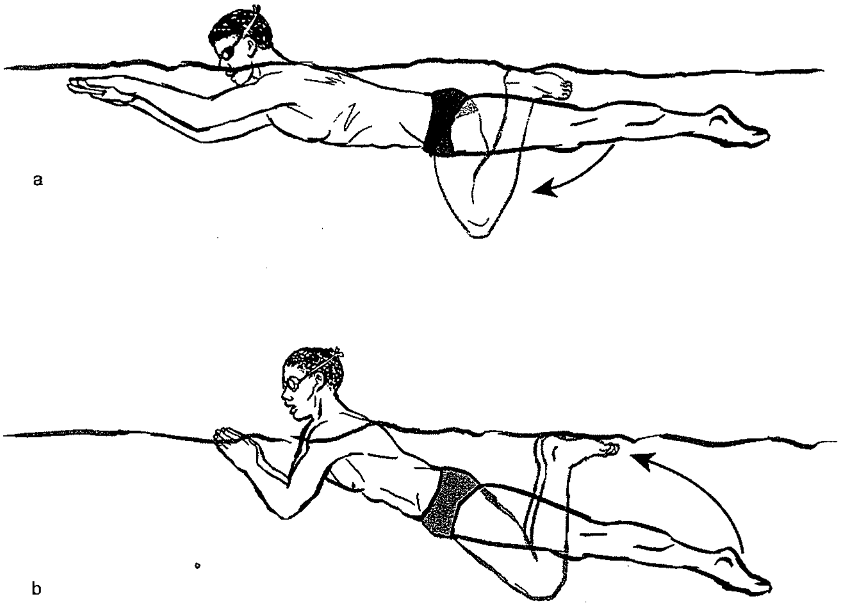


Figure 7.21 Two leg recovery styles in the breaststroke. The swimmer in *(a)* is recovering his legs incorrectly because he pushes his thighs down and forward against the water to raise his legs. The swimmer in *(b)* recovers his legs forward by flexion at the knee only. Thus, he pushes less water forward with his legs.

The swimmer in figure 7.21a lowers his shoulders into the water too early during his leg recovery and this pushes his hips up, near the surface, so that he has to recover his legs by pushing his thighs down and forward against the water. This type of leg recovery will slow his forward velocity considerably. By contrast, the swimmer in figure 7.21b keeps his shoulders above the water during his leg recovery, which maintains his body in an inclined position. With his hips down, this swimmer is able to bring his lower legs forward without flexing his hips during their recovery. This will reduce pushing drag during this phase of his leg recovery.

Recovering the arms at the surface of the water is another technique that aids swimmers in keeping the trunk elevated and the hips down during the leg recovery. On the other hand, when they recover the arms underwater, the head and shoulders are more likely to drop below the surface of the water while the feet are still traveling upward.

Underwater Armstroke

Rules permit breaststroke swimmers to take only one underwater stroke during each pool length and it is taken immediately after the start of the race and after each turn. After completing this underwater stroke, the head must break through the surface of the water before the hands turn inward at the widest point of the next armstroke. The longer underwater armstroke is considerably more effective than shorter surface strokes, so swimmers should practice this technique until they can get every bit of available propulsion possible from it.

The underwater armstroke is similar to an exaggerated butterfly armstroke. It consists of an outsweep, a catch, an insweep, and an upsweep. There are also two glides, one before the stroke begins and one after it has been completed. The second glide is followed by a kick to the surface. That kick is identical to the one described earlier in this chapter. The outsweep is a nonpropulsive movement that is used to place the arms in position for delivery of propulsive force. The insweep and upsweep are the propulsive phases of the armstroke. The techniques of the underwater armstroke are shown from a side view in the series of photographs in figure 7.22 on pages 252–253.

First Glide

After the push-off or dive, swimmers hold a streamlined position until their speed decelerates close to race speed. The arms should be together and stretched tightly overhead during the glide. Placing one hand over the other helps in maintaining this streamlined position. The head should be between the arms and the body should not sag at the waist, nor should it be piked at the waist. The legs should be held tightly together with the toes extended back. This glide position is shown in figure 7.22a. Notice the downward inclination of Nall's body. Swimmers should push off at a slightly downward angle to achieve a greater depth during the long underwater armstroke.

Outsweep and Catch

When swimmers approach race speed, they should sweep the arms out, forward, and up until they are outside the shoulders where the catch is made. Nall is shown completing the outsweep and making the catch with her arms in figure 7.22, b and c. Her arms sweep up slightly in order to position them to execute the insweep that follows at the level of her body. The arms should be flexed gradually after they pass outside the shoulders to get them facing back for the catch as quickly as possible. The outsweep should be a gentle stretching motion of the arms. The hands should not push water to the side during the outsweep.

The palms of the hands should be facing down when the outsweep begins and remain in this position until they are outside the shoulders. Then swimmers should rotate the palms out until they are pitched out and back at the point of the catch and the start of the insweep. Arm velocity will accelerate slightly during the outsweep and then decelerate at the catch.

Insweep

After making the catch, swimmers should sweep the arms out, back, down, and in, with a wide adducting motion that brings the hands almost together under the body and the arms close to the ribs. The insweep is pictured in figure 7.22, c, d, and e. The arms should remain flexed at the elbows and swimmers should push back against the water with the underside of the upper arms and forearms and with the palms of the hands. Arm velocities should increase moderately from beginning to end of the insweep.

Upsweep

The transition to the upsweep should begin as the arms are approaching one another under the body (see figure 7.22e). Just after the hands finish their inward motion, swimmers should turn them out quickly and begin pushing them back, out, and up, toward the surface, until they are completely extended and resting against the thighs. The upsweep portion of the armstroke is shown in figure 7.22, e, f, and g. They should then push back against the water with the palms and the undersides of the forearms. Swimmers should maintain the arms in a flexed position during most of the upsweep in order to maintain a backward orientation with the forearms for as long as possible (see figure 7.22f).

When swimmers can no longer maintain a backward orientation with the forearms, they should extend the arms vigorously at the elbows until they are completely extended and back at the thighs. The upsweep should end with the arms at the thighs and with the palms facing outward. This will allow swimmers to direct the water back and up, away from the legs, in a natural follow-through motion during the final part of the upsweep. Nall is not doing this in the photos in figure 7.22.

The upsweep is the most propulsive phase of the underwater armstroke. Arm velocities will decelerate during the transition from insweep to upsweep and will then accelerate rapidly until the end of the movement. Arm velocities should be maximized during the upsweep.

Second Glide

Once the upsweep is completed, swimmers should turn the palms inward and place them against the thighs in order to glide in a streamlined position, as shown in 7.22g. The legs should be straight and together with the toes extended back and up. The head should be in line with the body and there should be no arch or pike at the waist.

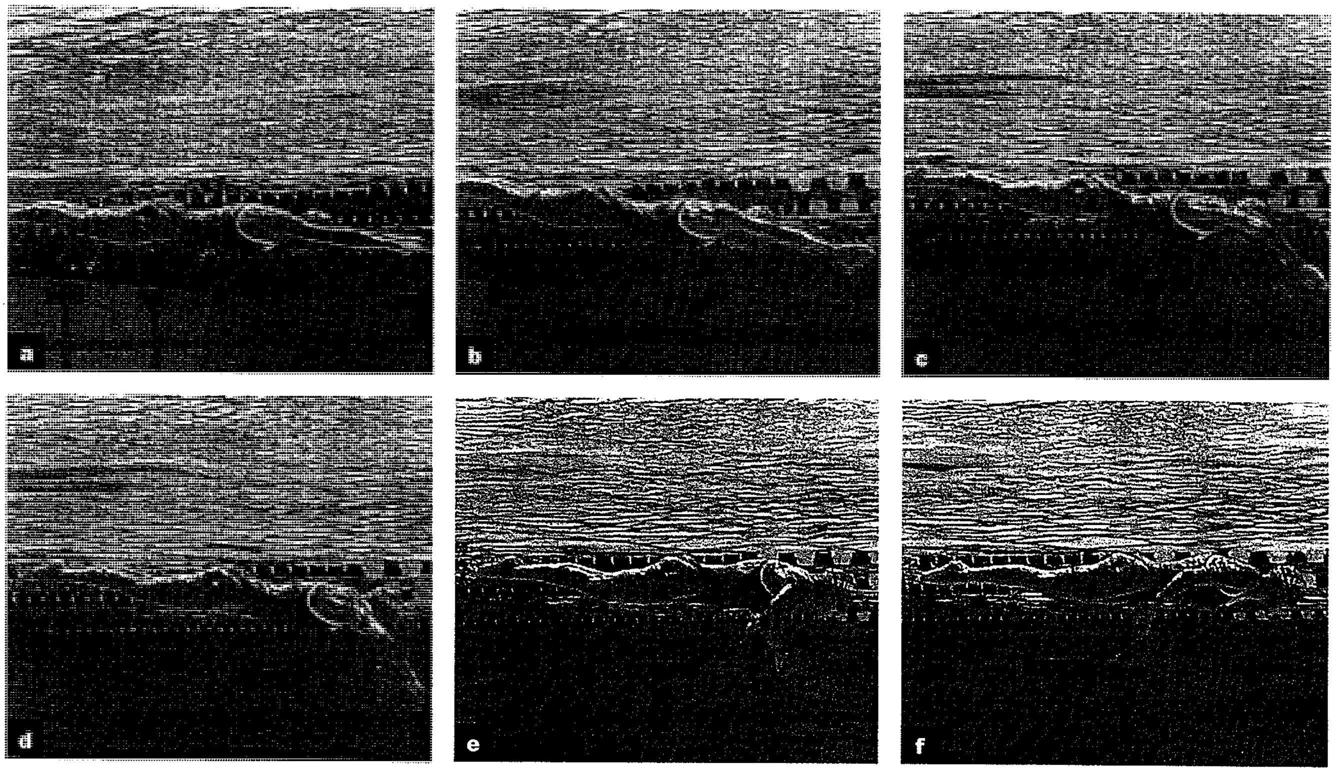


Figure 7.22 Sequence photographs of the underwater armstroke in the breaststroke, taken from a side view. The swimmer is Anita Nall.

(a) First glide (notice the downward body angle).
(b) Start of outsweep with arms.
(c) Catch with arms.
(d) Mid-insweep with arms.
(e) End of insweep. Start of upsweep with arms.
(f) Continuation of upsweep with arms.

This streamlined position should be held for only a very short time because swimmers will decelerate very rapidly. Once the impetus of the underwater stroke begins to dissipate, swimmers should recover the arms forward and kick the body to the surface.

Arm Recovery and Kick to the Surface

From the streamlined position of the second glide, swimmers should recover the arms forward under the chest. They should then reach forward and kick the body upward, through the surface of the water.

To reduce pushing drag, breaststroke swimmers should slide the arms forward underneath the body by flexing them at the elbows with the upper arms and elbows remaining close to the sides. The hands should move forward, thumbs first and with the palms facing up, so that they slide forward with the least amount of surface area pushing forward against the water. Nall is doing this very well in figure 7.22, h and i.

Swimmers should begin extending the arms forward when they pass the head, as in figure 7.22i. They should turn the palms down and extend the arms forward in a streamlined position with the elbows close together until the arms are completely extended in front of the body. Swimmers should also recover the legs when the arms pass the head and begin extending toward the surface. They should then execute a powerful kick as they complete their final extension and reach for the surface. The head should be down, in line with the body, during the underwater armstroke and during most of the arm

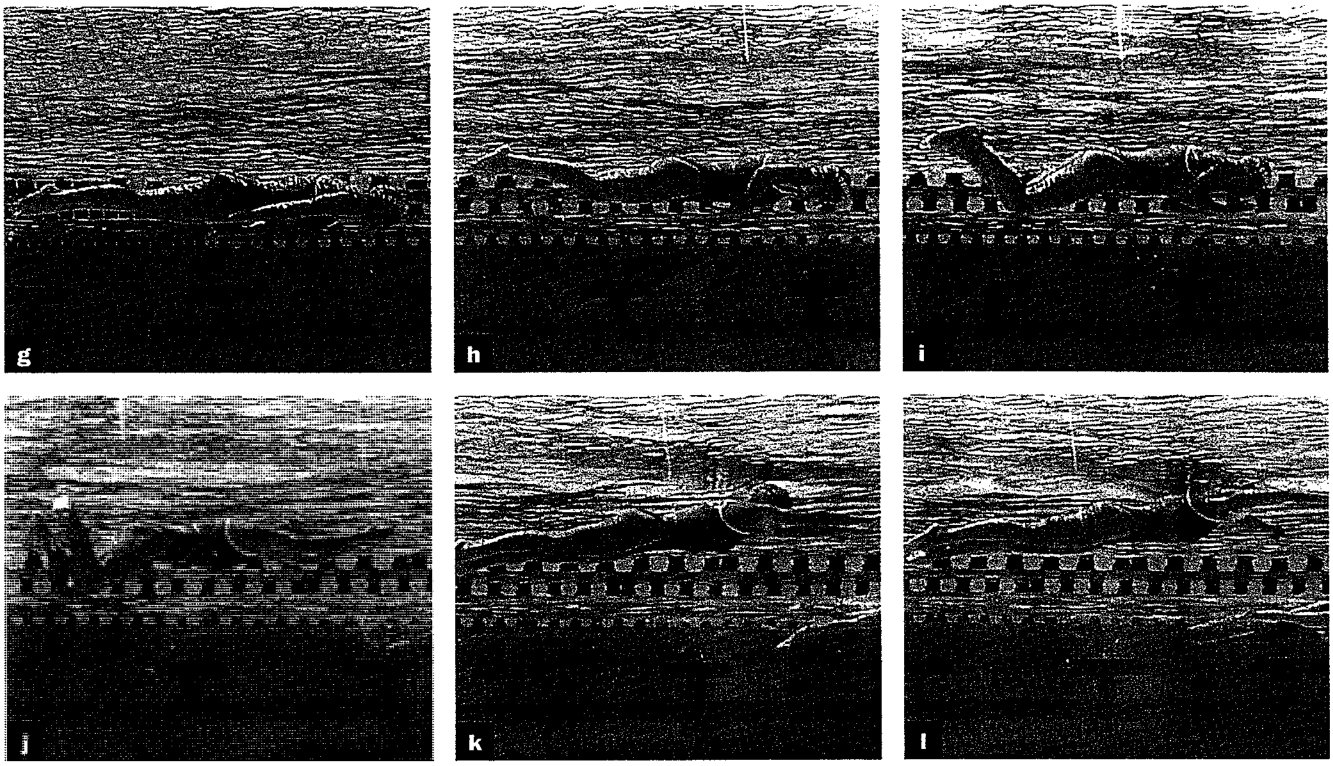


Figure 7.22 *(continued)*

(g) Second glide.
(h) Forward recovery with arms.
(i) Continuation of arm recovery. Forward recovery with legs.
(j) Extension of arms (toward surface). Start of propulsive phase with legs.
(k) Start of outsweep with arms (notice the head approaches the surface). Completion of propulsive phase with legs.
(l) Widest point in armstroke (notice the head is above the surface).

recovery. Swimmers should begin looking up as they extend the arms toward the surface, however.

The leg recovery should be as gentle as possible to reduce pushing drag. Swimmers should recover the legs forward without flexing the thighs at the hips until just before the legs begin to sweep outward to their catch position. The knees should also remain within the confines of the body during the leg recovery.

The kick should bring swimmers to the surface on a gradual diagonal so that they are moving more forward than upward when the body reaches the surface. Swimmers should not glide to the surface. Gliding will cause too much deceleration before beginning the first armstroke. Consequently, swimmers should begin sweeping the arms out when the propulsive phase of the kick ends and the legs are being brought together, as Nall is doing in figure 7.22k. That outsweep should begin while the head is still underwater. By doing so, the arms can be at the catch and swimmers can begin propelling the body forward with very little delay once the head reaches the surface, as in figure 7.22l.

Once the head reaches the surface, swimmers should take a breath at the normal point in their armstrokes, namely, when the propulsive phase has ended and they are recovering the arms toward the surface. Swimmers should not delay the outsweep or insweep of the arms to take a breath. Doing so will reduce their forward velocity considerably. Swimmers want to swim through the surface with that first armstroke. They do not want to glide to the surface, take a breath, and then begin pulling with the arms.

Timing is critical with this technique. Swimmers should be completing the outsweep of the armstroke as they reach the surface. But they cannot allow the arms to turn in before the head comes above the surface or they will be disqualified. With practice, swimmers should be able to use this technique without fear of disqualification and it will improve their times considerably. My own testing of several college swimmers has shown that pulling up and through the water surface will increase turning speed. From hand touch at the wall to the halfway point in the next short-course length, turning speed is increased by 0.30 sec, on average, when compared to gliding to the surface before taking the first armstroke. This means almost a 1 sec improvement in 100 yd and 200 m events in which swimmers make three turns. With seven turns, times could improve more than 2 sec for a 200 yd or 200 m short-course event.

Common Stroke Mistakes

The following lists include some of the most common mistakes breaststroke swimmers make. Mistakes during the various phases of the armstroke will be discussed first, followed by common mistakes during different phases of the kick and then mistakes in body streamlining and breathing. Mistakes made during the various phases of the underwater armstroke and the kick to the surface will also be described.

Armstroke Mistakes

The most common mistakes swimmers make during the outsweep, insweep, and recovery of their armstroke are described in this section.

Outsweep Mistakes

The most common mistakes made during the outsweep are (1) sweeping the arms out too little, (2) sweeping the arms out too much, or (3) putting too much effort into the outsweep.

1. Swimmers who use a short outsweep tend to turn the hands down and push against the water before the arms have moved out to the side enough to achieve a backward orientation to the water. As a result, they push down against the water in the classic dropped elbow position. Swimmers should wait until the arms are out wide enough to be facing back against the water before they start the insweep.
2. A second mistake occurs when swimmers sweep the hands out too wide before starting the insweep. Swimmers who pull too wide generally sweep the arms out and back during the outsweep and in and forward during the insweep. While used by many skilled breaststrokers, I believe this type of armstroke is potentially inferior to a stroke in which the arms sweep out and forward during the outsweep and in and back during the insweep.
3. The final mistake swimmers make during the outsweep is to push water sideward with the arms. As indicated earlier, this will only decelerate their forward speed. Swimmers should not push outward with the arms or palms during the outsweep. They should wait until both are outside the shoulders and facing back before they try to exert any force with them.

Insweep Mistakes

The most common mistake that swimmers make during this phase of the stroke has already been mentioned: to direct the hands forward. The forward speed of the body will drop off dramatically once swimmers begin moving the arms forward during the insweep. Consequently, they will either terminate the insweep early or they will waste time and effort performing a movement that is non-propulsive. The drawing in figure 7.23 shows why swimmers do not gain any propulsion when the arms are moving forward. The forward and inward arm movement produces an outward and backward drag force and a forward and outward lift force. Swimmers are bound to decelerate when they sweep the hands forward during the insweep because any small forward component of force that may be produced by this direction of limb motion will be negated by the large backward component of the drag force they are also producing.

Two mistakes are responsible for this loss of propulsion during the insweep: (1) concern with keeping the elbows from going back behind the shoulders and (2) overemphasis on getting the hands out in front quickly during the arm recovery.

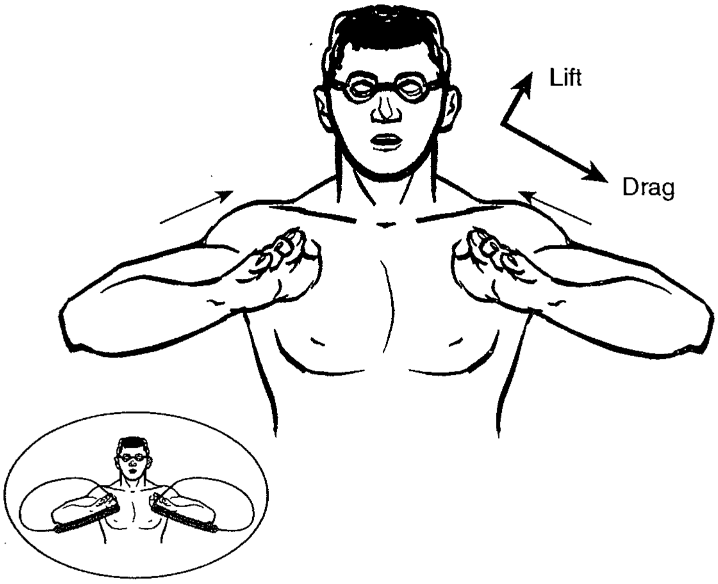


Figure 7.23 The effect of sweeping the hands forward during the insweep.

1. We have been told for years that swimmers should not let the elbows come behind the shoulders during the insweep to avoid making the mistake of dropping the elbows. As a result, many swimmers sweep the hands forward during the insweep in order to keep the elbows from traveling back behind the shoulders during this phase of the armstroke. In fact, swimmers cannot make a propulsive insweep without having the elbows come behind the shoulders. This does not necessarily mean they are dropping the elbows, however. They only drop the elbows if they push down against the water with the arms during the insweep. They do not drop the elbows if they make the insweep with a shoulder-adducting movement that keeps the arms traveling back until the insweep is completed. The arms will, and should, travel behind the shoulders somewhat when they complete the insweep in this manner.

2. Another error that causes swimmers to move the hands forward during the insweep is an attempt to get them out in front quickly during the recovery. Swimmers are often taught to accelerate the hands forward during the recovery to keep them from getting stuck under the chin. Unfortunately, this causes many breaststrokers to accelerate the hands forward during the insweep. While this gets the hands out in front quickly, it also causes a loss of propulsion during the insweep.

The method swimmers can use to adduct the arms back at the shoulders without getting them stuck was described earlier in the section on the insweep. They can squeeze the elbows down and forward quickly after the hands pass under the shoulders, and this will change their direction from back to forward with no hesitation.

Recovery Mistakes

The most common mistakes swimmers make during the arm recovery are (1) to push the hands forward with too much force and in poorly streamlined positions, and (2) to push the arms down too deep as they extend them forward.

1. Pushing the hands forward with too much force and in poorly streamlined positions will increase pushing drag in a backward direction, which will decrease forward velocity even more than it is already decreasing during this phase of the stroke cycle. One of the most common mistakes swimmers make in this phase of the stroke is to push the arms forward against the water with too much surface area as they recover them forward. A swimmer who is making this mistake is illustrated in figure 7.24b.

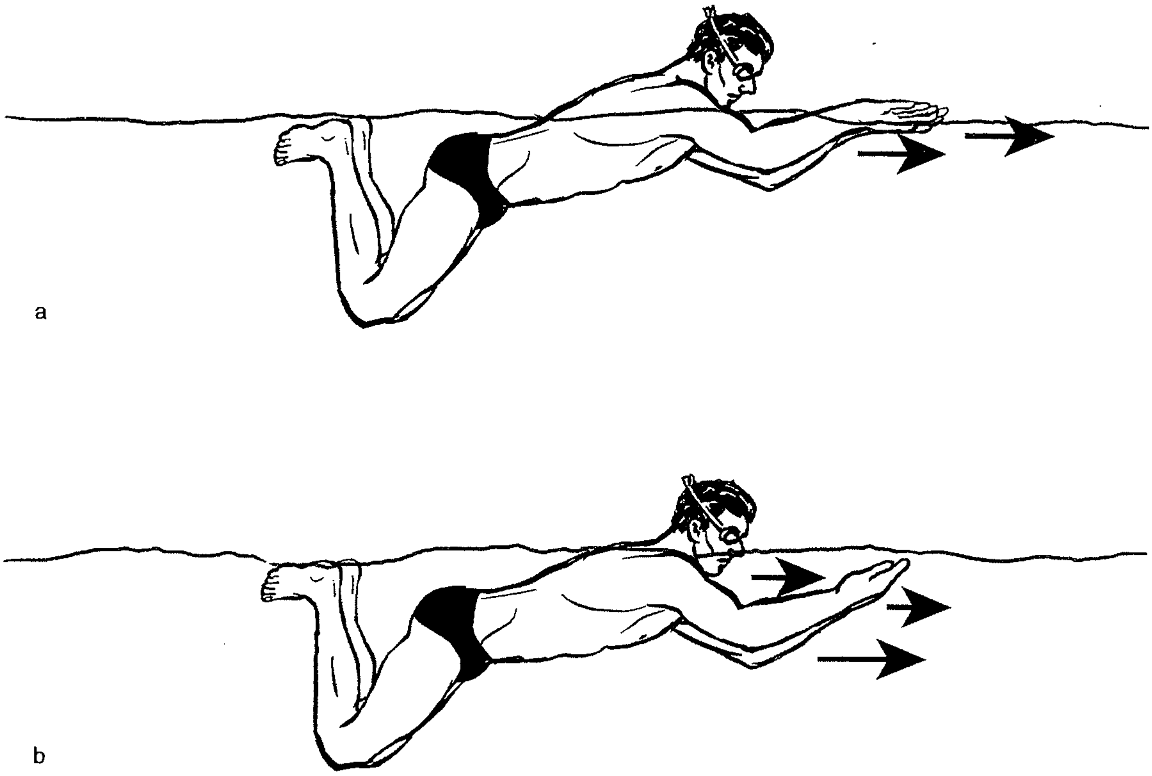


Figure 7.24 The swimmer in *(a)* is recovering his arms correctly, while the swimmer in *(b)* is making the mistake of pushing his arms forward to the surface as he begins to recover them forward. This will increase his drag considerably.

This swimmer begins pushing his arms forward while they are still very deep in the water. As a result, he will push forward against the water with his forearms and upper arms as he extends them toward the surface.

Swimmers should bring the arms to the surface before they begin extending them forward. Then they should turn the palms downward and slide the hands and arms forward along the surface, fingertips first, presenting the smallest surface area to the water. The swimmer in figure 7.24a is recovering his arms in this way.

2. The final problem is to reach too far downward as the arms extend forward. The arms should be stretched forward in line with the direction that the trunk is inclined. For a wave style breaststroker, this will be forward and slightly down. The drawing in figure 7.25 shows a swimmer who is reaching down too much as he extends his arms forward. Notice that his arms are inclined down more than his trunk.

Recovering his arms in this manner will cause the swimmer in figure 7.25 to push water forward with the upper sides of his arms. It will also increase the amount of

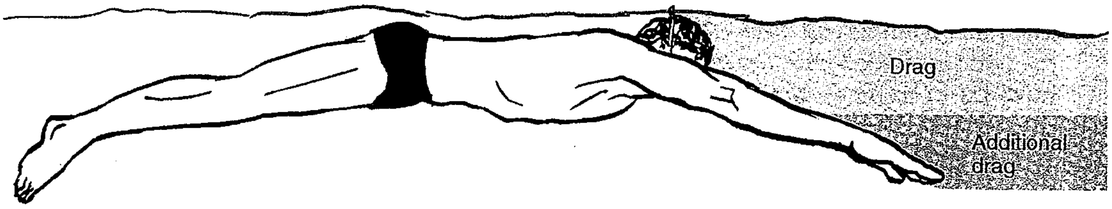


Figure 7.25 The mistake of reaching down too much during the arm recovery. Reaching down and forward will increase form drag because the swimmer's arms will be pushing water forward below the line of his trunk.

water his body pushes against as he moves forward. Plus, it will take him longer to get his arms up and into position for the catch as they sweep outward. The dark shaded area immediately in front of the swimmer indicates the additional area of drag created by the excessive downward movement of his arms.

Kicking Mistakes

The usual mistakes swimmers make during the recovery, outsweep, insweep, and leg lift are described in this section.

Recovery Mistakes

The most common mistake during this phase of the breaststroke was covered earlier in this chapter. It is when swimmers push the thighs down and forward against the water. Other common mistakes include (1) recovering the legs with the knees too wide or (2) with the feet in poorly streamlined positions, (3) lacking the flexibility to make a high catch, and (4) failing to set the feet in the proper catch position before extending the legs.

1. One error swimmers make is recovering the legs forward with the knees too wide apart in the fashion of the wedge kick. Form drag and pushing drag will be increased when swimmers bring the legs forward with the knees too wide. The knees should stay within the width of the shoulders during recovery.

2. Some swimmers also recover the legs with the feet in poorly streamlined positions. This will also increase form and pushing drag. Swimmers should keep the feet streamlined and pointed back and inside the hips until the leg recovery is completed and they begin to sweep them outward.

3. Another mistake occurs when swimmers circle the feet out to the catch position. Some swimmers do not possess the rotational flexibility with the hips, knees, and ankle joints that enables them to flex the feet and turn them out enough to make a high catch. As a result, they have to push the legs back somewhat before they can get the feet positioned properly to apply propulsive force. This will shorten the propulsive phase of the kick. Swimmers with this problem should do some special stretching exercises to increase flexibility in these joints.

4. A final error some swimmers make is in failing to set the feet in a good catch position before they begin extending the legs. Swimmers should circle the legs out gently with a minimum of backward motion near the end of the leg recovery, waiting until the feet are facing back against the water before they begin to extend the legs.

Outsweep Mistakes

The most common mistakes swimmers can make in the outsweep are (1) to push the legs down too deep or, conversely, (2) to push the feet back without circling them out. Swimmers may also make the mistake of (3) executing the outsweep with the feet plantarflexed (pointed back) instead of dorsiflexed (flattened).

1. The outsweep of the kick will have a small downward component, as swimmers drop the feet down to the level of the body while extending them backward. Kicking down excessively will cause them to lose some propulsive force, however. Swimmers should feel that they are extending the legs straight back in line with the body.

2. Some swimmers keep the knees too close together and kick backward with the feet very close together. This will reduce the effective range of the kick and reduce the insweep portion so much that some propulsion will be lost. It can also lead to sore knees if swimmers try to hold the knees close together while kicking back.

3. Some swimmers do not keep the feet dorsiflexed during the outsweep. Instead, they point the toes back and slide them through the water without generating any

significant amount of propulsive force as they extend the legs. Swimmers should pull the toes up, flexing the feet at the ankles, and maintain the feet in a flexed position until the propulsive phase of the kick has ended.

Insweep and Leg Lift Mistakes

The most common mistakes made in this phase of the kick are (1) extending the feet back before the insweep is finished, (2) failing to lift the legs after the insweep is complete, and (3) keeping the legs too close together.

1. The most common mistake swimmers make in this phase of the kick is to extend the feet back before the insweep is completed. Swimmers should not point the toes backward and lift the legs to the surface until the feet are nearly together. They should, instead, keep the feet traveling in and down across the water with the soles of the feet facing inward.

2. Another common mistake that swimmers make is to delay lifting the legs after the insweep has been completed. This mistake is illustrated by the drawing in figure 7.26. The swimmer in the drawing does not lift his legs after completing the insweep. Therefore, his legs remain below his trunk, where they increase form drag and reduce his forward velocity during the succeeding armstroke.

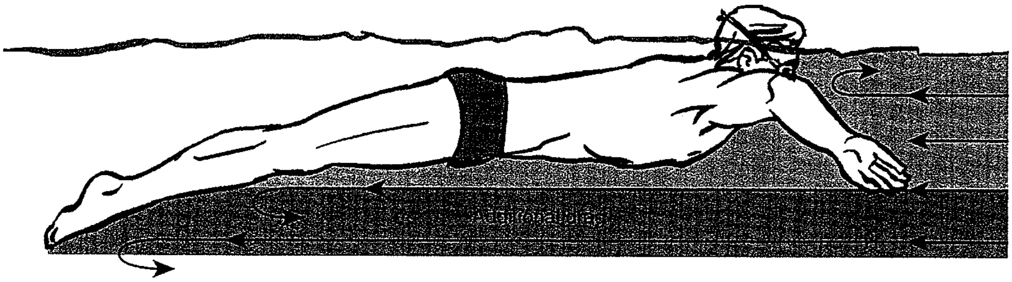


Figure 7.26 The mistake of leaving the legs hanging at the end of the propulsive phase of the kick. This will increase form drag because the swimmer's legs will be below his trunk.

3. Another mistake, this one involving the entire kick, is for swimmers to keep the legs too close together as they extend the legs back. With a narrow kick, many swimmers cannot get the feet facing back for the catch until they have already extended the legs quite a bit, which reduces the length of their propulsive phase. In addition, holding the knees close together places greater stress on the ligaments and medial menisci as swimmers try to rotate the lower legs outward into position for the catch. A kick that is wide enough to prevent injury and loss of propulsive force, yet not too wide, is one in which the knees are separated to approximately shoulder width when swimmers recover the legs forward. They should rotate the feet outside the shoulders during the outsweep and the first part of the insweep, but the feet should be coming back inside the shoulders as the legs near complete extension.

Timing and Breathing Mistakes

The mistakes swimmers make in the timing of the arms and legs, body position, and breathing are described in this section.

Timing Mistakes

The major errors swimmers make in this area, which were covered earlier in this chapter, are to use glide or continuous timing instead of overlap timing. A mistake that was not mentioned earlier is that some swimmers attempt to recover the legs during the propulsive phase of the armstroke. When this happens, the legs act like brakes, reducing forward speed. Swimmers should wait until the insweep of the armstroke is completed before they begin to recover the legs forward.

Breathing Mistakes

The most common mistakes include (1) breathing too early, (2) coming to the surface at too steep an angle to breathe, and (3) keeping the head above the water during the kick.

1. The most frequent mistake among breaststrokers is breathing too early. They breathe during the outsweep of the armstroke, which reduces streamlining during a phase of the armstroke when swimmers are already decelerating. Breathing at this time will also cause swimmers to push the arms down during the outsweep to provide support for the head. Swimmers should breathe at the end of the insweep. The head and shoulders will be at their highest point, so this is the ideal time to take a breath.

2. Another mistake is coming to the surface at too steep an angle when they breathe. Swimmers push the head up and back and arch the back to get them high out of the water. This will decelerate forward speed. They should bring the head and shoulders to the surface on a gradual diagonal so that the body is moving forward as well as upward when they breathe.

3. Some breaststroke swimmers keep the head above the water as they kick the legs back. As mentioned earlier, new rules permit swimmers to put the head underwater during much of the stroke cycle. Swimmers should take advantage of this opportunity for streamlining and put the head underwater in line with the arms during the kick. Swimmers who use this technique must not bury the head below the arms, however, nor should they dive down excessively to submerge the head.

Underwater Armstroke Mistakes

Swimmers can and do make mistakes during every phase of the underwater armstroke. I will begin with some of the common mistakes made during the periods when they glide just before and just after they complete their underwater armstrokes.

Mistakes During the First and Second Glides

Many swimmers glide too long in order to maximize the distance they travel underwater. They should never glide so long that they decelerate below race speed before they begin the underwater armstroke, however, or before they begin kicking to the surface. They will actually add time to their races if their velocity falls below race speed during the glide.

Conversely, it is senseless for swimmers to begin the underwater armstroke while they are traveling faster than race speed. Swimmers must learn to sense when it is time to begin the underwater armstroke. They should glide less in short races and slightly longer as the race distance increases because average velocity per stroke cycle will be lower in longer races.

Mistakes During the Armstroke

The four most common technical errors swimmers make during the underwater armstroke are making (1) a narrow outsweep or (2) a wide insweep, and (3) pushing up too much or (4) too little during the upsweep.

1. Swimmers make the same mistake in the underwater armstrokes that was described for the surface armstroke when they do not sweep the arms wide enough to orient them backward before starting to push against the water. Instead, they push down on the water, raising the body to the surface more than they propel it forward.

2. Some swimmers push the hands back too much and in too little during the insweep. The insweep of the underwater armstroke is an example of adducting the arms

at the shoulder joints. During this sweep, swimmers should bring the upper arms back, down, and in, toward the ribs. As a result, the hands should come very close together under the midline of the body as the insweep is being completed.

3. Swimmers who push up too much during the upsweep extend the arms too early. As a result, the arms are extended while they are still underneath the body. In this position, they will be pushing up instead of back against the water with the forearms and that will decelerate forward speed.

4. Many swimmers also commit the opposite mistake during the upsweep of the underwater armstroke. That is, they push up too little at the end of this sweep. They stop the underwater armstroke before the hands pass up above the legs. When they do this, they tend to surface too quickly during the second glide. Swimmers should always finish the upsweep with the arms above the thighs.

Mistakes During the Leg Recovery and Kick to the Surface

One of the most common mistakes swimmers make in this part of the stroke is gliding to the surface, the effects of which were described earlier in this chapter. Other mistakes include (1) recovering the arms in poorly streamlined positions, (2) recovering the legs too early, (3) flexing the thighs too much at the hip joints, and (4) moving the arms and legs forward with too much force.

1. Some swimmers hold the hands and arms away from the body in poorly streamlined positions as they recover them forward. This increases their surface area as they push forward through the water. The arms and hands should be on edge, close together, and close to the body during their movement forward.

2. Some swimmers recover the legs forward at the same time they recover the arms toward the surface. Consequently, they recover the legs slowly for a long period of time, which causes forward speed to decelerate more rapidly during this phase of the underwater armstroke. They should not begin recovering the legs forward until the arms are passing the shoulders and reaching forward during their recovery. They will still have plenty of time to get the legs in position for the kick to the surface if they wait until the arms are midway through recovery before they begin to recover the legs forward. The legs should be recovered quickly but gently, with a minimum of hip flexion until the outsweep of the kick begins.

3. Swimmers should recover the legs forward during the underwater armstroke in the same manner they use for surface stroking. That is, they should bring the lower legs forward by flexing them at the knees, and without flexing the thighs at the hips until they are ready to sweep the legs out to the catch. Flexing at the hips during leg recovery will only decelerate their forward speed to a near standstill.

4. Some swimmers move the arms and legs forward with too much force. All recovery movements of both the arms and legs should be made quickly but gently. Swimmers should present the least surface area to the water with the arms and legs as they recover them forward, and they should not push them forward with great force.

Breaststroke Drills

Some of the best drills for improving the breaststroke are listed in this section. They include drills for the armstroke and the kick, and drills to improve body movements and breathing. Some drills for improving the underwater armstroke are also listed.

Armstroke Drills

The exaggerated breaststroke pull drill described in chapter 3 (page 83) is excellent for learning the armstroke. Following are some other good drills.

ONE-ARM BREASTSTROKE DRILL

Swimmers can swim or pull the breaststroke using only one arm. The other arm should be held extended in front of them. This drill, because they are using only one arm at a time, helps breaststroke swimmers concentrate on the techniques of the armstroke. It is also an excellent drill for improving the stroke of the nondominant arm.

FIST PULLING DRILL

This drill is designed to help swimmers learn to use their arms more effectively during the pull. Swimmers can pull or swim repeats of any distance with the hands shaped in fists. This is also a good drill for improving the nondominant arm if they pull or swim repeats with the hand of the dominant arm in a fist and the hand of the nondominant arm open. They may learn to use the nondominant arm more effectively when the dominant arm is limited in its ability to produce propulsive force.

OUT SLOW, IN FAST DRILL

This can also be performed as a pulling or swimming drill. Swimmers should sweep the arms out slowly and gently until the water is behind the arms and then make the insweep quickly and powerfully. This is an excellent drill for teaching swimmers to make a good catch and to put the emphasis where it belongs, on the insweep of the armstroke.

Kicking Drills

There are five drills that are very good for improving the breaststroke kick. Each is described in this section.

DISTANCE PER KICK DRILL

Swimmers kick down the pool using the fewest number of kicks possible. They can do the drill with a kickboard or without. This drill encourages them to maximize the propulsive phases of the kick and to streamline the trunk and legs during the glide. They should be reminded to lift the legs up in line with the body during the glide.

DOLPHIN KICK DRILL

This drill can also be done with or without a kickboard. It works better without a kickboard, however, because swimmers can undulate the body more naturally. Swimmers emphasize pressing the hips up and forward over the water with each kick. Swimmers should be cautioned not to overdo the undulation.

KICK ON BACK DRILL

In this drill, swimmers can kick any number of pool lengths on their backs. The arms should be extended overhead and laying in the water with the palms facing up. This drill helps breaststrokers learn to recover the legs without pulling the thighs up because, if they do, the knees will break through the surface of the water.

KICK WITH HANDS BACK DRILL

This, perhaps, is the best drill for teaching breaststroke swimmers to recover the legs forward without flexing at the hips. It is also excellent for teaching them to drop the hips and elevate the head and shoulders as they recover the legs. Swimmers kick down the pool without a kickboard. The arms should be extended behind them and the hands should be resting beside the hips, near the surface of the water. They should touch the feet to the hands each time they recover the legs forward.

Swimmers should be instructed to delay flexing the thighs at the hip joints until they start the outsweep of the kick. They should also be instructed to raise the head and lower the hips to breathe during the leg recovery, and to lower the head and shoulders into a streamlined position underwater before they execute the propulsive phase of the kick. A swimmer is shown doing this drill in figure 7.27.

Figure 7.27 The kick with hands back drill performed by Mindi Bach.

LEG RECOVERY DRILL

In this drill, swimmers should kick in a prone position without a kickboard. The arms should be together and extended forward in the water. They should concentrate on keeping the body moving forward during the leg recovery by shrugging the shoulders forward as the legs move up, then by dropping the head and trunk underwater into a streamlined position as they extend the legs back. Breaststrokers should also concentrate on flexing the legs properly during the recovery and lifting them into a streamlined position during the glide. It is best to do this drill with long glides initially so that swimmers learn to streamline during the insweep of the kick and the glide that follows. Later they can kick with shorter glides to improve streamlining at rhythms similar to those used in competition.

Body Position and Timing Drills

Three of the best drills for improving the undulating body motion of the breaststroke and the timing of the arms and legs are described in this section.

KICK AND STRETCH DRILL

Swimmers should kick without a kickboard executing a half-pull with the arms after each kick. After the outsweep, and without completing the insweep of the armstroke, they should extend the arms in front of the body so that they remain streamlined while they recover the legs and execute a kick. They should begin sweeping the arms out again just after they complete the insweep of that kick. This is a good drill to teach overlap timing.

DOLPHIN PULL DRILL

Swimmers use a dolphin kick while they pull several pool lengths without a pull-buoy or tube. The timing is one dolphin kick per armstroke. That kick should take place while the arms are sweeping out. This drill helps swimmers get a feel for the wave style of the breaststroke. The dolphin motion should not be excessive. The hips should rise only slightly to the surface when they kick down and they should not lower the hands and head too deep into the water as they extend them forward. They should also concentrate on riding the body wave of the kick by looking up and starting the hands out and up as the hips pass the peak of their upward undulation.

TWO PULLS, ONE KICK DRILL

This is a modification of the previous drill and is used for the same purposes. Swimmers should swim any number of pool lengths while executing several continuous series of three armstrokes. They should use dolphin kicks during the first two armstrokes of each series and a breaststroke kick during the third armstroke.

Underwater Armstroke Drills

Three drills are recommended for improving both the distance and speed of swimmers during this important part of their races.

DOUBLE PULLDOWNS DRILL

Athletes should swim repeats doing two underwater armstrokes after each turn before they come to the surface. This drill helps them develop the ability to maximize their underwater pulldowns in races without becoming fatigued.

PULLDOWNS FOR DISTANCE DRILL

Swimmers should try to travel the maximum distance they can during each underwater armstroke before they surface. This is a good drill for teaching them to maximize the propulsive elements of their underwater armstrokes and to streamline the body well during the glide phases. Breaststrokers must be cautioned not to extend their time underwater to the same extent during races, however, or they will spend too much time traveling at slow speeds.

PULLDOWNS FOR SPEED DRILL

This drill is used to counteract the overlong gliding that may develop from the previous drill. Swimmers should be timed from when they touch the wall with the hands to begin the turn until they reach some predetermined point in the pool after the turn and underwater armstroke. That spot should usually be where they surface. Swimmers should try to maximize propulsion from the arms and legs during the underwater armstroke while at the same time seeking the optimum gliding time that does not cause too much deceleration. They should also be instructed to surface on a gradual diagonal with the first surface armstroke underway as the head breaks through the surface.

8

Starts, Turns, and Finishes

New in this edition:

- Discussion of adding an armswing to the grab and track starts
- New research on the starting position for the track start
- Latest research on the step-up relay start
- Descriptions of the underwater dolphin kick as used with starts and turns in three of the four competitive strokes

In these days of crowded pools and high-mileage training programs, athletes spend very little time perfecting the techniques of starting, turning, and finishing. This is a serious oversight. Start times account for approximately 25% of the total time spent swimming 25 races, 10% of the time in 50 races, and 5% of the time in 100 races. Freestyle swimmers spend between 20% and 38% of their time turning in short-course races that range from 50 yd/m to 1,650 yd, respectively. Breaststrokers in short-course 200 races spend a whopping 39% of their time turning and completing their underwater armstrokes (Thayer and Hay 1984).

Testing I have done over several years indicates that improving the start can, on average, reduce race times by a minimum of 0.10 sec, while improving turns will decrease race times by at least 0.20 sec per pool length. Many swimmers also make mistakes when they finish their races. They may take unnecessary strokes or glide into the wall. Finishes that are poorly timed often cost swimmers 0.10 sec or more.

Swimmers can make major improvements in the techniques of starting, turning, and finishing races by spending just a few hours working on these skills each week. Thus, with a minimal time investment, swimmers could improve their short course 50 times by at least 0.40 sec. They could reduce their times by at least 0.80 sec in short-course 100 races because there are two additional turns. Improvements in longer races would be even more dramatic. For example, improving turns could reduce their times by as much as 5 sec in long course 1,500 m races and by 10 to 12 sec over short-course races of 1,500 m and 1,650 yd.

The significance of these improvements is evidenced by the fact that only 0.44 sec separated the first and fourth place finishers in the women's 50 m freestyle at the 1996 Olympic Games. In the men's 1,500, 14 sec separated first and fourth place. Certainly, practicing starts, turns, and finishes would be time well spent for many swimmers.

Starts

Swimmers start from a block on the pool deck in freestyle, butterfly, and breatstroke events. They start in the water in backstroke events. Many starting styles have been used over the years. Initially, swimmers took a preparatory position on the starting block with arms extended back. They soon found they could get the body moving toward the water faster by starting with the arms forward and then swinging them back. This technique became known as the *straight backswing start.* It was later replaced by a faster *circular backswing start* in which the arms were circled up and backward overhead and then down and forward as the body extended from the starting platform. Circling the arms enabled swimmers to overcome backward inertia during the first part of the swing without bringing the arms to a stop before swinging them forward in the second half. This, in turn, increased their forward velocity during their flight through the air. The circular backswing start has now been replaced by even faster methods: the *grab start* and *track start.*

The grab start was introduced by Eric Hanauer in the late 1960s and rapidly gained popularity. Today, it is used by practically all competitive swimmers (Hanauer 1967). In the majority of research studies where the grab start was compared with conventional methods, it proved to be faster (Bowers and Cavanaugh 1975; Cavanaugh, Palmgren, and Kerr 1975; Jorgenson 1971; Michaels 1973; Roffer and Nelson 1972; Thorsen 1975; Van Slooten 1973; Winters 1968). This is because swimmers can get the body moving toward the water faster by pulling against the starting platform than they can by swinging the arms backward. Swimmers will also decelerate more quickly, however, once they enter the water without momentum from the armswing.

Nevertheless, studies show that swimmers who use the grab start are usually faster to reach the water and also the surface, called the *break-out,* even though they lose some speed during the glide. For example, Thorsen (1975) found that horizontal and vertical velocities were greater with the circular backswing start, yet the grab start was faster by 0.10 sec to the point of entry. Bowers and Cavanaugh (1975) reported that swimmers left the block 0.17 sec faster, on average, when they used the grab start as compared to the circular backswing. This accounted for practically all of the difference in time between the two starts at a point 10 yd down the pool.

At first, swimmers using the grab start entered the water similarly to the way they had entered with previous starting methods: very shallow. They would land almost flat on the surface and begin swimming almost immediately. After some time, however, they adopted a new style of entry known by various names, the two most common being the *pike start* and *scoop start.* I prefer the former term and will use it throughout this section.

In the pike start, swimmers travel through the air in a high arc, often bending (piking) at the waist, so that they can enter the water at a very steep angle. The major advantage of the pike start is that swimmers encounter less drag at the point of entry. Consequently, they travel faster during the glide underwater. Differences between the pike and flat entries are illustrated in figure 8.1.

The first swimmer, on the left, is using a shallow entry. She enters the water flat, causing her to decelerate rapidly because her body strikes the water in several places at once. Conversely, the entire body of the swimmer using a pike start, shown on the

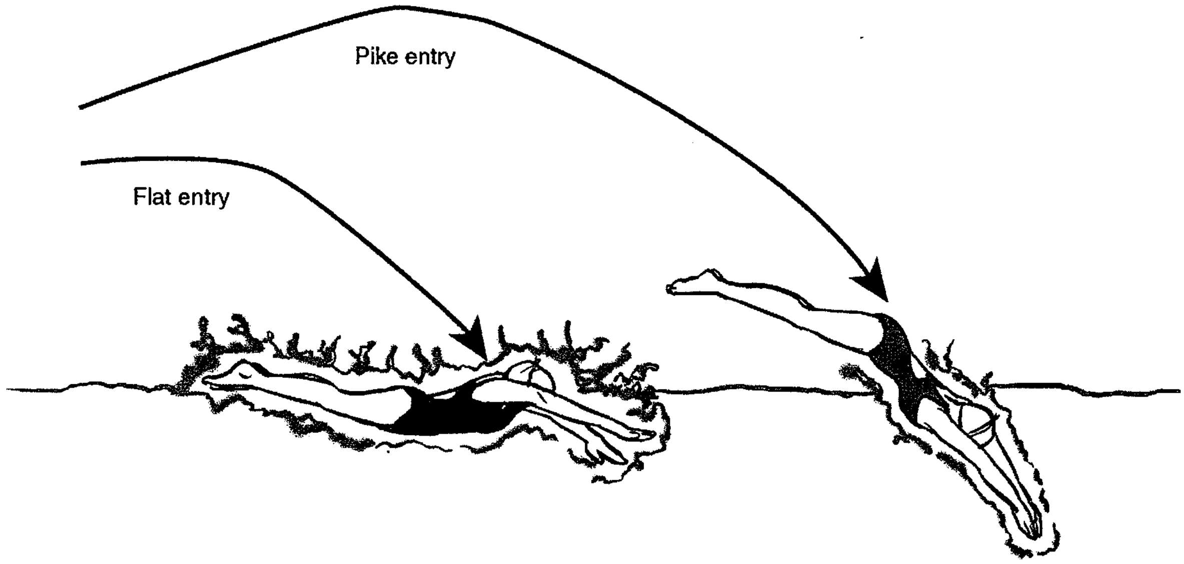


Figure 8.1 A comparison of the pike and flat entries.

right, can enter the water through one spot, allowing it to slip underwater with less resistance. Consequently, she will decelerate less rapidly during her underwater glide.

A word of caution is in order regarding the pike start. It has proven to be very dangerous when used in shallow pools. Several accidents have been reported in which swimmers hit their faces and heads on the bottom. A small number of these swimmers suffered serious neck injuries that left them paralyzed. This dive should not be attempted in pools that are fewer than 6 ft deep. The depth that swimmers reached with the pike start varied from 3 to 5 ft (1 to1.7 m) in a study by Counsilman and others (1988).

Another recent modification of the grab start is the track start. The major difference between this and the traditional grab start is in the preparatory position on the starting platform. With the track start, swimmers place one foot near the rear of the block and the other over the front edge. Both feet are placed over the front edge of the starting block when using the traditional grab start.

To date, only a handful of studies have compared the track and grab starts. In one, there was no difference in speed to 5, 10, and 12.5 yd from the starting end (Counsilman et al. 1988). In another, swimmers left the block significantly faster with the track start but actually lost speed once they entered the water. There was no difference in time between the track and grab starts to a distance of 5 m (approximately 16 yd) from the starting end (Ayalon, Van Gheluwe, and Kanitz 1975). In still another study, swimmers left the block significantly faster (0.07 sec faster) with the track start and they maintained most of that advantage to a distance of 5 m (Welcher and George 1998). The difference at 5 m was 0.06 sec—1.81 sec for the track start and 1.87 sec for the grab start—a significant difference.

In a fourth study, the track start was significantly slower than the traditional grab start for a distance of 5.5 m (approximately 18 yd) from the starting end (Zatsiorsky, Bulgakova, and Chaplinsky 1979). In a fifth study, the track start was significantly faster. Start times to a particular distance from the starting end were not measured in the sixth study. Other variables were, however. Subjects left the block faster using a track start, but they traveled significantly farther through the air using the grab start (Allen, 1997).

Apparently, the jury is still out on the track start. Swimmers who use this style seem to get off the block faster, but they enter the water at a somewhat flatter angle and lose time during the glide. On the other hand, swimmers who use the conventional grab start (both feet at the front edge of the block) are slower leaving the block but enter the water at an angle that permits a faster glide. Both Guimares and Hay (1985) and Zatsiorsky, Bulgakova and Chaplinsky (1979) reported that the gliding speed after entry accounted for most of the difference in starting times between swimmers. The latter group of researchers reported a significant relationship of 0.94 between starting speed and gliding speed. By comparison, the correlation between starting speed and speed off the block was a nonsignificant 0.60.

A growing number of swimmers are now using the track start, even though it has not been proven superior to the traditional grab start in the few studies conducted. Apparently, swimmers have intuitively decided that the track start is faster or they may prefer it because it results in fewer false starts. Swimmers have a more stable position on the platform and are not as likely to lose their balance if they pull early when they use the track start. Since neither the grab nor track start has been proven superior to the other, I will describe both in the following two sections. In addition, I will recommend some modifications to both that may increase starting speed.

Traditional Grab Start

Techniques of the grab start are shown for a freestyle swimmer in the series of photographs in figures 8.2 and 8.3. For descriptive purposes, the grab start is divided into the following: (1) the preparatory position, (2) the pull, (3) the drive from the block, (4) the flight, (5) the entry, and (6) the glide and pull-out.

Preparatory Position

Swimmers should stand at the rear of the starting platform until the starter gives them permission to assume the preparatory position by saying, "Take your marks." After that command, swimmers grip the front edge of the starting platform with the toes. The feet should be approximately shoulder-width apart. This foot position permits a stronger leg drive than one in which the feet are outside the shoulders or positioned close together. They should grasp the front edge of the starting platform with the first and second joints of the fingers. The hands may be either inside or outside the feet. Both hand placements have been used by good starters and research has failed to show that one of these methods is superior to the other. The knees should be flexed approximately 30° to 40° and the elbows should be flexed slightly. The head should be down and swimmers should be looking at the water just beyond the starting platform. They should lean forward in the preparatory position and should maintain themselves just on balance by holding onto the block with the hands, as shown in figure 8.2a.

The positions of the knees and head that I have described are different from those usually recommended. Swimmers are usually instructed to bend the knees more and keep the head up higher in the preparatory position. To get a fast start, however, they need to keep the center of mass as close to the front edge of the starting platform as possible because they cannot begin driving the body away from the starting platform until the center of mass is outside the front edge. Thus, keeping the center of mass close to the front edge will reduce the distance they must travel before they can begin driving the body away from the starting platform after the starting signal sounds. They can shift the center of mass forward by putting the head down and flexing the knees only slightly when they are in the preparatory position. A deep crouch places more of the body behind the front edge of the starting platform and, therefore, causes the center of mass to shift backward away from the front edge. Consequently, additional time will be required to move the center of mass beyond the front edge of the starting block after the starting signal sounds.

Center of mass position is compared for the recommended preparatory positions and a deep crouch in figure 8.4. The drawing on the right shows a swimmer in a deep crouch. The swimmer in the drawing on the left has his legs flexed less. As illustrated, the center of mass tends to be farther back behind the front edge of the platform when a deep crouch is used.

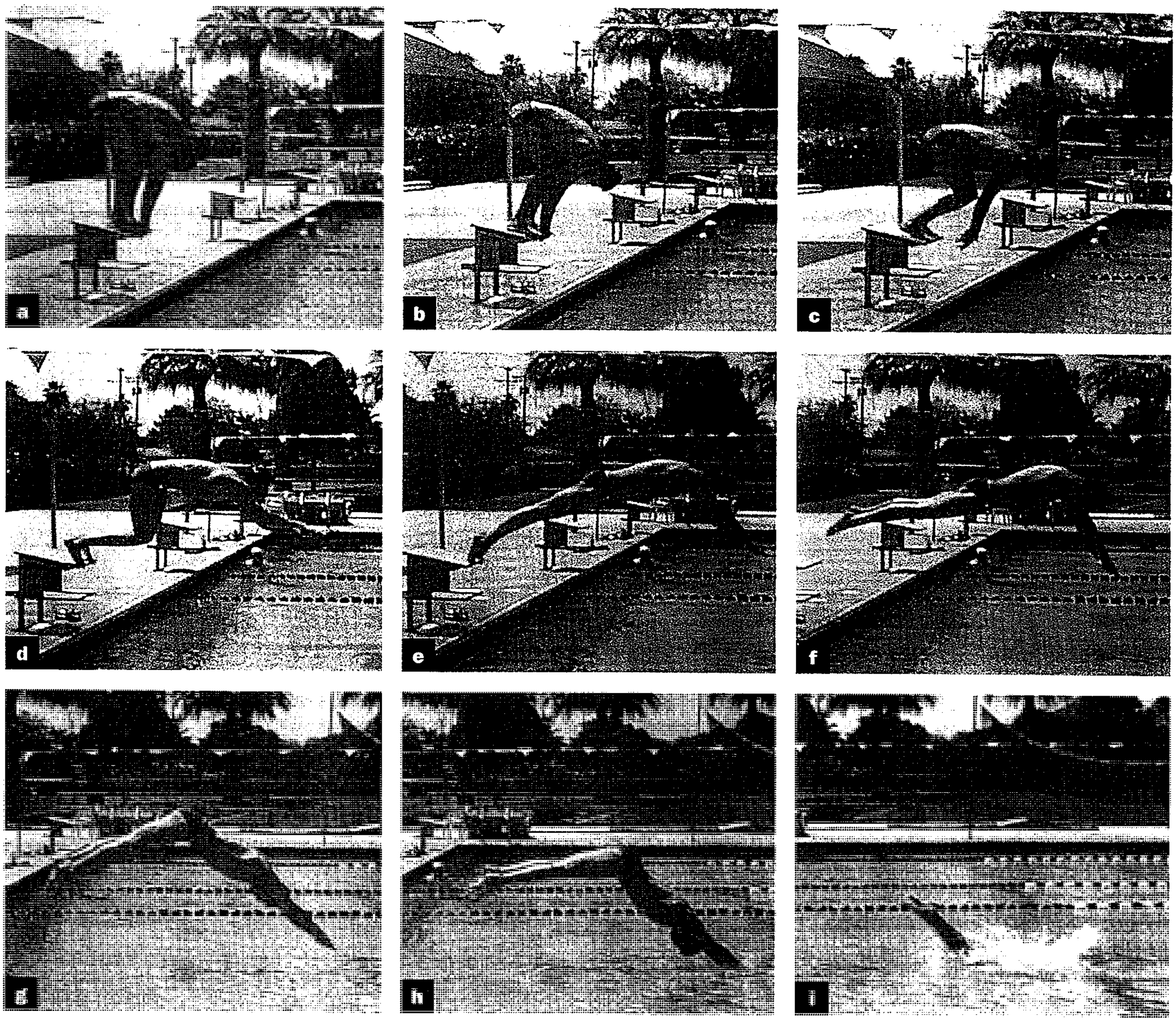


Figure 8.2 The grab start. The swimmer is Craig Hutchison, former NCAA all-American at Arizona State University and a member of the 2000 Canadian Olympic team.

(*a*) Preparatory position.
(*b*) Upward pull against underside of starting platform at starting signal.
(*c*) Release of block. Beginning of leg extension.
(*d*) Continuation of leg extension.
(*e*) Reach for entry position. Completion of leg extension.
(*f*) Flight.
(*g*) Pikes at waist.
(*h*) Start of entry with hands.
(*i*) Entry of body.

The position of the head also plays a role in positioning the center of mass closer to the front edge of the starting platform. When it is down, as it is in the drawing on the left side of figure 8.4, the center of mass tends to shift forward slightly. When the swimmer is looking up, as he is in the drawing on the right side of figure 8.4, the position of the center of mass shifts back slightly. This is why I recommend swimmers look down when they are in the preparatory position.

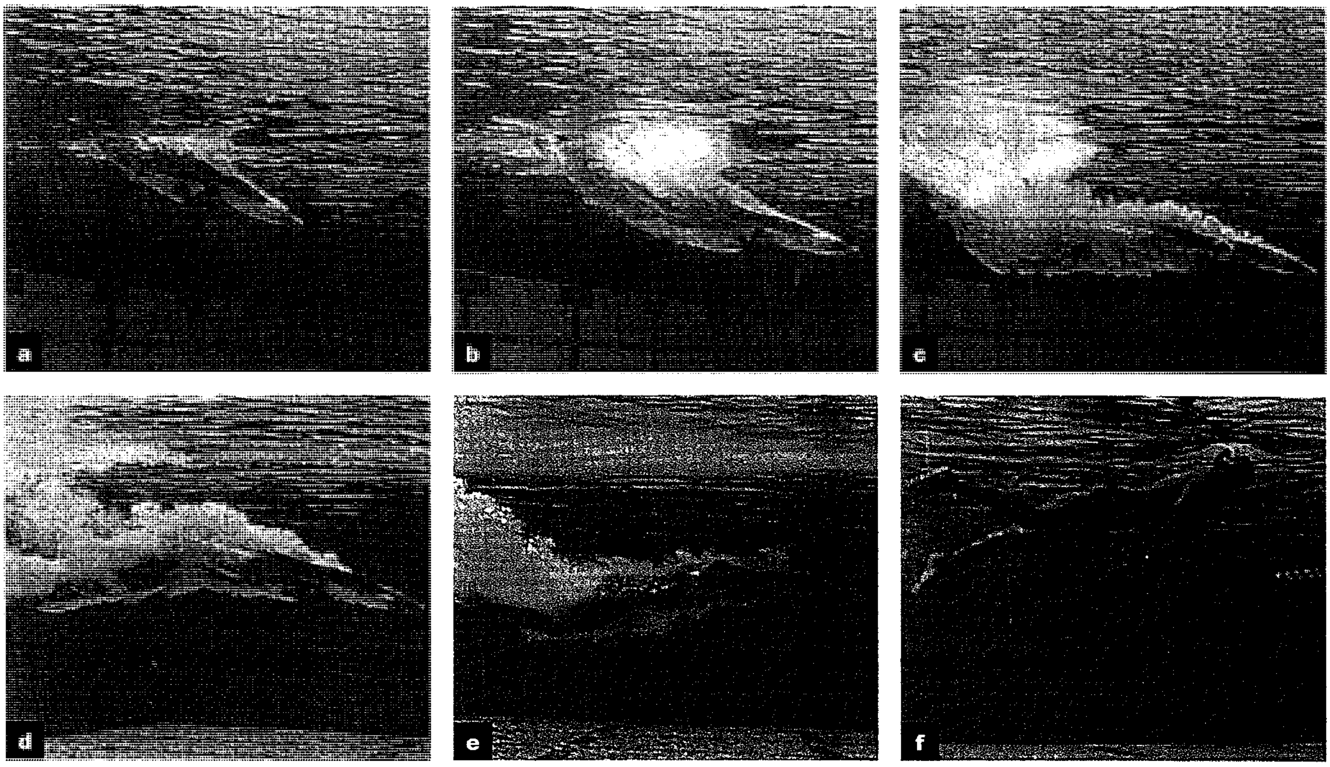


Figure 8.3 A sequence of photos of the entry and underwater portions of the grab start. The swimmer is Guillermo Diaz DeLeon, former NCAA all-American from Arizona State University.

(*a*) Entry into water traveling down and forward.
(*b*) Arch of back during entry. Change of trajectory from downward to forward.
(*c*) Preparation for first dolphin kick with legs.
(*d*) Completion of first dolphin kick.
(*e*) Completion of additional dolphin kick.
(*f*) Start of flutter kick and first armstroke.

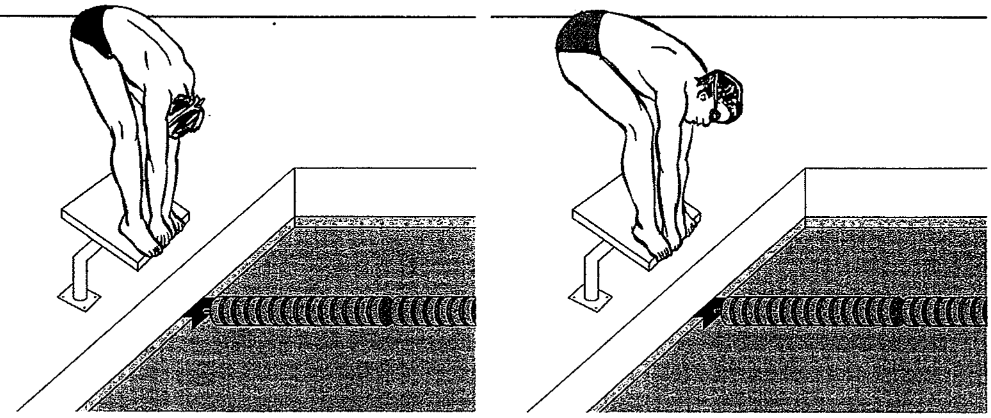


Figure 8.4 A comparison of the position of the center of mass in two preparatory positions for the grab start.

Pull

At the sound of the starting signal, swimmers should pull up against the bottom of the starting platform. This will pull the hips and the center of mass down and forward beyond the front edge of the starting platform so that they can begin driving the body forward, toward the water. Pulling in this direction will also flex the knees and hips to extend them more forcefully once in position to do so. Swimmers should not push back against the starting platform with the hands. Pulling up will get the body moving forward faster (Guimares and Hay 1985). The pull is pictured in figure 8.2b.

There is no need for swimmers to use a long or powerful arm pull to get the body in motion. This will not add speed or force to the drive. They need only get the body moving forward and gravity will take over from there. This is accomplished with a short upward pull against the underside of the starting platform, after which the hands are released as quickly as possible.

Drive From the Block

Swimmers generally spend 0.70 to 0.90 sec driving the body from the starting platform once they get in motion (Lewis 1980; Bloom, Hosler, and Disch 1978). They can stay near the minimum time in this range by releasing the front of the starting platform immediately when the body starts moving forward. A quick pull will get the body moving forward and once it is in motion, gravity will pull it down and forward until the knees are flexed approximately 80°. At this time, they should extend the legs as they drive the body forward and up from the starting platform. The leg drive is executed by a powerful extension at the hips and knee joints followed by extension of the feet at the ankle joints. Hutchison is driving his body away from the starting platform in figure 8.2, c, d, and e.

When the hands release the block, swimmers should extend the arms forward in a semicircular path until they are pointing at the same area in the water where the body should enter. The arms should bend rapidly during the first half of the movement to bring them up under the chin during the fall forward. They should then extend the arms rapidly forward and down while extending the legs during the second half of the drive. The timing of the arms and legs should be similar to their timing during a vertical jump or a rebound in basketball. If you can picture yourself leaping into the air for a rebound, you should be able to understand how timing the upward swing of the arms with the extension of the legs can increase distance. That same timing can increase your distance over the water after leaving the starting platform. Hutchison is extending his arms and legs simultaneously in figure 8.2, d and e.

The angle of take-off, from feet to hips, should be approximately 30° to 40° from the top edge of the starting block, as shown in figure 8.2e. This angle will give swimmers the arc-like trajectory needed for a streamlined entry.

Flight

After leaving the starting platform, swimmers will travel in an arc, traveling up during the first half and toward the water during the second half of the flight through the air. The body should be in a pike position (bent at the waist) as they pass over the peak of the arc so that they can make a streamlined entry into the water. Hutchison assumes this pike position in preparation for the entry in figure 8.2g.

The pike position must be established before leaving the starting platform or swimmers will not be able to get the body in a streamlined position as they enter the water. The pike position is achieved by driving the arms forward and down, and by looking down as they drive the body away from the starting platform. These actions will cause the upper body to start down, even as the hips and legs continue up over the peak of the flight. Swimmers should time these head movements so that they are looking up as they fall forward, as shown in figure 8.2, c and d, and looking down as they extend the legs, as in figure 8.2e. After the body passes the peak, swimmers should pull the legs up in line with the trunk so that the entire body will be streamlined as it enters the water. Hutchison is doing this in figure 8.2h.

Swimmers generally spend between 0.30 and 0.40 sec in the air during the start and they travel between 3 and 4 m (11 and 13 ft) from the starting platform before they enter the water (Spina 1995; Lewis 1980; Hanauer 1972).

Entry

During the entry, the feet should pass through the same spot in the water where the hands and head entered initially. This entry is shown in figure 8.2i.

Glide

The glide portion of the start is shown in the series of photographs in figure 8.3. The body should be streamlined during the entry. The arms should be fully extended and together, preferably with one hand over top of the other, and the head should be between the arms. The legs should be fully extended and together with the toes extended back (pointed) and there should be no arch or pike at the waist. The angle of entry should be approximately 30° to 40° from the surface of the water (Spina 1995; Counsilman et al. 1988; Beritzhoff 1974). This angle allows swimmers to slip into the water with a minimum of resistance. It can also cause them to plunge too deep beneath the surface, however, unless they change body direction from downward and forward to forward and upward almost immediately after entering the water.

This directional change is accomplished by snapping the legs down in a dolphin kicking motion while at the same time arching the back and lifting the head and hands toward the surface. The timing of these actions will vary according to how fast swimmers wish to reach the surface. In shorter races, they will begin changing directions as the body enters the water, as Diaz DeLeon is doing in figure 8.3, b and c. They will wait until after the body is nearly submerged in longer races. The only exception to these statements is in the breaststroke, where swimmers purposely glide deeper underwater in preparation for their underwater armstrokes.

This downward snap of the legs is shown in figure 8.3, c and d. Butterfly swimmers usually do two or three dolphin kicks underwater before coming to the surface. Many swimmers in freestyle sprint races also use two or three dolphin kicks after they enter the water before they start the flutter kick and begin stroking. I recommend doing this in freestyle events because the dolphin kick is more propulsive than the flutter kick and, therefore, keeps swimmers moving faster toward the surface during the glide after the start. Arellano and coworkers (1996) reported that swimmers in freestyle races were significantly faster by nearly 0.20 sec for a distance of 10 m after the start when they used the dolphin kick instead of the front crawl flutter kick.

The underwater dolphin kicks after entry should be executed in the same manner recommended for butterfly swimmers in chapter 5. That is, swimmers should use a body shimmy motion.

Some sprint freestyle and butterfly swimmers are now dolphin kicking for most of the allowed 15 m after starting before they come to the surface and begin stroking. Whether or not they choose to stay underwater for this distance should be determined by each particular swimmer's speed with the underwater dolphin kick. I would only recommend they do so if testing proves that they can kick faster underwater than they can swim on the surface.

Regardless of whether they glide or kick, swimmers should reduce form drag after they enter the water by maintaining the trunk, head, and arms in a streamlined position. The head should remain down between the arms. The arms should be extended overhead and held tightly together with one hand over top of the other. The trunk should be straight, neither piked nor arched at the waist, and the legs should be extended and together with toes extended back while they are gliding.

Pull-Out

Swimmers should kick diagonally toward the surface so that they reach it traveling forward faster than they are traveling upward. In freestyle events, they should begin to flutter kick just before they start that first stroke. This will establish a rhythm so that they come through the surface swimming the front crawl stroke. Diaz DeLeon has started his flutter kick and is midway through his first armstroke as his head breaks through the surface in figure 8.3f.

The first armstroke should begin when swimmers near the surface and the head should break through the surface as the first armstroke is being completed. It should be a powerful sweep back with one arm in the front crawl stroke, or with both arms in the butterfly. This pull should bring the body upward through the surface traveling forward at race speed. The head should remain down during the underwater stroke and they should not look up until they feel the head break through the surface.

Swimmers should not hesitate to catch a breath or look around at other swimmers when they reach the surface but instead should establish the proper stroke rhythm for the race as quickly as possible. Breathing and looking around, two of the most common mistakes swimmers make, slows their speed when they reach the surface. For this reason, it is best for swimmers in freestyle and butterfly events to delay breathing until the end of the first stroke cycle or, better still, to wait until the second stroke cycle before taking a breath. In short sprint events of 25 and 50 yd/m, they should wait to breathe until they have taken several strokes.

Of course, these procedures do not apply to swimmers in breaststroke races. Breaststroke swimmers will glide longer until they approach race speed after entering the water. Then they will take one underwater armstroke and another short glide before kicking to the surface. They should pull the body upward and forward through the surface with the arms while making sure that they surface before the arms reach the widest point of their first surface armstroke. Techniques for the glides and the underwater armstrokes used after entering the water are the same as those described for the underwater armstroke in the breaststroke, in chapter 7.

I want to elaborate on the head movements swimmers should use during the grab start, because this is perhaps the key technique in achieving a streamlined entry. As mentioned, swimmers must begin looking down the instant the feet leave the starting platform. Lowering the head establishes a downward trajectory for the upper body during flight so that they can pike as they pass over the peak of the arc-like trajectory and lift the legs in time to enter the entire body through the same spot in the water. Many swimmers are not able to pike and enter the water correctly because they look up and arch the back during the flight.

Figure 8.5 shows the entry for a swimmer who makes these mistakes. He keeps his head up and he arches his back during his flight through the air. As a result, he cannot get his body into a pike position until after it has passed the peak of his trajectory over the water. Thus, his body enters the water while it is still in a partial pike position, causing his trunk and feet to enter the water behind the point where his arms entered. This increases his water resistance, which in turn decelerates his speed rapidly just after the entry.

Track Start

The track start is illustrated in figure 8.6. The major differences between it and the grab start are in the preparatory position and the angle of take-off. The preparatory position is pictured in figure 8.6a. The obvious difference is that one foot is behind the other. The angle of take-off is shown in figure 8.6d. Notice that it is somewhat flatter than the take-off angle for the grab start.

While awaiting the starting signal, swimmers will have the toes of one foot over the front edge and the other foot back pressing against the incline of the starting platform.

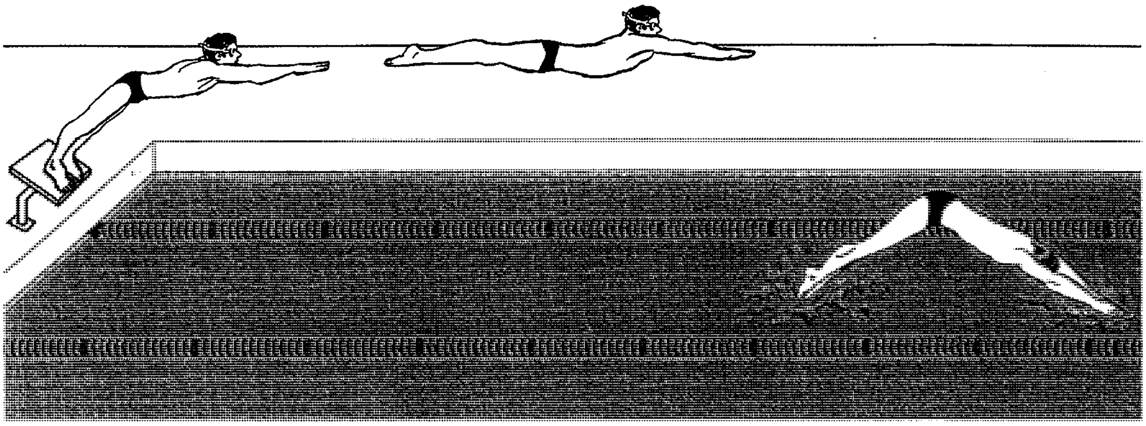


Figure 8.5 A swimmer who keeps his head up and back arched too long during his flight through the air.

The rear foot should be near the back edge of the starting platform to make use of the largest incline as a surface to push off from. The head should be down and they should be gripping the front edge of the block with both hands. When the starting signal sounds, they will pull up and back on the block with the hands to get the body moving forward toward the water. Then they should let go with the hands and shoot them forward in the same semicircular arc described for the grab start. At the same time, they should be driving the body off the block with the legs. They should accelerate the body forward, first by pushing against the back of the starting platform with the rear leg and then by immediately extending the front leg. The back foot will leave the starting platform first, followed by the front foot.

The flight through the air will necessarily be somewhat flatter with a track start than with the traditional grab start. Nevertheless, swimmers should get as much arc into the flight as possible, without slowing the time required to leave the starting platform. As with the traditional grab start, swimmers should look up when pulling the body forward and they should look down when the front foot is leaving the block. They should also pike at the waist during flight to achieve a better angle of entry.

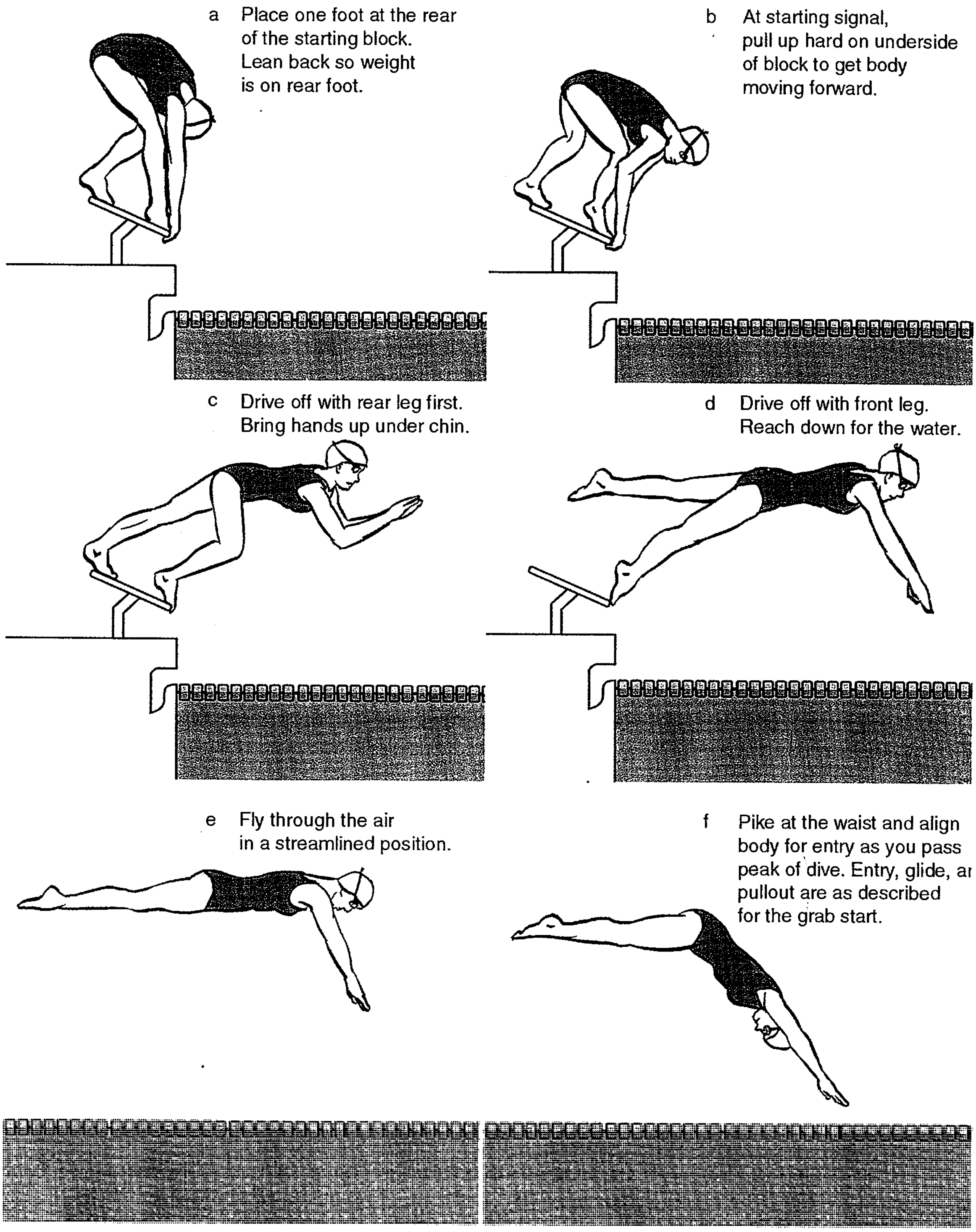
One area of controversy about the track start concerns whether swimmers in the preparatory position should be leaning forward with their weight centered over the front foot or leaning back with their weight over the rear foot. I recommend the latter. When swimmers use the track start, they initiate the drive from the block with the rear foot. Therefore, it makes sense to have their weight over that foot. If they were leaning forward, they would have to shift their weight back before they could begin to push against the block.

Studies conducted by Welcher and George (1998) and Vilas-Boas and colleagues (2000) suggest that swimmers are slower to leave the block when they start with their weight over the rear foot. But they have a greater velocity upon entering the water, which allows them to catch up with swimmers who start with their weight over the front foot.

Using an Armswing With the Grab and Track Starts

Research has shown that incorporating some type of armswing with a vertical jump will improve performance by 10 to 23% because it permits the use of elastic energy (Bosco and Komi 1979 and 1980). Perhaps this is why some swimmers have intuitively learned to combine an armswing with the grab and track starts in an effort to improve horizontal velocity once they enter the water. They generally use one of two methods. The first can be characterized as a *straight backswing* style in which they swing the arms back and then forward after the starting signal.

In the second method, using a motion similar to a butterfly arm recovery, swimmers swing the arms back, up, and forward in a clockwise circle after the starting signal.



a Place one foot at the rear of the starting block. Lean back so weight is on rear foot.

b At starting signal, pull up hard on underside of block to get body moving forward.

c Drive off with rear leg first. Bring hands up under chin.

d Drive off with front leg. Reach down for the water.

e Fly through the air in a streamlined position.

f Pike at the waist and align body for entry as you pass peak of dive. Entry, glide, ar pullout are as described for the grab start.

Figure 8.6 The track start.

This method, called the *butterfly armswing*, is a variation on the circular backswing start that was popular before the grab start appeared on the scene. The clockwise arm movements of the butterfly armswing work better than the counterclockwise arm movement of the circular backswing with the grab and track starts. The butterfly armswing allows swimmers to keep the arms moving throughout the time on the starting block once they get the body in motion. If the circular backswing is used, they have to stop the backward movement of the arms after they pull against the front edge of the block and start them swinging forward. This causes an increase in the time it takes to leave the starting platform.

We tested both the straight backswing and butterfly armswing against the traditional grab and track starts (Spina 1995). A group of experienced competitive swimmers spent two weeks learning to perform both the straight backswing and the butterfly armswing starts. All of the subjects were accustomed to using either the grab or track start with no armswing in competition. They were then timed by means of video analysis using both these methods and their preferred method, either the conventional grab or track starts with no armswing. A statistical analysis did not show any significant difference between the three methods of starting to a distance of 11.3 m from the starting end. Further analyses revealed several differences between the three during various phases of the start that favored the straight backswing and butterfly armswing methods, however.

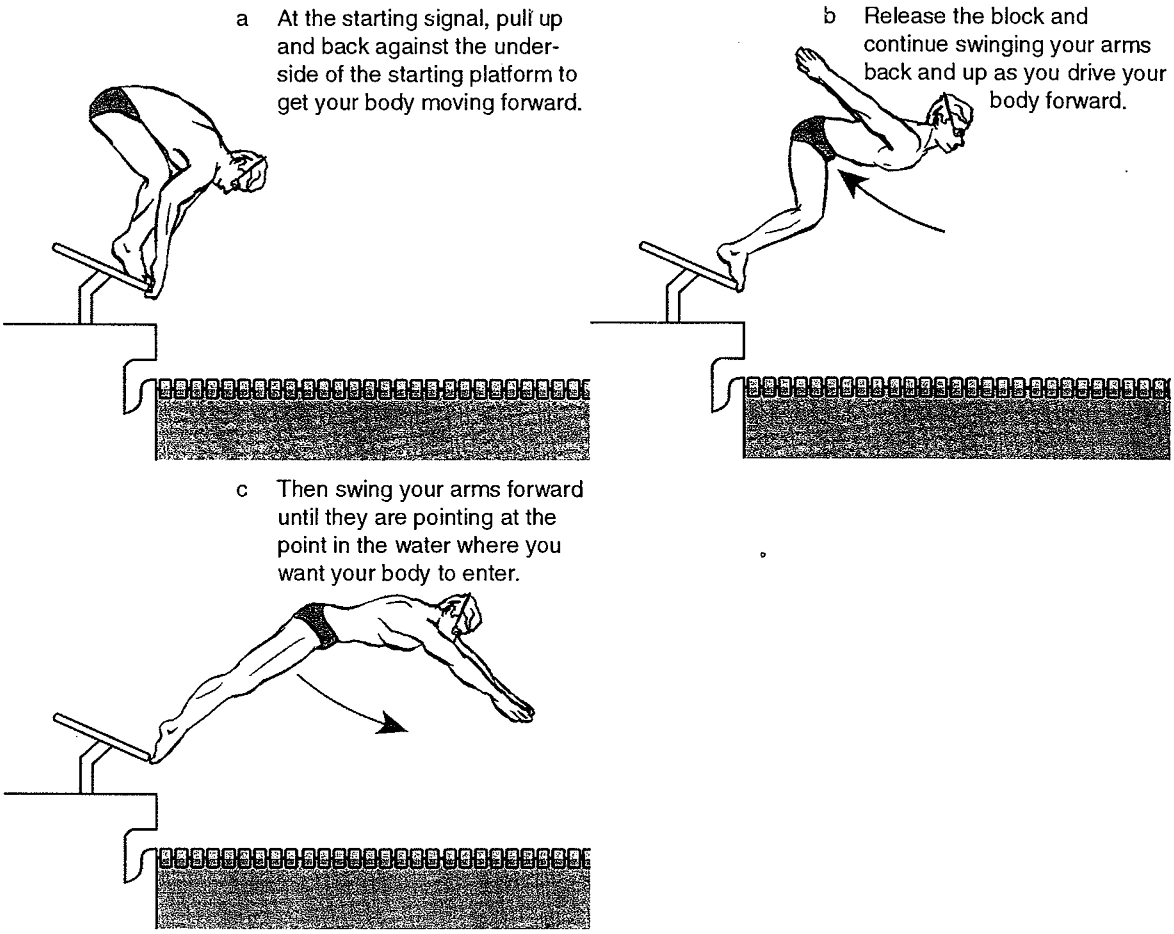
The major advantages of both armswing starts over the traditional grab and track starts with no armswing were that swimmers traveled through the air longer and entered the water in more streamlined positions. Flight distance for the butterfly armswing start averaged 11.32 ft as compared to 10.89 ft for the grab and track starts with no armswing. This difference proved to be significant. The average flight distance for the straight backswing start was also greater than for the traditional grab and track starts, although the difference was not significant. The swimmers also had higher angles of take-off and greater angles of entry with the butterfly armswing and straight backswing starts, which probably accounted for their longer flight distances.

Despite the obvious suspicion, the swimmers did not leave the block slower when they used either of the armswing methods. Although their times to 11.3 m were not significantly different with the armswing methods vs. the traditional grab and track starts with no armswing, we thought that the armswing methods were potentially superior. One reason was that our training period had been too short to properly master the armswing starts, because none of the swimmers in the study had ever used them before. It should be mentioned that several of the swimmers continued to practice the armswing starts after the study was completed. Within six months, all were faster using either the straight backswing or butterfly armswing start than they had been using the grab and track starts with no armswing.

The straight backswing start is illustrated with a traditional grab start (both feet forward) in figure 8.7. The preparatory position is the same as described earlier. When the starting signal sounds, however, swimmers should pull back very vigorously against the underside of the block. As the body starts moving forward, they should release the block and allow the momentum of the backward movement of the pull to continue the arms back and up above shoulder level behind them. After that, they should swing the arms vigorously down and forward until pointing at the place where they intend to enter the body into the water. This start seems to work equally well from the preparatory positions of both the traditional grab start and the track start.

The drawings in figure 8.8 illustrate the butterfly armswing as it would be used with a track start. Once again, the preparatory position is the same as described for the traditional track start. When the starting signal sounds, swimmers should pull up and back against the underside of the starting platform to get the body moving forward. Then they release the block with the hands and allow their backward momentum to continue so that the arms swing in a clockwise circle, back, up, forward, and down until they are pointing at the spot in the water where the body should enter.

I believe that the butterfly armswing has the potential to be faster than the straight backswing. Its advantage lies in the fact that swimmers can gain more momentum from the armswing because they can keep the arms moving from the time they release the starting platform until the arms are extended in front of them. Thus, they can attain


a At the starting signal, pull up and back against the underside of the starting platform to get your body moving forward.

b Release the block and continue swinging your arms back and up as you drive your body forward.

c Then swing your arms forward until they are pointing at the point in the water where you want your body to enter.

Figure 8.7 The straight backswing start.

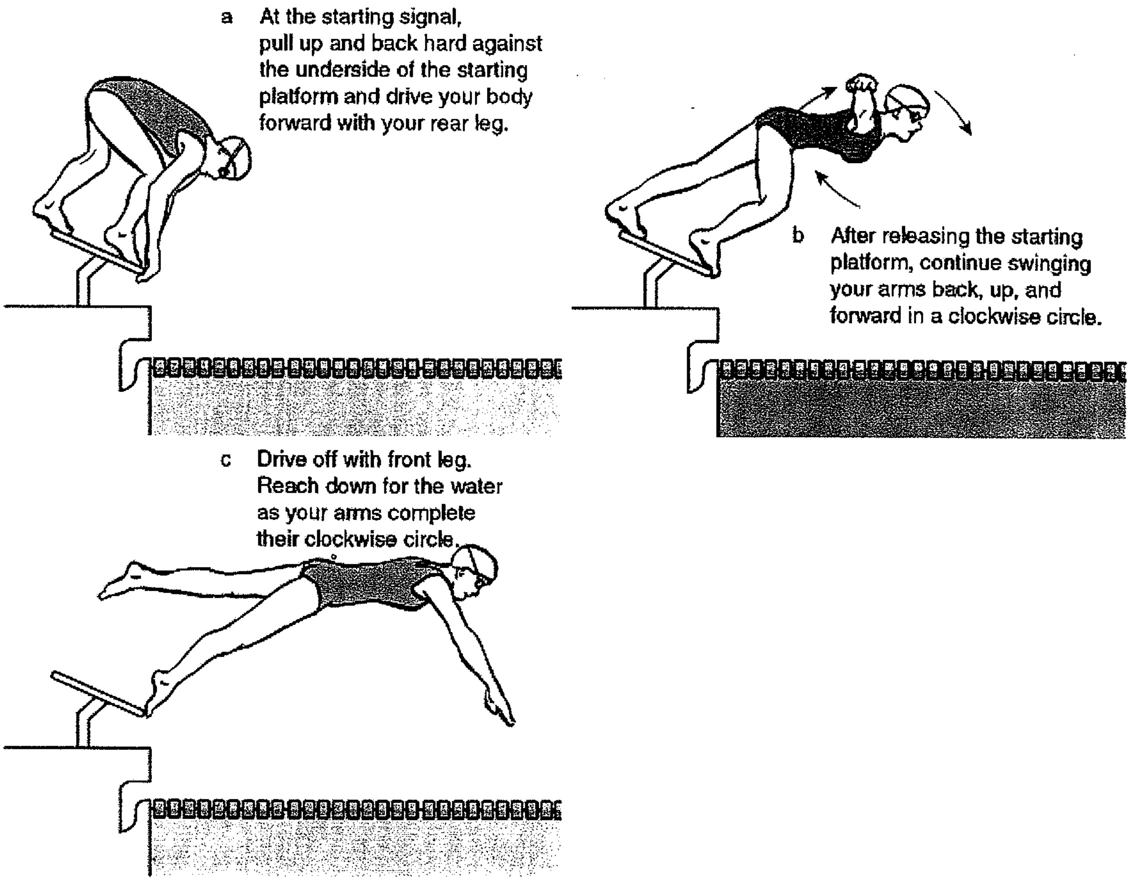
a faster arm velocity that will, in turn, result in greater horizontal velocity for the body as they leave the starting platform, fly through the air, and enter the water.

The butterfly armswing is unorthodox and difficult to learn. Nevertheless, I believe it can improve starting speed significantly for those swimmers who take the time to learn it. While it can be used effectively with the traditional grab start, the butterfly armswing seems to work best with the track start.

Reaction Time

Reaction time is the interval between the starting signal and the first movement on the block. That time can be shortened by a simple procedure in which swimmers focus on the starting signal instead of the starting movements.

That statement is based on research by Henry and Rogers (1960), who reported that concentrating on the starting signal rather than the starting movements produces faster reaction times. They believed this was because the brain takes longer to mobilize its neural signals when required to process more information. In other words, swimmers will take longer to react after the starting signal has sounded if they are thinking about the myriad movements they will execute during the dive. On the other hand, those signals that get the proper muscles contracting will be mobilized in a shorter time if swimmers concentrate only on the starting signal. Measurements with several athletes indicate that reaction time can be shortened by 0.03 to 0.06 sec by concentrating on the starting signal instead of the starting movements.



a At the starting signal, pull up and back hard against the underside of the starting platform and drive your body forward with your rear leg.

b After releasing the starting platform, continue swinging your arms back, up, and forward in a clockwise circle.

c Drive off with front leg. Reach down for the water as your arms complete their clockwise circle.

Figure 8.8 The butterfly armswing start.

To use this technique successfully, swimmers must learn the mechanics of the start so thoroughly that they can perform them almost perfectly without conscious thought. It would do no good to react fast and dive poorly. The reaction time gained would be lost several times over if their flight were compromised, or if they were to enter and glide through the water with lower velocities and poorly streamlined bodies. Consequently, swimmers should not use this technique until they learn to start correctly. In the meantime, they can improve their reaction times by reducing the number of self-instructions to the absolute minimum needed to perform a reasonably good start. Although they will not react as quickly as possible, their reaction times should still be somewhat faster if they concentrate only on those few elements of the start that remain to be mastered rather than the entire sequence of movements.

Start Drills

Many studies have reported that the entry and underwater portions of the start seem to be the two phases that separate fast starters from those who are not so fast (Arellano et al. 1996). Consequently, some of the best starting drills focus on those aspects. They are described in the next three sections.

OVER AND UNDER DIVES

In this drill, swimmers dive off the side of the pool, over the nearest lane line, and they kick under the next two lane lines, surfacing before they come to the fourth lane line. This is a good drill for teaching swimmers to enter the water correctly and change their direction from downward to forward quickly. Young swimmers and poor starters may find it difficult to clear the near lane line. If this happens, move it in closer to the wall until they can clear it easily.

DIVE OVER THE BAR

The coach should hold a shepherd's crook or other rescue pole in front of the starting platform and a short distance away from it. The pole should be held at about waist height. Swimmers should then try to dive over the pole and enter the water correctly. This drill helps swimmers learn how to achieve the proper arc and pike during the dive. Swimmers should also work on break-outs with this drill. Consequently, they should dolphin kick two or three times underwater and surface with one or two armstrokes.

DIVE THROUGH THE HOOP

Hula hoops are placed in the water in front of the starting platform at the spot where swimmers wish to enter. They then try to dive through the hoop without touching it. This drill is obviously designed to teach swimmers to enter the entire body through the same hole where the hands entered the water. As with the other drills, swimmers should be expected to streamline and kick properly while underwater and then to surface correctly. Both this and the preceding drill should be practiced in deep water because swimmers tend to enter the water at a steep angle during practice.

Relay Starts

In relay races, the rules permit the second, third, and fourth swimmers to start their dives from the starting platform before incoming teammates have finished their segment of the race. Some part of the outgoing swimmer's foot must remain in contact with the platform until the incoming swimmer has touched the wall, however. Being in motion when the incoming swimmer touches the wall can provide a time saving of 0.60 to 1 sec over a signaled start. Consequently, three swimmers with good relay starts could swim a time 2 to 3 sec faster than the sum of their best flat start times. This could easily make a difference of two or more places in today's closely contested championship meets and, because five relay events are usually contested, the number of points to be gained from good relay starts is substantial. Good relay starts are often the deciding factor in dual-meet victories as well. For this reason, swimmers should practice relay starts until they can regularly leave the block as early as possible without being disqualified.

The conventional grab or track starts should not be used on relays, except by the lead-off swimmer. A circular backswing start is preferable because the additional momentum from the armswing will provide greater speed through the air and water. The arms should be circled up, back, and then forward in a counterclockwise direction. The illustrations in figure 8.9 show a swimmer using a circular backswing windup with his arms.

Proper timing of the armswing is critical so that the outgoing swimmer gains the maximum possible advantage from being in motion without leaving the starting platform before the incoming swimmer has touched the wall. Consequently, the outgoing swimmer must make judgments based on the incoming teammate's speed and distance from the wall. In relays, the usual practice is to begin the windup after the incoming swimmer's head crosses the T of the black lane marker on the bottom of the pool. A simpler way, however, is for the outgoing swimmer to start the windup when the incoming swimmer has one arm recovery remaining before touching the wall. From that point, it should take approximately 0.60 sec for the incoming swimmer to touch the wall and it generally takes about this same amount of time for the outgoing swimmer's feet to leave the block once he or she starts the arms moving in the circular backswing motion.

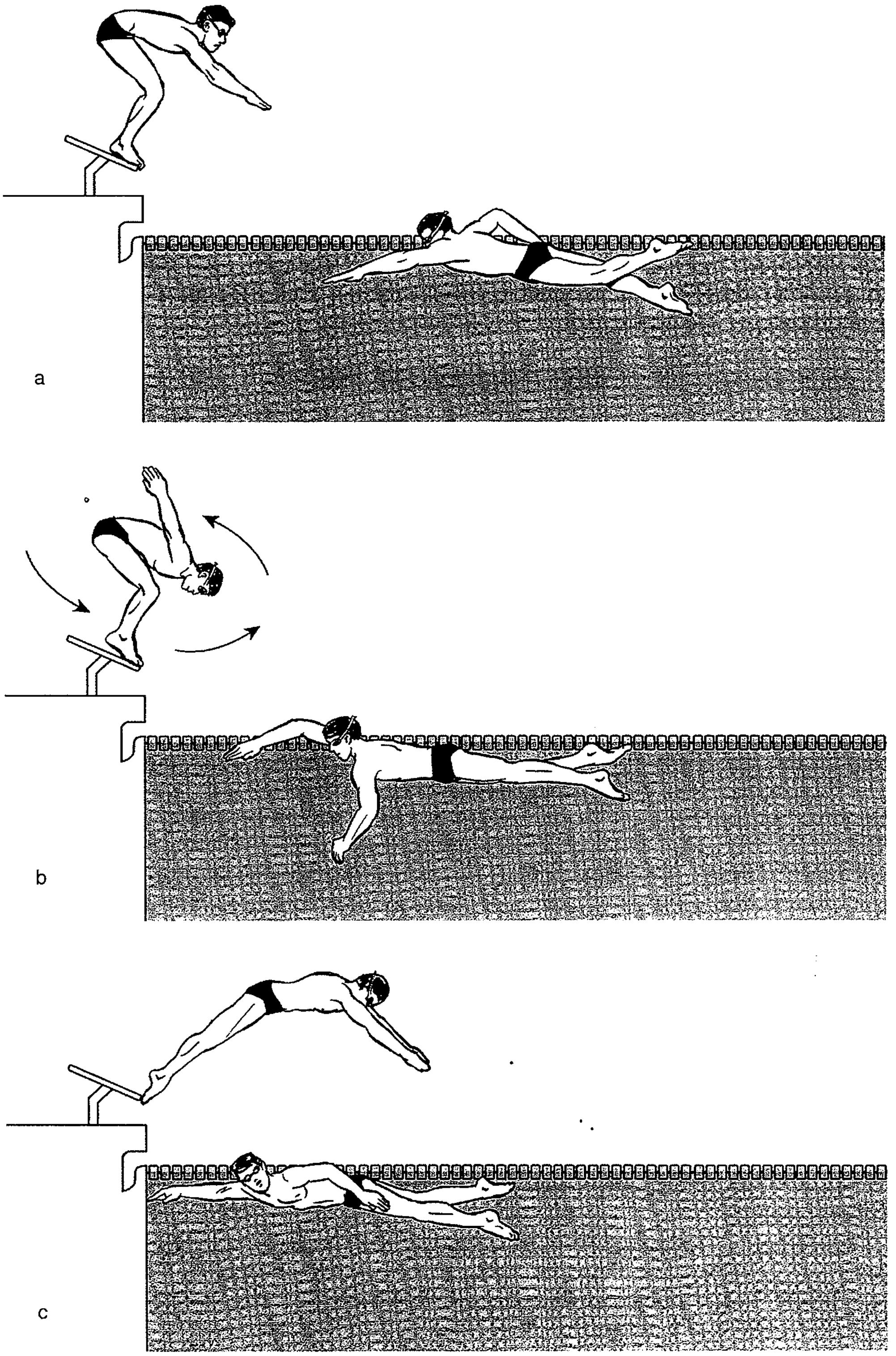


Figure 8.9 The circular backswing arm movements during the relay start.

The timing of the outgoing swimmer's windup with the incoming swimmer's arm recovery should be coordinated in the following manner. In backstroke, butterfly, and freestyle races, outgoing swimmers should establish a recovery rhythm for incoming swimmers by pumping the arms back and forth in time with the arm recoveries of their teammates as they approach the starting end of the pool. Once they have the rhythm, outgoing swimmers should coordinate the circular backswing with the final recovery of incoming swimmers' arms, starting their armswings just after incoming swimmers' hands leave the water. The timing should be such that outgoing swimmers are completing the armswing and extending the legs as incoming swimmers touch the wall.

The manner in which butterfly swimmers time their relay starts from incoming breaststrokers must be adjusted slightly because incoming breaststrokers make their last arm recoveries underwater. Because it is more difficult to see swimmers' arms when they are underwater, butterflyers should time their windups with breaststrokers' breathing movements. Outgoing butterflyers should wait for breaststrokers' heads to reach their highest point in the breathing cycle as they take the last breath prior to touching the wall. The breaststrokers' arms will be under the chin at that time and ready to stretch forward to touch the wall. Thus, if outgoing butterflyers begin the armswing at this time, they will be able to complete the armswing and be extending the legs to leave the starting platform as incoming breaststrokers' arms reach the wall.

A recent development in relay starting has been the use of a *step-up* method in which swimmers use a one- or two-step approach before driving off the starting platform. Research on vertical jumps has shown that taking one or more steps prior to take-off will increase jump height considerably compared to jumping with no approach steps (Enoka 1971; Healy 1977; Kayambashi 1977; Maxwell, Bratton, and Fisher 1980.) This was true even when the number of approach steps was limited to one or two (Enoka 1971; Healy 1977). It seems reasonable to assume, therefore, that adding one or two steps to a relay start might also improve flight distance. Although the distance traveled is more horizontal than vertical in the latter technique, the techniques of the vertical jump and the relay start have many similarities.

There are several versions of the step-up relay start in use today. In one version, outgoing swimmers stand at the rear of the starting platform and take two steps forward to drive off the front of the platform with both legs simultaneously as incoming swimmers touch the wall. I'll refer to this as the *double step* method. In another version, outgoing swimmers stand on the starting platform with one foot over the front edge and the other at the rear of the platform in the style of a track start. They then step forward with the rear leg to drive off the front of the platform with both legs simultaneously as incoming swimmers are about to touch the wall. This style will be called the *single step/front push-off* method.

A third step-up method of relay starting has outgoing swimmers standing with both feet at the rear of the starting platform. They then take one step forward, placing the toes of one foot over the front edge of the platform before driving off in the manner of a track start, as incoming swimmers touch the wall. The name given to this method is the *single step/track push-off* relay start. The single step/track push-off relay start is pictured in the sequence of photographs in figure 8.10.

McLean and coworkers (1999) conducted a comprehensive study of step-up relay starting methods. They compared the three step-up methods with each other and with the conventional relay start. They used measurements of various phases of the starts to investigate differences between the four relay-starting methods that might make one potentially superior to the others.

Take-off height and flight distances tended to be superior for all of the step-up methods when compared to the traditional method of relay starting. The single step/track push-off relay start appeared to be the best of the step-up methods. When compared with the other two step-up methods and the traditional relay start, take-off height and take-off distance were significantly greater when the swimmers used the single step/track push-off method. Assuming equal gliding proficiencies after entering the water, it stands to reason that swimmers will travel not only further but also faster through the air if they can improve flight distance without reducing take-off speed. In fact, those swimmers using the single step/track push-off relay start actually improved take-off speed by an average of 0.10 sec while also improving take-off distance.

Although the difference in take-off speed reached the 0.02 level of confidence, it was not reported as significant because it did not reach the 0.01 level preselected for significance in this study.

The authors did report one negative aspect of the step-up starts, namely, that subjects tended to use their arms less vigorously during windup and take-off. The authors believed that this was because the swimmers had not had time to fully learn the step-up methods. They reported data on two of the subjects who were familiar with step-up relay starts and had been using them regularly in competition. These swimmers exhibited take-off angles and take-off speeds with step-up starts that were considerably better than those of the other subjects.

At present, the available research is too meager to state unequivocally that the step-up starts are superior to the traditional method of relay starting. I would recommend them, however, based on the study by McLean and his associates (1999) and from my personal experience with swimmers I have trained to use the step-up method. I would also recommend starting with both feet back and taking only one step forward (the single step/track push-off method) as potentially superior to the other two methods of relay starting because swimmers have an easier time maintaining forward momentum. They can begin driving the body away from the starting platform with the rear leg just as the other leg is being placed over the front of the block and, with no hesitation, they can transfer their weight to the front leg and continue the drive. That should increase their horizontal velocity as they leave the platform. Both of the other step-up methods cause swimmers to stop their forward motion momentarily because, on the final step, they have to plant the rear foot at the front of the platform with the front foot before they can begin to drive the body away.

Following is a description of the single step/track push-off relay start, which is illustrated in figure 8.10. Outgoing swimmers should stand on the platform with both feet at the peak of the incline on the rear. If the starting block is longer than usual, however, they should stand back a distance that will allow a comfortable, rather than exaggerated, step forward.

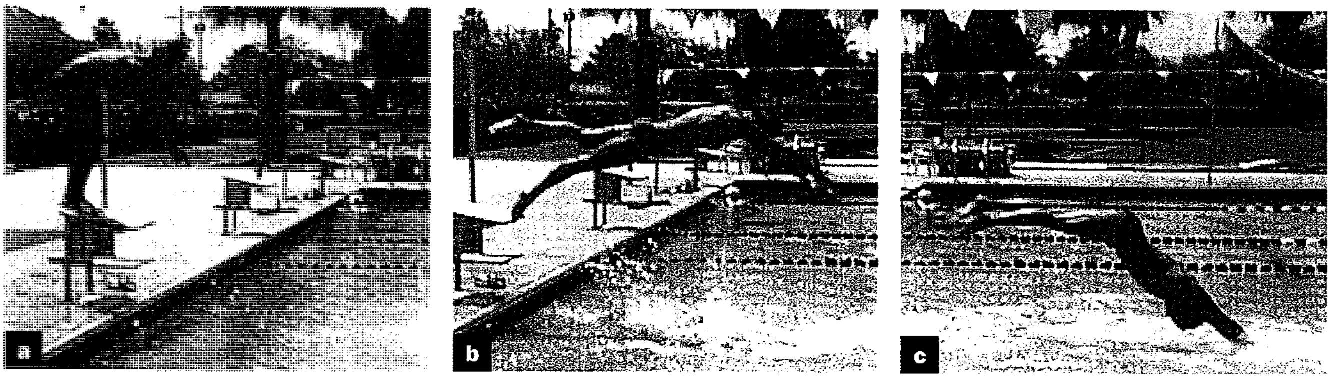


Figure 8.10 The single step/track push-off relay start.

(*a*) Start of forward weight shift. Start of circular backswing with arms. Start of incoming swimmer's last arm recovery.

(*b*) Drive off platform in track start style (notice the front foot is in contact with front edge of platform when incoming swimmer touches the wall).

(*c*) Entry into water.

The timing of the outgoing swimmer's armswing and step forward should be coordinated with the final recovery of the incoming swimmer's arm(s), just as was described for the traditional relay start earlier in this section. The drive off the starting platform should be made in the manner of a track start. The outgoing swimmer steps forward with one leg only and then drives off the platform in the manner of a track start, pushing first with the rear leg followed immediately by an extension of the front leg.

Swimmers should be cautioned to stay low and keep the body moving forward as they step forward and complete the armswing. They can easily lose the forward momentum provided by the step forward if they raise the body up and back or hesitate just before they begin the drive from the starting platform.

Backstroke Start

Short-course and long-course rules have now been standardized so that in all backstroke races, swimmers must have the feet entirely underwater in the preparatory position and they are not permitted to curl the toes over the edge of the gutter, if one is available. This rule change has eliminated the stand-up backstroke start that was used so successfully when short-course rules allowed swimmers to stand in the gutter. Now, all swimmers have to push off from the flat end wall of the pool, making it more difficult to drive the body up and over the water with the legs. The backstroke start is shown from a surface view with a series of photographs in figure 8.11. The underwater portion is shown in figure 8.12. The parts of the start that will be described are (1) the preparatory position, (2) the drive from the wall, (3) the flight, (4) the entry, (5) the

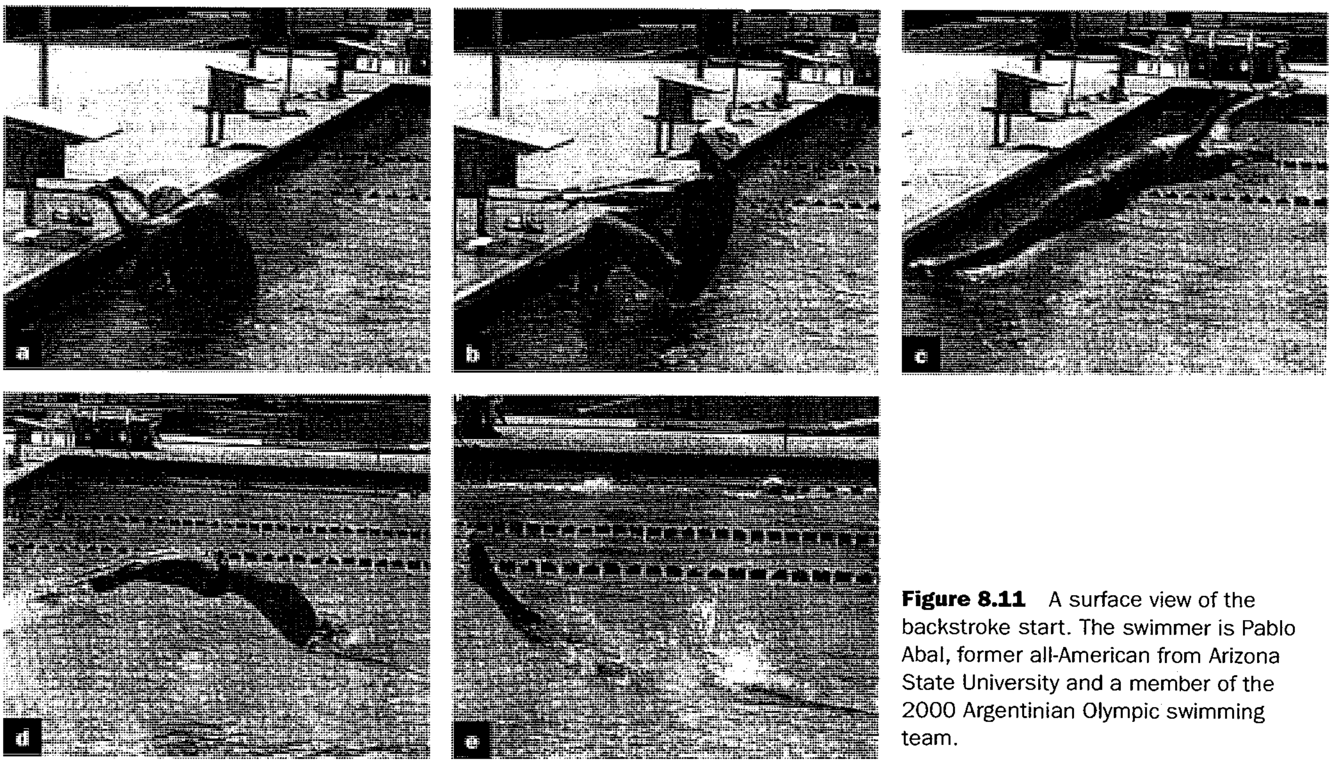


Figure 8.11 A surface view of the backstroke start. The swimmer is Pablo Abal, former all-American from Arizona State University and a member of the 2000 Argentinian Olympic swimming team.

(a) Preparatory position.
(b) Start of drive from the wall.
(c) Feet leave the wall. Arms should be extended back behind the head at this time.
(d) Entry of upper body.
(e) Lift with legs to enable entry through same hole.

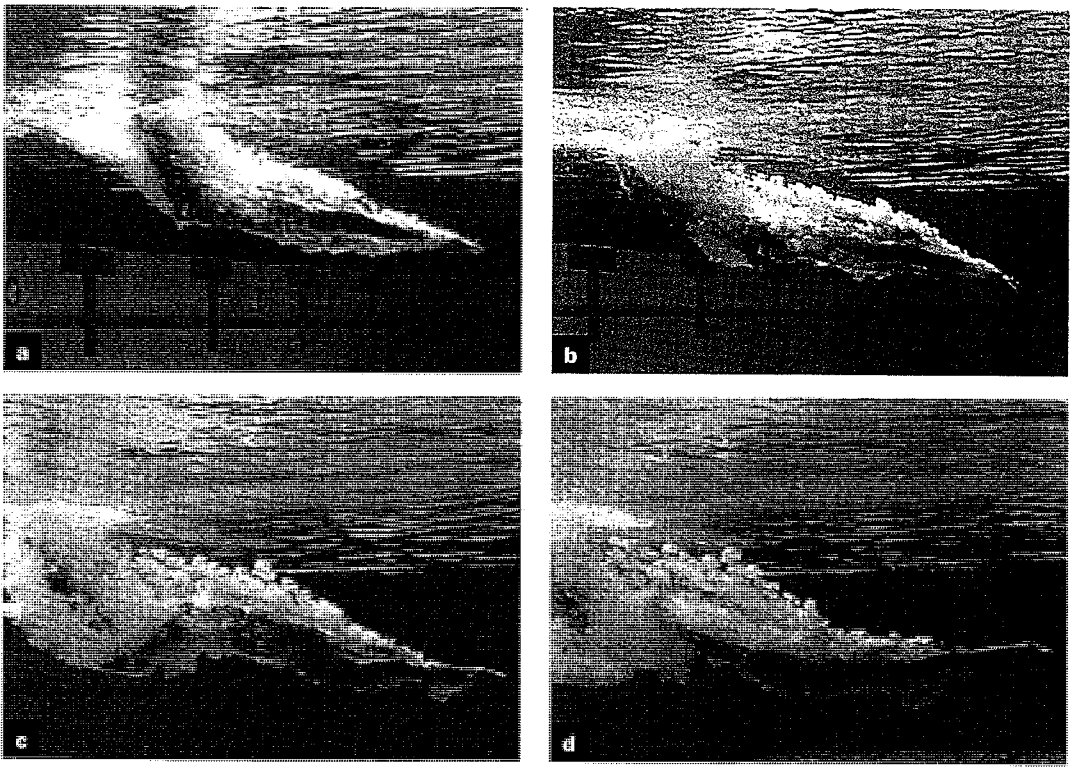


Figure 8.12 An underwater view of the backstroke start. The swimmer is Guillermo Diaz DeLeon, former NCAA all-American from Arizona State University.

(*a*) Entry of body (notice the pike at the waist).
(*b*) Entry of legs. Start of downbeat of first dolphin kick.
(*c*) Start of upbeat of first dolphin kick.
(*d*) Completion of first dolphin kick. Change of direction from downward to forward.

underwater dolphin kick, and (6) the pull-out. A description of underwater dolphin kicking has been included because this technique is in such common use throughout the world.

Preparatory Position

While waiting for the "take your marks" command, swimmers should be in the water, facing the wall and gripping the backstroke bar or handles with both hands. The feet should be entirely underwater and in contact with the end wall. The balls of the feet and the toes should be against the wall, and the heels should be away from the wall. The legs should be bent and the hips should be in the water.

They should pull themselves into a crouched preparatory position when commanded to take the mark. In that position, the head should be down and they should be looking at the gutter in front of them. The arms should be flexed at the elbows and out away from the body. The hips should be as high as possible without bringing the feet above the surface of the water. The feet should be entirely underwater with the buttocks close to the heels, as shown figure 8.11a.

Some swimmers keep the feet together on the wall while others prefer to place them in a *staggered* position, with one foot slightly below the other. Research has not resolved whether this method is superior to placing both feet at the same level, so the best advice is to try both placements and select the one that seems to work best.

Drive From the Wall

When the starting signal sounds, swimmers should pull up or push down and back against the starting bar with the hands (depending on its location) so that they can lift the trunk somewhat higher out of the water before driving the body away from the wall. At the same time, they should throw the head up and back, as if looking for the opposite end of the pool. Once the body is in motion, they should continue to push it up and back, away from the wall, by extending the arms forward against the starting bar (see figure 8.11b). After releasing the bar, they should throw the arms up and over the head as quickly as possible.

Swimmers should begin extending the legs to push the body away from the wall as the arms pass overhead. The leg drive is accomplished by a powerful extension at the knees followed by a final extension of the feet against the wall. The arms should be overhead and extending at the same time. As shown in figure 8.11c, Abal is a little slow in getting his arms overhead. They should be overhead and extended at this time.

There are two aspects of the drive from the wall that I would like to comment on because they are different from the techniques that are commonly taught. The first concerns the swing of the arms over the water and the second is about the timing of leg extension as swimmers push the body away from the wall.

Swimmers should throw the arms back and overhead as they drive the body away from the wall. They should not swing them around to the side, as is commonly recommended. The arms should be overhead in a flexed position during the first half of the swing and they should be extended and reaching back to enter the water as swimmers extend the legs. There are at least three reasons that backstrokers should swing the arms overhead instead of to the side.

1. The arms will get overhead faster. Thus, swimmers will have more time to align the body from fingertips to toes for the entry.
2. Because swimmers can get the arms overhead faster, they will be able to extend the arms as they extend the legs in the manner of a vertical jump, and this will add additional momentum to the drive from the wall. With the sideward swing, the arms will be traveling around to the side while swimmers extend their legs. As a consequence, the arm swing will contribute less force to the leg drive.
3. An overhead armswing will encourage a higher arc and more body arch during flight, which should provide for a more streamlined entry.

One of the most unsettling experiences backstrokers can have is for the feet to slip on the wall during the start. This slip, unfortunately, is all too common because swimmers try to push the legs away from the wall too quickly after the starting signal sounds. Swimmers will be pulling the body up, not driving it back, just after the starting signal sounds. If they try to push the body away from the wall with the legs while they are pulling the body up, the feet will slip down the wall. If they wait until the body is away from the wall and heading backward before pushing with the legs, they will be pressing the feet back, instead of down, into the wall when they extend the legs and they will be less likely to slip.

Flight

Swimmers should travel through the air in an arc, with the back arched, the head back, and the arms extended overhead. The legs should also be extended and together with the feet extended at the ankles.

They should try to have the entire body out of the water during the flight, although this will be difficult to do because they will have started down in the water. Nevertheless, if swimmers get a reasonably high angle of take-off and arch the back sufficiently during flight, they should be able to keep the lower legs and feet from dragging through the water during most of the flight through the air.

The back arch and head movements control the success of the flight and the entry into the water. Therefore, I want to elaborate on how they should be done. Swimmers should throw the head up and back as they push the body away from the starting end.

They must arch the back and look back, toward the other end of the pool, before the feet leave the wall to make a streamlined entry. As mentioned, Abal is a little slow in doing this in 8.11c. Perhaps the most common mistake backstroke swimmers make is to keep the head up and the hips piked during flight. Swimmers will most certainly land flat on their backs when they do this. They must be instructed to keep pulling the head back and the hips up as the body travels over the water.

Entry

The entry should be made in a streamlined position, with arms extended and together. The head should be between the arms, with the legs and feet remaining in an extended position. The angle of entry should be such that the hands enter first, followed by the head, the trunk, and finally the legs. Ideally, every body part should enter through the same hole in the water. This is difficult to accomplish, however, because swimmers will be so close to the water during flight. Most backstrokers use a leg lift during the entry to reduce drag. They lift the legs into a piked position as the trunk enters the water, making it possible for the legs to enter at nearly the same hole where the hands entered. The leg lift is accomplished by contraction of the hip flexors and is shown from the surface in figure 8.11e and from an underwater view in figure 8.12a.

Underwater Dolphin Kick

After entering the water, swimmers should lift the arms slightly and lower the legs to change the direction of the body from down to forward. A number of quick dolphin kicks should follow for any distance up to the allowable 15 m that is permitted by the rules (see figure 8.12b, c, and d). The recommended number of underwater dolphin kicks for each race and the techniques of dolphin kicking underwater were discussed in chapter 6. Backstroke swimmers who intend to dolphin kick for a long distance will allow the body to travel deeper into the water by lifting the arms less and gliding for a short time before they begin to dolphin kick. Swimmers who are only going to dolphin kick two or three times will lift the arms more sharply and bring the legs down in preparation for the first dolphin kick almost immediately after the legs enter the water.

Pull-Out

Swimmers should start angling toward the surface on a gradual diagonal after completing the desired distance underwater. The final two or three dolphin kicks should be used to bring them gradually toward the surface. They should begin the backstroke flutter kick just before they reach the surface, after which they should take one underwater armstroke that brings them through the surface, ready to stroke at race rate. They should remain streamlined until they reach the surface. In particular, they should not lift the head from between the arms until they are on the surface.

Above all, swimmers should not kick to the surface before taking the first stroke. This will cause them to decelerate well below race speed before they start that armstroke. The first armstroke should begin while still underwater and should be timed so that the body breaks through the surface traveling forward at race speed before the underwater propulsive phase of that armstroke has been completed.

Backstroke Start Drills

The most common mistakes swimmers make when performing the backstroke start are to drag the legs through the water during flight and have the body enter the water in several places simultaneously. The following drills are designed to help correct these mistakes.

DIVE OVER THE ROPE

The coach should place a rope or piece of surgical tubing between lane lines a short distance from the starting end of the pool. Starting in the water, swimmers should dive over the tubing on their backs. This drill is good for learning to arch correctly over the water and to lift the legs during the entry. Swimmers should take several underwater dolphin kicks before surfacing so that they can also work on streamlining after entry.

BACK DIVE DRILL

The purpose of this drill is to teach swimmers to arch the back properly and to lift the legs during entry. It is really a soft version of the backstroke start. Swimmers do not push off too strongly and they stay close to the water while they arch the body correctly over the surface and lift the legs properly during entry.

Swimmers do not use the starting block with this drill. Instead, they grip the gutter in the back start preparatory position, with the feet underwater and the toes against the wall. From that position, they should perform a small, gentle, backdive over the water. The emphasis during the dive should be on taking the body through a small arc in which they get the hips out of the water and the hands back in the water behind them before the feet leave the wall. Once they become proficient at doing this, they should lift the legs into a piked position after the feet leave the wall and they should enter the legs into the water in that piked position. The drawing in figure 8.13 shows the entry of the arms during this drill.

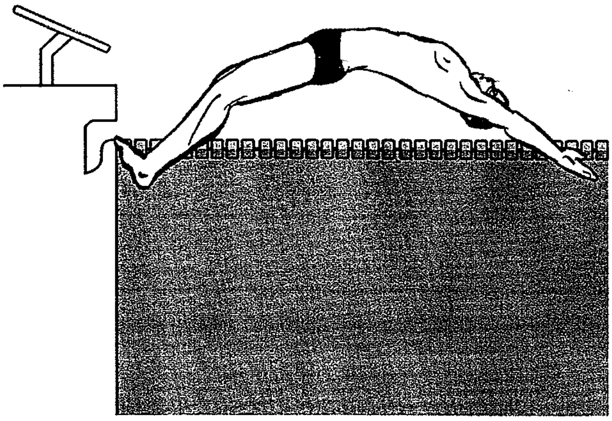


Figure 8.13 The back dive drill. Notice the entry position. His hands are back in the water before his feet leave the wall.

DECK STARTING DRILL

The purpose of this drill is to help swimmers learn to dive over the water and enter it correctly. They start on the deck in a crouched position with their backs to the water, similar to the preparatory position for the backstroke start. From there they should dive back into the water trying to get a clean, streamlined entry with a good leg lift. They should also be required to take a few dolphin kicks underwater to help them learn how to change their entry velocity from downward to forward velocity.

Turns

Turns for freestyle, backstroke, butterfly and breaststroke races will be described in this section. In addition, the turns swimmers use while changing from one stroke to the next in the individual medley will also be explained.

Freestyle Flip Turn

The series of photographs in figure 8.14 show a swimmer executing the freestyle flip turn from an underwater view.

The freestyle flip turn is essentially a forward somersault with a slight twist of the body toward the side, followed by a push-off from the wall. The body rotates the remaining distance to a prone position as they are leaving the wall. The turn will be described in the following parts: (1) the approach, (2) the turn, (3) the push-off, (4) the glide, and (5) the pull-out.

Approach

Hutchison is shown approaching the wall in figure 8.14a. He will actually begin the turn while taking his final armstroke into the wall. Most swimmers begin that final

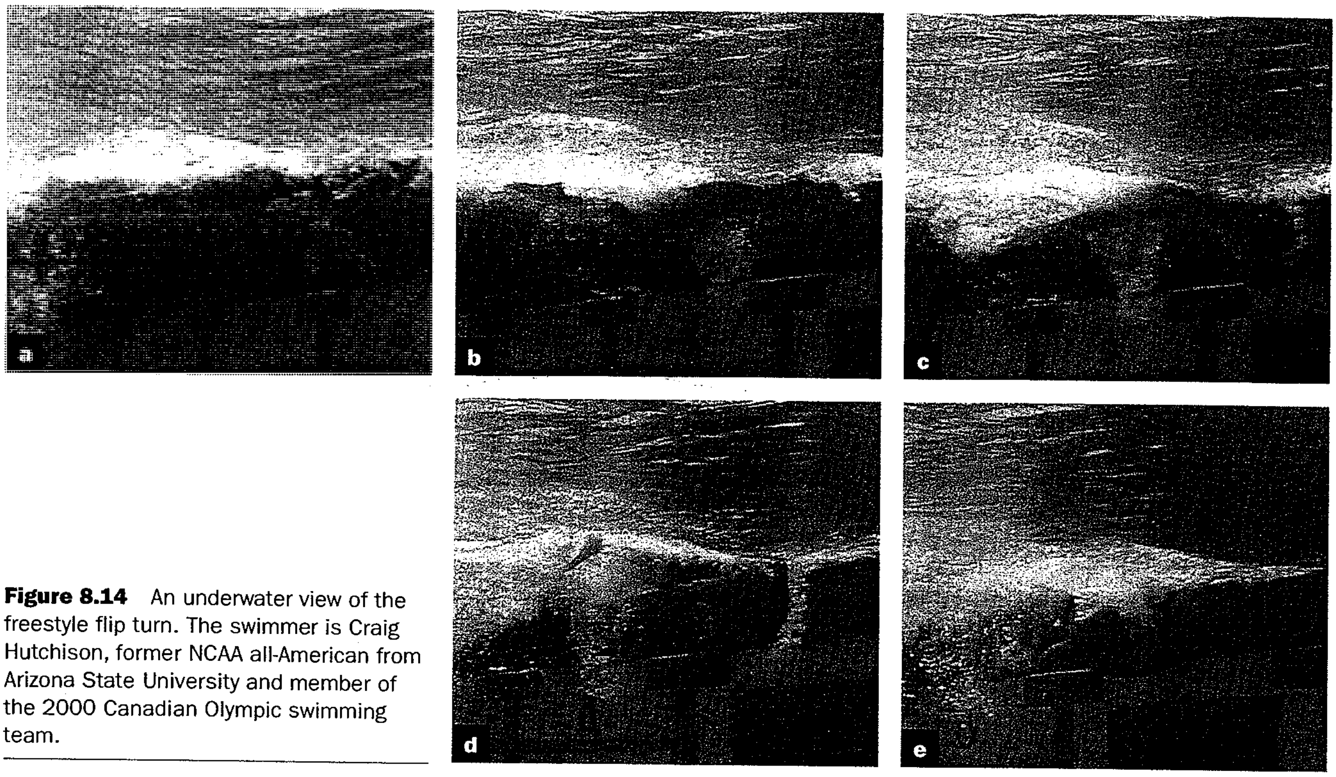


Figure 8.14 An underwater view of the freestyle flip turn. The swimmer is Craig Hutchison, former NCAA all-American from Arizona State University and member of the 2000 Canadian Olympic swimming team.

(a) Approach (notice overlap in armstroke).
(b) Duck of the head. Start of dolphin kick during completion of final stroke (notice both arms back at his sides).
(c) Completion of dolphin kick. Mid-somersault.
(d) Continuation of somersault.
(e) Tuck with legs (notice both hands overhead with elbows flexed in preparation for push-off).

armstroke 1.70 to 2.00 m (5.50 to 6.50 ft) from the wall (Chow et al. 1984). Sprinters tend to start the turn sooner, probably because they are traveling into the wall faster.

Swimmers should sight the wall from several strokes away so that they can make modifications in their approach that will take them into the turn with no loss of speed. Swimmers must maintain race speed on the approach because they can gain an advantage over many competitors who will decelerate in anticipation of the turn. Notice how Hutchison has begun the underwater stroke with his left arm while he is still completing the stroke with his right. He overlaps his arm pulls in this way to gain additional speed as he approaches the turn.

Turn

The actual mechanics of the turn are shown in figure 8.14, a through e. Swimmers leave the opposite arm in the water back at the hip while completing the final armstroke prior to the turn. They pull the front arm back to the other hip during the final armstroke. They tuck the chin and begin somersaulting. The eyes should be focused on the wall at the beginning of that stroke, but they should duck the head and follow the final armstroke backward, once the stroke is underway.

Swimmers will execute a small dolphin kick during the final armstroke to assist in pushing the hips up over the water during the turn. Hutchison is doing this in figure 8.14, b and c. They continue somersaulting nearly straight over until the head comes between the arms. The legs should be tucked as they travel over the water to produce a faster somersault. The hands, which were back at the hips during the first portion of the somersault, should be turned palms down and pressed down against the water to help pull the head toward the surface, as shown in figure 8.14, d and e.

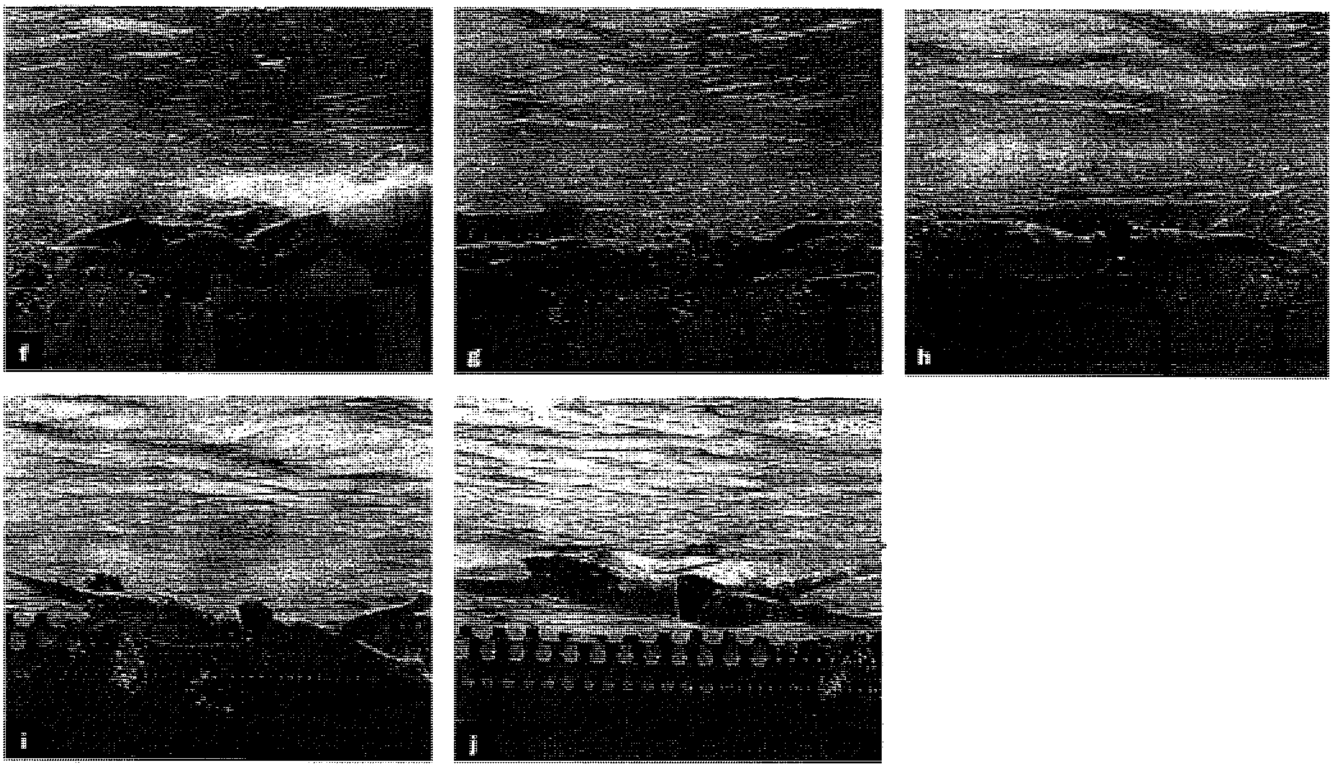


Figure 8.14 *(continued)*

(f) Extension of arms and legs during push-off (notice body rotation toward prone position).
(g) Completion of rotation to prone position.
(h) Start of flutter kick.
(i) Start of pull-out.
(j) Surface. Start of second armstroke.

The head should come up between the arms, before the feet reach the wall so that the body will be aligned and ready for the push-off at the instant the feet make contact. The hands should also be overhead with elbows flexed before the feet make contact with the wall, as shown in figure 8.14e. At contact, the feet should be planted on the wall with toes facing up and slightly to the side in the same direction that the body is rotating.

Swimmers should be mostly on their backs when the feet reach the wall. They should also be rotated approximately one-eighth of a turn toward the side, however. This small amount of rotation is accomplished by turning the head slightly to one side as the feet are coming into the wall. This head action starts a body rotation that will continue toward a prone position during the push-off and glide. Swimmers may rotate the body to whichever side they prefer. Most, however, will turn the head away from the arm used during the last stroke into the turn. Thus, they will be looking up and slightly toward the side opposite that arm as they push off the wall.

Push-Off

The feet should hit the wall at a depth of approximately 30 to 40 cm (12 to 15 in). The legs should be flexed nearly 90° at the hips and beyond 90° at the knees when the feet make contact. They should begin extending the legs immediately when that contact has been made and should rotate the body toward a prone position while pushing it away from the wall and during the glide that follows (see figure 8.14, f and g). The drive off the wall should be powerful, but it should be graduated. Leg extension should begin gradually, with speed building up until swimmers extend the legs as fast as possible just before the feet leave the wall. Building the speed and power from beginning to end of the drive from the wall allows swimmers to get streamlined by the time they achieve their greatest push-off velocity. Consequently, they will encounter less drag as they leave the wall.

They should extend the arms and legs simultaneously to add impetus to the push-off. The push-off should be made horizontally, not upward, to take advantage of the lower water resistance underwater compared to near the surface. The push-off should be executed at a depth of approximately 0.40 m (1.5 ft) underwater so that swimmers will encounter less drag during the glide (Lyttle et al. 1998). Drag is 15% to 23% lower at depths of 0.4 to 0.6 m (1.5 to 2 ft) than near the surface (Lyttle et al. 1998).

I want to comment on the gradually accelerating push-off just mentioned. It is commonly believed that swimmers should push off the wall with a powerful burst of leg extension. Blanksby, Gathercole, and Marshall (1996), however, showed that a gradual acceleration produced better results. The velocity leaving the wall was increased 0.57 m/sec, from 2.46 to 3.03 m/sec, by pushing off in this manner, even though the push-off force was almost 300 N lower. The graph in figure 8.15 demonstrates their results.

Figure 8.15 shows the push-off velocity for two subjects: swimmer A who pushed off rapidly and swimmer B who used a gradually accelerating push-off. Swimmer A developed a peak force of 1396 N early in the push-off but achieved a velocity of only 2.46 m/sec leaving the wall because his drag force was 929 N. By contrast, swimmer B developed his peak force later in the push-off and left the wall traveling 3.03 m/sec, even though his peak push-off force was only 1,074 N. The difference in velocity leaving the wall was probably due to the fact that swimmer B's drag force was only 235 N when he left the wall.

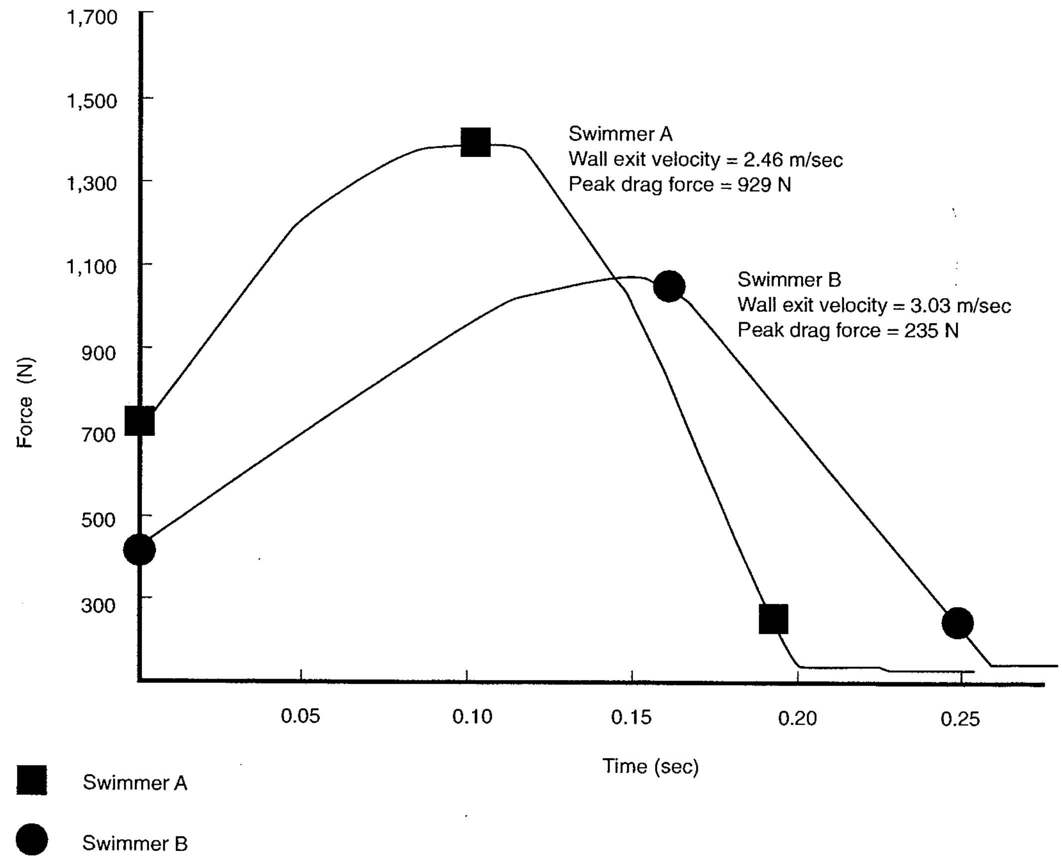


Figure 8.15 Comparison of a gradual and explosive push-off during a freestyle flip turn.

Adapted from Blanksby, Gathercole, and Marshall 1996.

Glide

The glide away from the wall should be deep enough that swimmers can travel underneath the surface turbulence created during the approach, yet not so deep that they cannot travel on a gradual diagonal that will bring them to the surface approximately three body lengths down the pool. The speed of ascent should be such that only two or three flutter kicks are needed during the glide to bring them close enough to the surface to take the first stroke.

The upper body should be very streamlined during the glide. That is, the arms should be extended overhead in line with the body and with one hand over the top of the other so that the water is split in front with the fingertips. The head should be nestled between the arms.

Swimmers should complete the rotation to a prone position while traveling away from the wall. The legs should be crossed with the top leg (the one closest to the surface) over the bottom leg as the feet leave the wall. During the glide, they will uncross the legs and bring the top leg down and the bottom leg up to help rotate the body to a prone position. Hutchison is using his legs to help rotate his body in figure 8.14, f and g.

Kicking During the Glide Swimmers will be traveling faster than race speed when they leave the wall, but they will decelerate very quickly soon thereafter. Consequently, they should start kicking almost immediately after the feet leave the wall in sprint races. They may glide for a short time before starting to kick in middle distance and distance races, however. Kicking during the glide helps swimmers keep their velocity slightly above race speed while they are traveling underneath the surface turbulence during their gradual ascent to the surface. Hutchison is shown starting his flutter kick in figure 8.14h.

Dolphin Kicking During the Glide Some swimmers are now using one or more underwater dolphin kicks after the push-off because the dolphin kick is so powerful that it reduces their rate of deceleration more than the flutter kick. For this reason, I suggest that sprint swimmers take one or two dolphin kicks immediately after the push-off and before starting the flutter kick and pull-out. They should begin the flutter kick immediately after completing these dolphin kicks and, after taking one or two flutter kicks, they should be close enough to the surface to start the first armstroke.

I would not advise swimmers in distance races to use the underwater dolphin kick during their glides, however, because of the effort involved. The dolphin kick requires a short but large expenditure of muscular effort, and in longer races, that expenditure of effort may not be worth the small amount of additional propulsion swimmers receive on each turn.

Pull-Out

The glide and gradual ascent toward the surface should result in freestyle swimmers reaching the surface approximately 4 m down the pool (assuming they have used up to two dolphin kicks). They should start the first stroke while the body is still under the surface and that stroke should bring the body through the surface traveling forward at race speed before its propulsive phase has been completed. Hutchison is doing this in figure 8.14, i and j. Swimmers must sense when they are close enough to the surface to begin that stroke and should remain streamlined with the head down during that first stroke. They can raise the head slightly to a normal swimming position after it breaks through the surface. Above all, they should not glide or kick to the surface before beginning the first armstroke. If they do, the body will decelerate well below race speed before they reach the surface.

Swimmers should take the first stroke toward the surface with the arm opposite their breathing sides in sprint races. By doing so, they can complete that stroke and half of the next before they take a breath. This will make it easier to maintain race velocity as they surface and will reduce the tendency for some to delay in attaining race stroke rhythm as they breathe immediately after surfacing. I do not recommend that swimmers in middle distance and distance races use this technique, however, because of its potentially fatiguing effect in those races. Swimmers in middle distance and distance races are advised to pull the body through the surface with the arm on their breathing sides. Considering also that they will not have taken a breath since before they started the turn, approximately 3 to 5 sec earlier (Thayer and Hay 1984), it may be wiser for these swimmers to take a breath immediately upon surfacing instead of delaying the first inhalation for an additional armstroke. Doing so should reduce discomfort and provide an extra inhalation on each pool length.

Of course, swimmers should learn to take that first breath after the turn with the least possible disruption in stroking rates and body alignment. This statement applies whether the first breath is taken during the first armstroke after the turn or the second armstroke after the turn. Many swimmers, particularly those who are inexperienced, tend to hesitate or throw the head to the side when they take that first breath simply because they have been deprived of oxygen for so long. What they should do is concentrate on attaining race stroke rate while rotating the body and head smoothly to the side without lifting either out of the water when they breathe.

In light of research by Ransom (1973), who reported that this method was slower than delaying the breath until the second armstroke, it may seem ill-advised to recommend that middle distance and distance swimmers breathe immediately upon surfacing. The design of that research was flawed, however, because it failed to take the effects of fatigue into account. The turns were timed at sprint speeds and the subjects swam only a few yards into and out of each turn when they were tested. It has never been shown that turning times would be slowed by breathing on the first stroke when swimmers are not sprinting, nor has the possibility that delaying the first breath would cause swimmers to fatigue earlier been adequately examined.

Common Mistakes

Many swimmers tend to make one or more of the following mistakes during the freestyle flip turn: (1) turning in a piked position, (2) throwing the legs over the water, (3) failing to align the body before the feet reach the wall, (4) pushing toward the surface at too steep an angle, (5) breathing during the approach, (6) gliding into turns, (7) pushing off in poorly streamlined positions, and (8) gliding too long after the turn. I will now discuss each of these mistakes and methods swimmers can use to correct them.

1. The pike turn was very popular at one time because coaches believed that the legs traveled over the water faster when they were straight than when they were bent. Hence, experts recommended that swimmers turn by bending only at the waist while maintaining the legs in a nearly extended position. Actually, the reverse is true. Swimmers can turn much faster when the legs are tucked (Ward 1976). The feet will travel over the water more quickly in a tucked position for the same reason that divers can somersault faster in a tucked position: The axis of rotation is reduced. While it is true that the legs will drag through the water when tucked, the savings in rotation time negate this disadvantage compared to the slower method of bringing them over the water in a pike position. In addition, with the legs bent, the feet will be moving back instead of down as they make contact with the wall. Thus, swimmers will not experience the slight delay required to change the direction of the legs from down to back before they can push off the wall.

2. Another common mistake swimmers make is trying to increase their speed of rotation toward the wall by thrusting the legs vigorously over the water. This introduces a stop-start action that delays the beginning of body rotation. Swimmers will hesitate for a moment to mobilize the body before throwing the legs over the water. As a result, the feet usually reach the wall before they can align the body for the push-off, causing another hesitation at that point. A time analysis revealed that swimmers who

fail to align their bodies before their feet reach the wall may require 0.20 to 0.40 additional sec to align their bodies before they can push off. Swimmers who try to avoid this delay by pushing off the wall immediately will do so with the body poorly aligned, and the additional water resistance they encounter will quickly decelerate the body during the glide that follows.

The speed of body rotation into the wall is really controlled by how quickly swimmers can rotate the head around and in line with the body, not by how fast the legs travel over the surface. If they simply tuck and roll and bring the head up between the arms as fast as possible, there will be no delay between the approach and the beginning of the rotation into the wall. As a result, the legs will travel through the water even faster than they could be thrust over it and the body will be aligned ready to push off in a streamlined position as soon as the feet make contact with the wall.

3. Many swimmers make the mistake of pulling one of the arms back, toward the wall, when they somersault over the water. As a result, they end up with that arm back at the waist when the feet reach the wall. They then have to delay pushing off until they get that arm overhead or, worse, they try to bring that arm forward through the water while they are pushing the body away from the wall. Both arms should remain back at the waist as swimmers somersault through the water. In this way, they can align the arms with the body before the feet make contact with the wall.

4. Swimmers should push off so that the body travels gradually toward the surface. Both the speed and distance of the glide through the water will be reduced if the body is angled upward too sharply as it drives away from the wall. On the other hand, if swimmers push off on a gradual diagonal toward the surface, they can travel away from the wall under the turbulence of the wake they created while making the turn and they will be traveling forward faster when they reach the surface.

The easiest way to achieve gradual ascent toward the surface is to push the body forward horizontally under the surface. When they do this, the kick and the pressure of the water pushing up from underneath the body will bring them to the surface gradually so that they reach it traveling forward much faster than they are traveling upward.

5. Swimmers should never breathe during the armstroke that carries them into the turn. This will cause them to delay the start of the somersault over the water. I'm surprised how many swimmers, even world-class athletes, make this mistake. It is likely that the technique described earlier, namely, delaying the first breath after the turn, is responsible for the large number of swimmers who are now breathing as they start the turn. These swimmers probably began snatching a breath immediately before turning so that they could get enough air to delay breathing until they started the second armstroke after the turn. Breathing into the turn, then, became a bad habit and they continued to use it even after they became accustomed to breathing later after the turn.

Swimmers who make this mistake could easily improve their times by 0.10 to 0.20 sec per turn if they did not delay the somersault while catching a breath during the last armstroke before turning. That could mean an improvement of 3 to 4 sec in long-course 1,500 m races and more than double that amount in short-course races of 1,500 m or 1,650 yd. Swimmers should always take the last breath on the next-to-last armstroke before the somersault commences. They should, then, begin that somersault in conjunction with the final armstroke, with no breath to slow the rate of rotation.

6. Many swimmers take the final armstroke quite a long distance from the wall and then they glide until they are close enough to begin the somersault. They do this in the mistaken belief that they are saving time by starting the turn earlier on the pool length. Swimmers who glide into turns may start to turn sooner, but the feet will usually reach the wall later than competitors who swim into and through the turn. This is because forward velocity begins decelerating at the very instant they stop applying propulsive force with the armstroke. Thus, there should be no delay between the end of the final armstroke and the beginning of the somersault into the wall. In fact, that somersault

should begin before the final armstroke has been completed. Athletes should always swim into and through the turn.

7. Many swimmers push off in poorly streamlined positions. Swimmers who make this mistake arch the back and drop the abdomen, or they push off with the arms apart, with the head up, or with the legs separated. It is easy to see how swimmers will decelerate faster when they leave the wall with the body in such poorly streamlined positions. The good news is, they can learn to align the body and hold the hands and legs together in an extended position with only a small amount of concentrated practice. Correcting the head position is another matter, however.

Swimmers almost universally push off the wall with the head up during practice to prevent their goggles from filling with water and to avoid collisions with other swimmers. They may do this literally thousands of times a week, so it is no wonder that it becomes a habit that carries over into competition. Time should be spent training swimmers to keep the head down between the arms on the push-off, particularly near the end of the season as the time for the most important meets approaches.

8. A final problem associated with turns in the freestyle and other strokes is that swimmers frequently lose time by gliding too long or too little after they push the body away from the wall. In the first case, they allow the body to decelerate below race speed during the glide so that additional time and energy are required to regain that speed once they reach the surface. Swimmers should never decelerate below race speed just for the sake of gaining additional distance from the glide. The distance of the glide should be increased by good streamlining, which will allow them to travel further underwater before they decelerate to race speed. The kick can also play a very important role in maintaining velocity during the glide.

Kicking during the glide will maintain their velocity until they get close enough to the surface to start the first armstroke. Even though the push-off should be made at a depth that will allow them to glide under the surface turbulence, swimmers should never need more than two or three kicks to maintain their velocity as they approach the surface. Otherwise, they will most certainly decelerate below race speed—unless they are using a dolphin kick, that is. Even then, swimmers would have to be excellent dolphin kickers or very poor freestylers to kick underwater faster than they can swim on the surface.

Swimmers spin their wheels if they make the mistake of taking the first armstroke before decelerating to race speed. That is because they will be traveling so fast that the arms cannot accelerate them further. Swimmers should begin their first armstrokes when they feel themselves approaching race velocity.

Rollover Backstroke Turn

Recent rule changes have resulted in significant changes in the backstroke turn. Swimmers no longer need to touch the wall with the hand before they begin to somersault into the wall. Interpreting when they may leave the position on their backs to begin the turn and when they must return to a supine position after the turn, however, has caused many problems for officials and swimmers alike. For this reason, I want to quote the present FINA rule on the backstroke turn before describing it.

> Upon completion of each length, some part of the swimmer must touch the wall. During the turn the shoulders may be turned past the vertical toward the breast after which a continuous single arm pull or a continuous simultaneous double arm pull may be used to execute the turn. Once the body has left the position on the back, there shall be no kick or arm pull that is independent of the continuous turning action. That swimmer must have returned to a position on the back upon leaving the wall (USA Swimming 1999).

The present interpretation of this rule is that swimmers can leave the position on their backs after they begin the next-to-last armstroke of each length. They may then take the final armstroke while in a prone position as they somersault into the turn, provided the turn and stroke are executed as one continuous motion. A hand touch is not required. It is sufficient if any part of the body touches the wall during the turn.

To turn quickly, backstroke swimmers should take almost two full underwater armstrokes in a prone position as they rotate the body into the turn. They can move faster by pulling under the midline of the body in the style of the front crawl than they can when they pull to the side in the style of the backstroke. This technique does not violate the rules of the backstroke turn, although it may seem to at first glance. To comply with the rules, the final armstroke prior to turning must begin with swimmers on their backs. They are free to rotate to a prone position immediately after that stroke is initiated, however. If they rotate quickly enough, they can be in prone position during the insweep and upsweep of that armstroke and they can execute one more armstroke in the prone position without violating the rules, provided they initiate the somersault immediately as they reach a prone position and there is no hesitation between the final armstroke before turning and the armstroke during the turn.

The rollover backstroke turn is pictured from a surface view in the series of photographs in figure 8.16 and can be seen from an underwater view in figure 8.17. It will be described in the following sections: (1) the approach, (2) the rotation, (3) the turn, (4) the push-off, (5) the underwater dolphin kick, and (6) the pull-out.

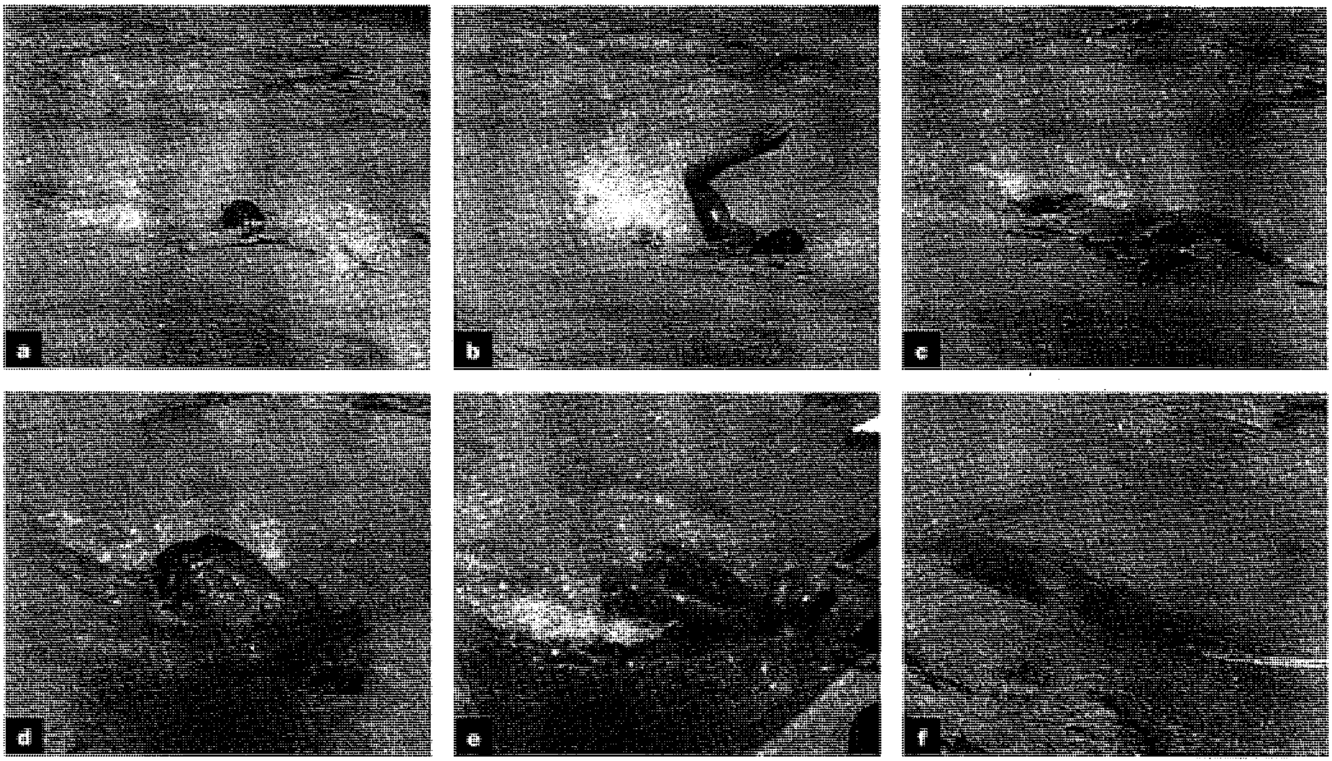


Figure 8.16 A surface view of the backstroke rollover turn. The swimmer is Guillermo Diaz DeLeon.

(a) Last stroke before turn.
(b) Rotation to prone position (notice high elbow recovery).
(c) Prone position. Entry of arm into water.
(d) Start of somersault (notice head is tucked). Dolphin kick with legs.
(e) Preparation for the push-off (notice the feet high on the wall).
(f) Drive away from the wall while remaining on the back.

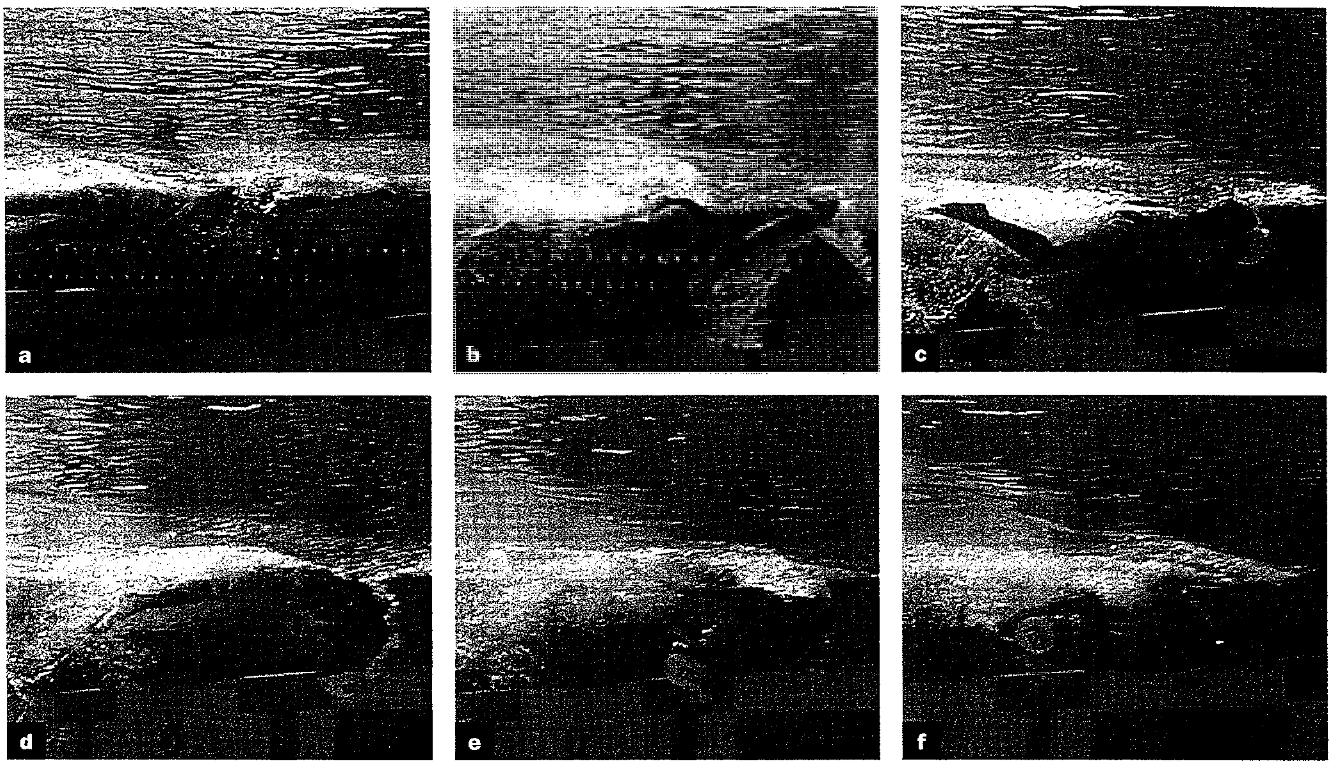


Figure 8.17 An underwater view of the backstroke rollover turn. The swimmer is Pablo Abal.

(a) Start of last stroke before turn.
(b) Start of front armstroke (notice completion of last stroke with rear arm).
(c) Completion of arm pulls (notice arms back at his sides). Start of somersault.
(d) Completion of dolphin kick.
(e) Somersault (notice downward palms to help momentum).
(f) Preparation for the push-off (notice aligned body position with arms overhead and elbows flexed).

Approach

The prerequisite to making any good backstroke turn is judging the distance from the wall with a minimum of looking around. One way swimmers can make this judgment is by using the backstroke flags to determine when they are approaching the turn and then counting the number of strokes needed from the flags to the point where they begin rotating toward a prone position. For most teenage and senior swimmers, the turn should follow the beginning of the second or third armstroke after passing under the backstroke flags. Swimmers should practice at race speed until they know whether they can initiate the turn on the second or third armstroke without gliding into the wall.

Rotation

Swimmers should begin the turn as they start the second or third armstroke after passing the flags. That stroke should begin when swimmers are on their backs, but they should rotate quickly to a prone position once it is underway, as shown in figure 8.16, a through c. They should roll toward the stroking arm and away from the recovering arm as they move into a prone position. In the meantime, the recovering arm should be brought over the water and across the body in a manner similar to the high elbow recovery of the front crawl stroke (figure 8.16b). Swimmers should be in a completely prone position as the stroking arm comes under the chest and the other arm is entering the water. They should take a breath while rotating to a prone position.

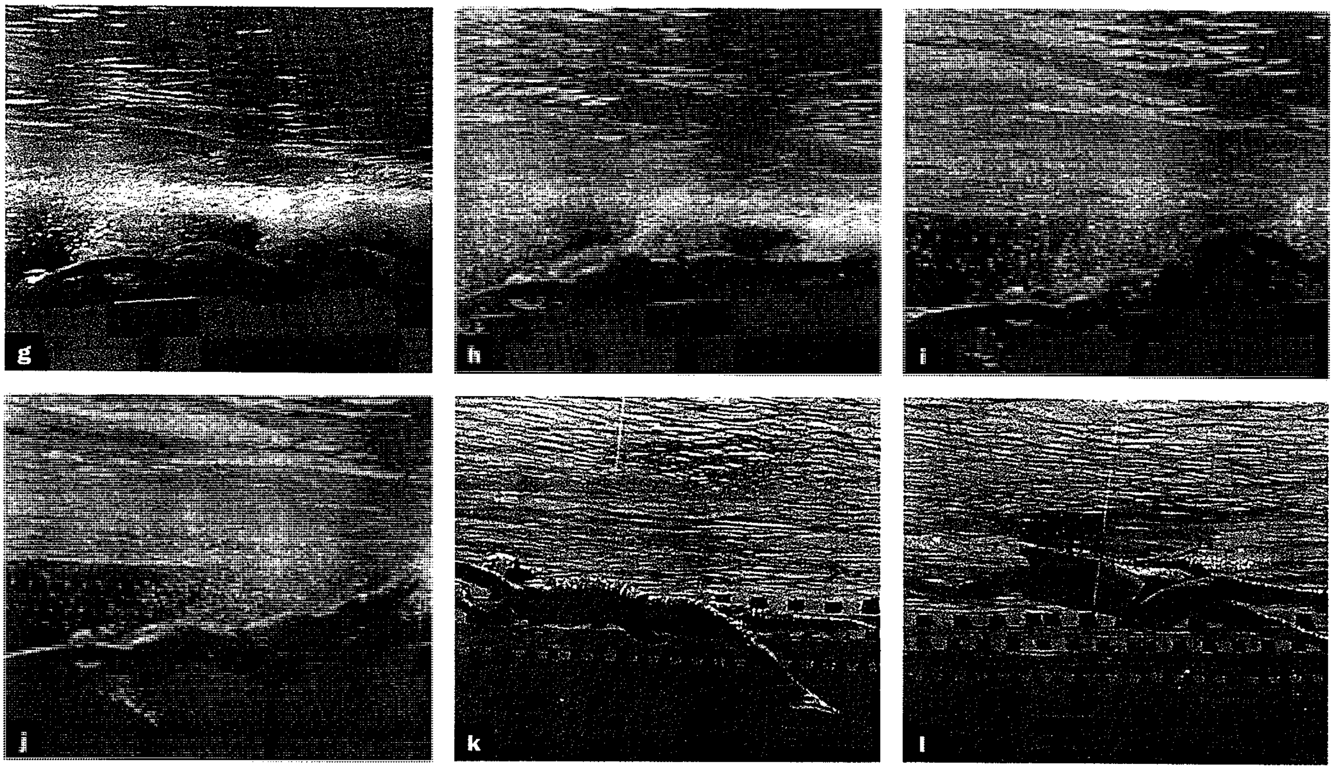


Figure 8.17 *(continued)*

(g) Beginning of drive away from the wall with a simultaneous extension of the legs and arms.
(h) Drive away from the wall while remaining on the back (notice slight downward angle).
(i) Start of first dolphin kick.
(j) Completion of first dolphin kick.
(k) Start of flutter kick.
(l) Surface. Start of second armstroke.

Turn

Once a prone position is reached, the turn is executed like a freestyle flip except, of course, that swimmers stay on their backs throughout. They should start the underwater stroke with the front arm as they are completing the underwater stroke with the rear arm. This will accelerate rotation into the wall (see figure 8.17b). They should duck the head and start a dolphin kick as they complete these strokes, also to speed rotation into the wall. When the strokes are completed, they should leave both arms back at their sides while completing the dolphin kick (see figure 8.17, c and d).

Swimmers should turn the palms of the hands toward the bottom of the pool and use them to assist in pulling the head up and the feet over (see figure 8.17e). Both hands should meet overhead before the feet reach the wall. The head should be back between the arms, the arms should be flexed at the elbows, and the upper body and arms should be aligned to push off without delay once the feet make contact. Abal is aligned properly before his feet reach the wall in figure 8.17f.

The feet should be planted on the wall just below the surface and the body should be inclined down from feet to head so that swimmers can make a deep push-off that will allow them to take several strong dolphin kicks after they push the body away from the wall. Abal's feet have made contact with the wall and he is just starting to push his body away in figure 8.17g.

Push-Off

The arms and legs should extend simultaneously and swimmers should drive the body away from the wall while completely on their backs. They should push off in slight downward direction to glide under the surface turbulence and to keep the body deeper during the dolphin kick (see figure 8.17h). The depth during the push-off and dolphin kick that follow should be at least 0.6 m (2 ft) underwater to reduce resistive drag as compared to remaining closer to the surface.

Dolphin Kick

Swimmers will leave the wall traveling much faster than race speed, but their velocity will drop off quickly after that. The body should be streamlined from head to toes and they should glide in this position for a short time until they sense that they are approaching race speed. At that point, they should take several underwater dolphin kicks until they are ready to come to the surface. The technique for the underwater dolphin kick and the suggested distances that swimmers should kick underwater in both 100 and 200 backstroke races were discussed in chapter 6. In figure 8.17, i and j, Abal is executing the first of several underwater dolphin kicks following his turn

Pull-Out

When ready to surface, swimmers should angle up gradually, using a combination of two or three underwater dolphin kicks followed by two to three flutter kicks. When they sense that they are close enough to the surface, they should start the first armstroke. That armstroke should bring them to the surface traveling forward at race speed (see figure 8.17, k and l). The head should remain streamlined, in line with the other arm until reaching the surface. Then they can position the chin down for surface swimming. There should be no delay establishing the proper stroke frequency for the race once swimmers reach the surface.

Swimmers must start the first armstroke while still underwater. A common mistake is to glide or kick to the surface before they begin stroking. If they do this, they will decelerate well below race speed by the time they reach the surface.

Another common mistake is to begin the first armstroke while too deep underwater. Consequently, swimmers complete the underwater portion of the armstroke too early and must kick in a poorly streamlined position, with one arm overhead and the other back at the side, until they reach the surface and can recover the arm over the water to start its next underwater stroke.

Open Turns for the Butterfly and Breaststroke

The turns that swimmers use in butterfly and breaststroke races are almost identical to one another, with the exception, of course, that breaststroke swimmers execute underwater pull-outs while butterfly swimmers take several dolphin kicks after they leave the wall. Previously, short-course swimmers were required to touch the wall with both hands simultaneously and on the same level before they could begin turning. The rules now require only that swimmers touch the wall with both hands simultaneously. The rules also require that they keep the shoulders in line with the surface of the water until that touch is made, however. After the touch, swimmers may turn on their sides and push off the wall, but according to the rules, the shoulders must be at or beyond the vertical toward a prone position when the feet leave the wall. In both strokes, they must be completely prone from the start of the first stroke after the turn.

It is difficult for swimmers to keep the shoulders in line with the surface and still touch the wall with both hands simultaneously and at different levels, so there is probably nothing to be gained by doing so. They can save time by pushing off the wall on their sides, however, so this technique should be part of the turn.

The surface view photos in figure 8.18 show a breaststroke swimmer as she executes her turn. The mechanics of the turn are shown from an underneath view for a breast-

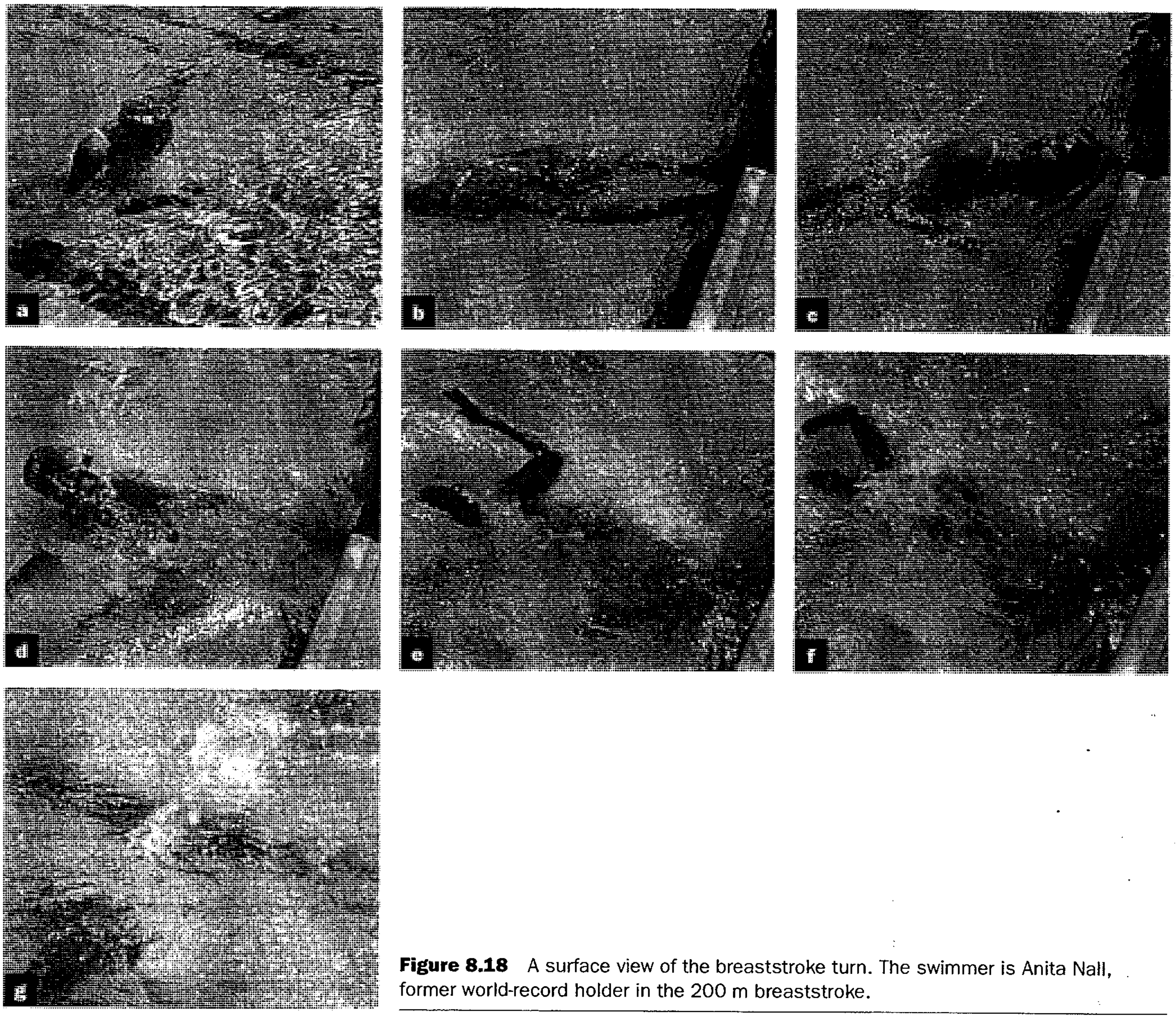


Figure 8.18 A surface view of the breaststroke turn. The swimmer is Anita Nall, former world-record holder in the 200 m breaststroke.

(a) Start of last arm recovery before touching wall.
(b) Swimmer touches wall with arms outstretched and shoulders level.
(c) Swimmer takes one arm from the wall and pulls that arm back into her side.
(d) Swimmer pushes her body away from the wall and takes a breath.
(e) She brings her arm overhead in a high elbow fashion while continuing to take a breath.
(f) Her arm enters the water as her feet make contact with the wall.
(g) Her feet leave the wall and she glides underwater while rotating toward a prone position.

stroke swimmer in figure 8.19. The turn will be divided into the following phases for descriptive purposes: (1) the approach, (2) the turn, (3) the push-off, and (4) the glide and pullout. An additional section about turning on a flat wall is also included because many pools do not have end gutters.

Approach

The approach for the breaststroke is shown in figure 8.18a. As mentioned, however, the mechanics of the turn are almost identical for butterfly and breaststroke swimmers from the time the hands touch the wall until the feet have left the wall. Swimmers should focus on the wall as they approach it so that they can adjust their strokes to

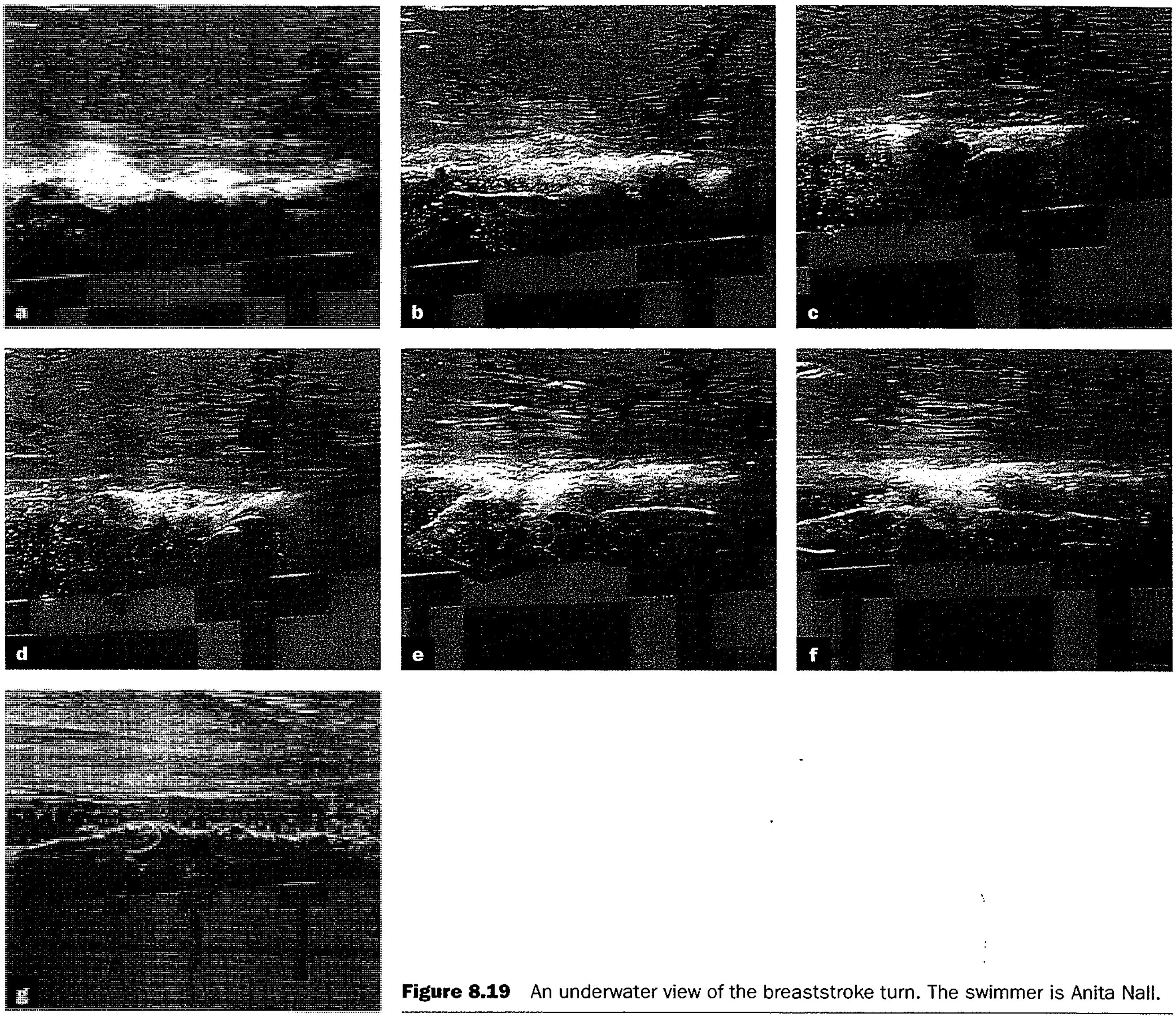


Figure 8.19 An underwater view of the breaststroke turn. The swimmer is Anita Nall.

(a) Swimmer touches the wall with her hands and begins turning toward her side and bringing her legs up from behind.
(b) She takes one hand off the wall and brings it back against her side.
(c) She flexes her legs and tucks them tightly into her stomach while pushing away from the wall with her other arm.
(d) Swimmer continues pushing her body away from the wall. She pushes up with the palm of her underwater hand to help bring her head and shoulders down into the water.
(e) She brings both hands together overhead and begins her pushoff as her feet reach the wall.
(f) She drives off the wall with her legs while rotating her body toward a prone position.
(g) She glides in a prone position until she is ready to begin her underwater armstroke. This athlete would start dolphin kicking if she were swimming butterfly.

reach the wall just as the arms are fully extended forward during their recovery. The final kick should be made powerfully so that the arms hit the wall with as much momentum as possible. Ideally, swimmers want to make contact with the wall just as the propulsive phase of the kick is ending. If they must glide to the wall, they should do so in as streamlined a position as possible to reduce the decelerating effects of drag.

Turn

The actual turning action is most accurately described as simply falling back. It can be seen best in the surface photos in figure 8.18. After touching the wall, swimmers should fall almost straight back as they bring the legs up under the body and the feet into the wall. Many swimmers waste time rotating the body from side to side during these turns. They move the head and trunk away from the wall in one direction while pulling the hips and legs into the wall in the other direction. Turning in this way greatly increases the distance the body travels into the wall and the amount of water swimmers push through to do so. It is faster and more efficient to drop the head and trunk back into the same water space they used to get the legs to the wall. They do this by dropping the head and trunk almost straight back as they bring the feet into the wall, turning the body just enough to allow it to enter the water on its side as they do so. A complete description of this turn follows.

Swimmers should touch the wall with both hands simultaneously. The shoulders should be level with the surface of the water. Nall is touching the wall in figure 8.18b. Once the touch has been made, they should glide into the wall a short distance by flexing the elbows. At the same time, they should get one hand off the wall and headed in the other direction as quickly as possible. That is done by bending the arm and pulling the elbow through the water into the ribs and then extending the arm forward, toward the opposite end of the pool. Nall is pulling one arm away from the wall in figure 8.18c. That arm will be used later to assist in bringing her body down into the water.

At the same time one hand is coming off the wall, swimmers should grasp the gutter with the other hand (if a gutter is available) and pull the hips and legs forward into the wall by flexing that arm. They should tuck the legs tightly and pull them directly underneath the body and into the wall. The legs should be held close together with one foot on top of the other to reduce drag and increase speed into the wall. The feeling should be one of pulling the knees tightly into the gut, shown in figure 8.19c.

The head, which was underwater when the hand touch was made, should be brought up out of the water and moved almost directly back as swimmers pull the legs under. Nall is doing this in figure 8.18, d and e. Once the legs pass under the body, swimmers should shove the body away from the wall by extending the arm that was in contact with the wall. There will be no part of the body in contact with the wall once swimmers push away with that arm. Nevertheless, the momentum developed by pushing the trunk away from the wall will produce a counterforce that will drive the legs into the wall. Swimmers should not hold on to the wall until the feet reach it. This will only delay the push-off. They should take a breath while pushing the body away from the wall.

Swimmers should turn the shoulder of the free arm into the water as they fall back so that they will enter the water on their sides, as Nall is doing in figure 8.18e. They should use the arm that was extended underwater to assist in this action by turning and pressing the palm upward to help bring the head and shoulders into the water. Nall is doing this in figure 8.19d. The arm that was used to push the body away from the wall should be brought over the water in a manner similar to that of a high elbow recovery (figure 8.18e). The eyes should follow that arm over the water so that the arm and head enter the water together. After entry, that arm should move down to meet the other arm.

Push-Off

Swimmers should try to have both hands overhead and the bodies aligned by the time the feet reach the wall. They can then push off immediately. Nall has done this in figure 8.19e. Her feet are planted on the wall with her toes facing sideward and about 45 to 50 cm (18 to 20 in) underwater. The push-off should start when swimmers are on their sides, after which they should rotate to a prone position while driving the body away from the wall and while gliding after the push-off, as shown in figure 8.19, f and g.

The push-off is made by extending the legs while pushing back against the wall. The arms should be extended simultaneously to add additional impetus to the leg drive. The feet should leave the wall with the top leg (the one closest to the surface) crossed over the other. Then they can complete the rotation to a prone position by bringing the top leg down over the bottom leg during the glide.

Glide and Pull-Out

At this point, the techniques for turning diverge for breaststroke and butterfly swimmers. Butterfly swimmers will take several dolphin kicks underwater before surfacing, while breaststrokers will take one underwater armstroke and one kick before surfacing.

Breaststroke Turn Breaststroke swimmers should angle the push-off slightly downward so that they can glide deeper, where the underwater armstroke and glide can be performed more effectively. They should glide in a streamlined position at least 0.60 m (2 ft) underwater until they are approaching race speed. At that point, they should execute one underwater armstroke and a very short second glide before kicking gradually to the surface. The first surface armstroke should begin before the body reaches the surface, but they must not allow the arms to reach the widest point in that stroke before the head breaks through the surface. The technique for the underwater armstroke was described in chapter 7.

Butterfly Turn Butterfly swimmers should push off at a slight downward angle if they intend to take several underwater dolphin kicks before they surface. Otherwise, they should push off horizontally. They should push off the wall and glide at a depth of at least 0.40 m (1.5 ft) to reduce resistive drag.

Butterflyers should glide in a streamlined position until they feel they are approaching race speed. At that point, they should begin the dolphin kick. The technique for surfacing after several underwater dolphin kicks is the same as that described earlier. Swimmers should start a gradual ascent using two or three dolphin kicks to bring the body close enough to the surface to take the first armstroke. That stroke should bring them through the surface traveling forward at race speed.

Butterflyers should not breathe on that first stroke in sprint races. They may take a breath on the first armstroke after the turn in longer races, but they should be sure to breathe near the end of the underwater portion of that stroke so that the act of lifting the head does not disturb stroke rhythm. They should not glide or kick to the surface and then breathe at the start of the first armstroke because that will slow their forward velocity too much.

Turning on a Flat Wall

Swimmers will not be able to assist the movement of the legs into the wall by pulling against the gutter with one hand if there is no gutter available. Except for this difference, however, the mechanics of the turn are very similar when the end wall is flat and there is no gutter to grasp.

Swimmers should touch the flat wall with both hands simultaneously, being sure to keep the shoulders horizontal with the water surface until the touch is made. After touching the wall, they should quickly pull one arm into the ribs, as described previously. The difference in this and the turn when a gutter is available lies in what they do with the hand they leave on the wall. Because they have no gutter to grasp, swimmers should place the palm of that hand against the wall with fingers pointing up and diagonally toward the opposite shoulder and let the body ride into the wall by flexing the arm. The legs should be tucked tightly into the abdomen while they are doing this. When the legs pass underneath the body, and before the feet reach the wall, they should push away from the wall with the palm of the hand by extending the arm at the elbow.

That arm is then brought over the water in high elbow fashion and the remainder of the turn is executed as described earlier.

Common Mistakes

The following are the most common mistakes made during the butterfly and breaststroke turns: (1) pulling the body too high out of the water, (2) turning the body to a prone position before pushing off, (3) pushing off too near the surface of the water, and (4) double breathing while hanging on the wall.

1. Swimmers waste time when they bring the head and shoulders too high out of the water during the turn and it requires unnecessary muscular effort to do so. Swimmers who make this mistake usually grab the gutter and pull themselves in and up before pushing the body away from the wall. Instead, they should keep the body in the water and simply pull it toward the wall for a short distance, until the legs are coming under it and the elbow is flexed enough that they can push away from the wall with a small amount of force. The head and shoulders should remain in the water while this is happening. Both should be brought up and back as swimmers push away from the wall but only high enough out of the water to take a breath as they fall backward.

As indicated earlier, faster turns will be achieved if swimmers fall nearly straight back from the wall with the head and shoulders close to the surface. While the upper body will rise somewhat as they pull the legs into the wall, and even more as they push back with the arm, swimmers should not make any additional effort to raise the body higher than it is already elevated by normal turning.

2. Swimmers will slow their descent if they fail to remain on their sides as they drop underwater. Many swimmers make the mistake of rotating the body to a prone position before they leave the wall. Turning to a prone position will slow the turn because it takes additional time on the wall to rotate the body before they can push off. Furthermore, they will encounter more resistance as they drop underwater because they will be pushing nearly the entire width of the trunk down through the water instead of dropping down on their sides. The effect of this mistake is illustrated in figure 8.20.

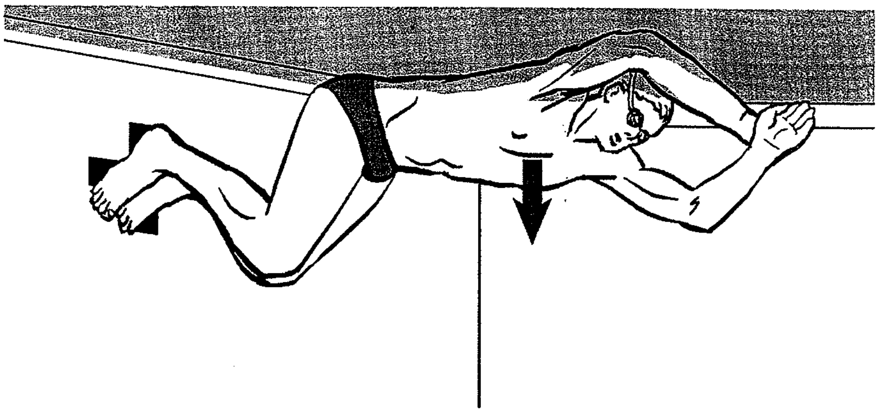


Figure 8.20 The mistake of dropping underwater in a partially prone position during butterfly and breaststroke turns.

Many swimmers make this mistake because they plant the feet with toes pointing down before they push off the wall. They should be coached to plant the feet on the wall with the toes pointed to the side and they will be much more likely to push off on their sides.

3. Swimmers push off at or too near the surface because they hold on to the wall too long with one arm as they pull the legs in. As a result, they are not able to get that arm aligned with the other and the head and trunk completely underwater before the feet reach the wall and they start to push off. They can correct this mistake by getting the hand off the wall and started overhead as soon as the feet pass under the body.

In addition, swimmers push off on the surface because they hold on with both arms as they pull the feet in to the wall and then throw them over the water simultaneously. Some experts have mistakenly advocated this method as a faster way to turn, but it is actually slower because swimmers must either delay the push-off to align the arms with the body underwater or they push off with the body in a poorly streamlined position.

4. The final mistake is to double breathe. Many swimmers lift the head and breathe immediately when they touch the wall and then they breathe again as the head comes back over the water. The first breath delays the turn because they hang on to the wall with both hands until the turn has been completed instead of taking one hand off the wall and starting the legs up immediately. They should breathe only once during each turn: when they drop the head back over the water.

Individual Medley Turns

Turns are often neglected in individual medley events. Practicing them could improve swimmers' times by at least 1 sec in 200 races and almost 2 sec in 400 events. The following changeover turns are required in the individual medley: (1) the turn from butterfly to backstroke, (2) the turn from backstroke to breaststroke (the most complex of the turns), and (3) the turn from breaststroke to freestyle.

Changeover From Butterfly to Backstroke

This turn is not much different from the regular butterfly turn. It is illustrated by a series of drawings in figure 8.21. According to the rules, swimmers must make contact with the end wall by touching with both hands simultaneously and with the shoulders level (figure 8.21a). After that, the turn is identical to the one described for the butterfly until they are pushing the body away from the wall with the hand. From there, the way they move the head and hand over the water and plant the feet on the wall will be somewhat different than the method described for butterfly and breaststroke turns.

Swimmers should still drop underwater mostly on their sides but, in this case, also slightly on their backs as they push the body away from the wall. This is accomplished by bringing the arm used to push away from the wall over the water and behind the head. They should plant the feet on the wall with the toes facing up and only slightly sideward, as shown in figure 8.21, b and c. Then they should rotate the body toward a supine position as they push it away from the wall to comply with the rules for backstroke swimming by having the shoulders beyond the vertical toward their backs when the feet leave the wall. That rotation should be completed shortly after the feet leave the wall so that they are in a perfectly supine position during most of the glide that follows. Once they are in a supine position, swimmers should take several underwater dolphin kicks before angling toward the surface. They should start to flutter kick as they approach the surface and use the same procedure for the first armstroke described for the backstroke rollover turn.

This turn is much faster than some of the others used by swimmers. Diving back or dropping straight back are both slower methods of changing from the butterfly to the backstroke because it takes longer for swimmers to get the feet to the wall and align the body before pushing off.

Changeover From Backstroke to Breaststroke

Swimmers cannot use the backstroke rollover turn in changing over from the backstroke to the breaststroke in individual medleys because the rules state that they must finish the backstroke leg in a supine position and they are not considered to have finished that leg of the race until they touch the wall with the hand. This is unfortunate because the rollover turn would certainly be the fastest method for making that changeover.

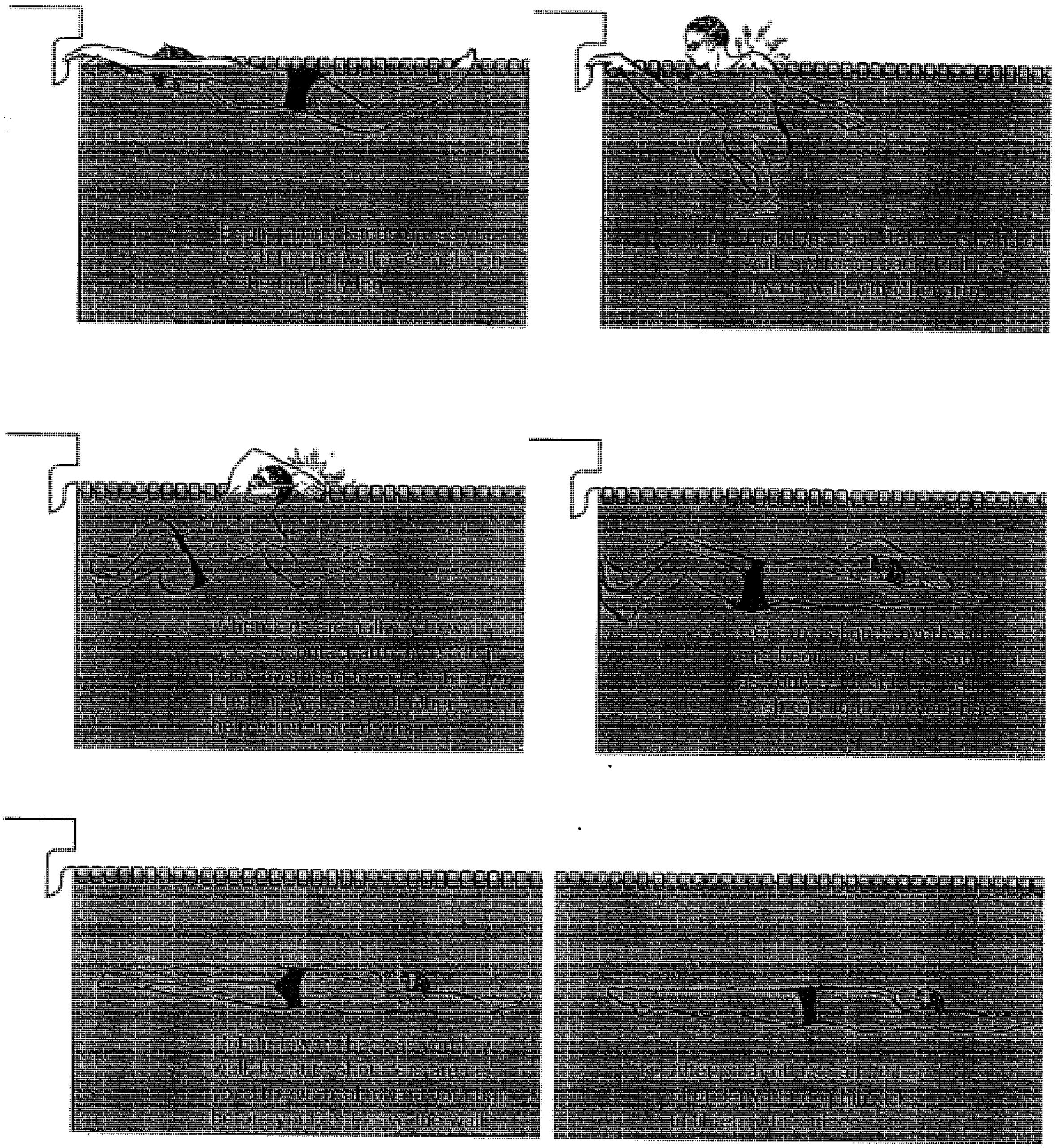


Figure 8.21 The butterfly to backstroke changeover turn used in individual medley races.

The great majority of individual-medley swimmers use one of four different turns in the changeover from backstroke to breaststroke. Some prefer an *open turn,* others a *somersault turn,* and still others use modifications of the *Naber turn* and the old *backstroke roll turn.* The open turn is the most popular, but it is probably the slowest of the four.

Open Turn A sequence of drawings of the open turn is displayed in figure 8.22. This turn can be used most easily when there are gutters to grasp. It is difficult to do against a flat wall, however.

Backstroke flags should be used to judge the approach to the wall in this and the other backstroke to breaststroke changeover turns. Swimmers reach back on the last stroke and grasp the gutter while turning toward the contact arm. After gripping the

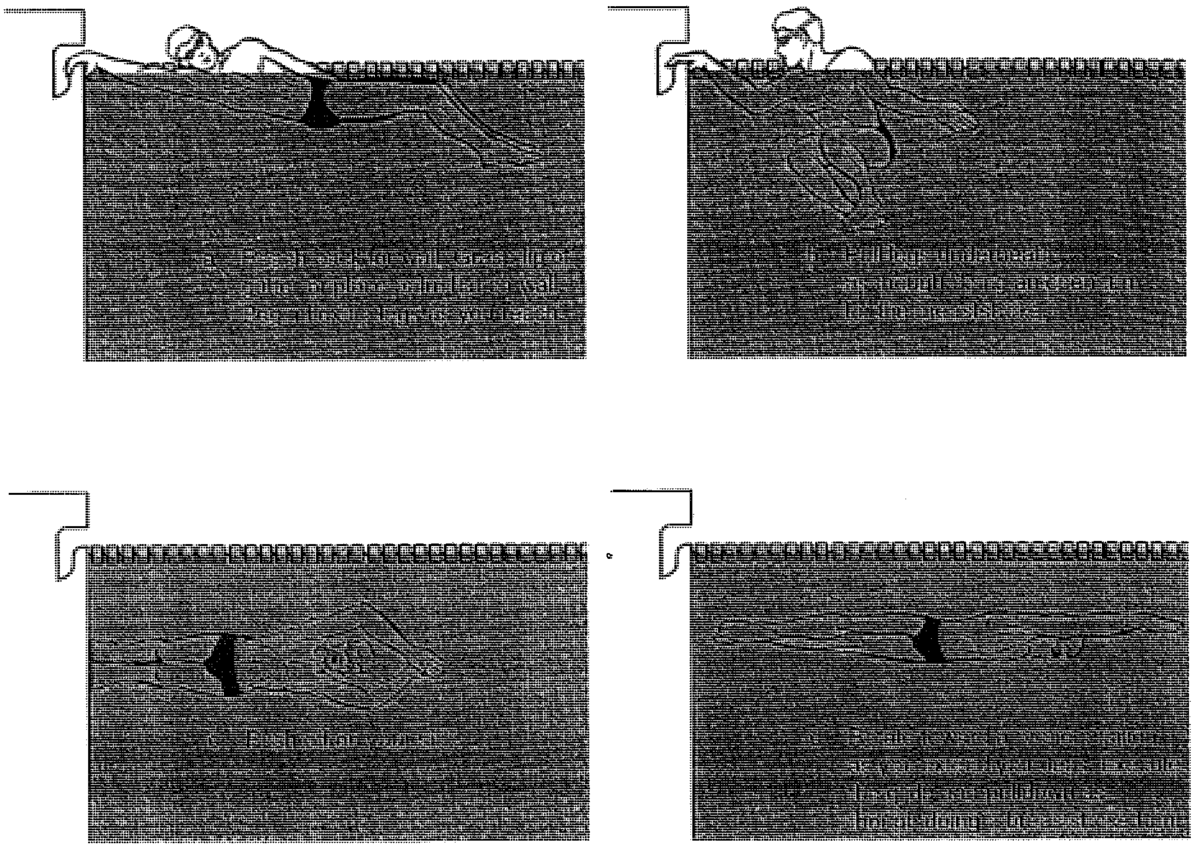


Figure 8.22 The open turn used in the backstroke to breaststroke changeover.

gutter, they pull the legs down and forward into the wall while moving the head and shoulders in the opposite direction over the water. The legs should be tucked tightly and swimmers should remain on their sides throughout the turn. These phases of the turn are illustrated in figure 8.22a and b.

The free arm, which was back at the hip when the turn began, remains extended forward with palm up and will be used to pull the head and trunk underwater later in the turn. This happens in figure 8.22, b and c.

Once the feet pass underneath the body, swimmers should push the body away from the wall with the contact arm and then bring the contact arm forward over the water with a high elbow in the same manner described for a breaststroke turn. The head should follow that arm over the water and they should drop underwater on their sides with one shoulder directly above the other. They should rotate toward a prone position as they push off the wall. (The angle of the push-off can be seen in figure 8.22d.) The push-off should be angled down slightly, after which swimmers glide in a streamlined position until they decelerate near race speed, when the breaststroke underwater armstroke is taken.

As with other open turns, swimmers should try to have the body aligned with both hands overhead and underwater before the feet reach the wall so that they can push off immediately. If the body is not perfectly aligned when the feet reach the wall, they should push off and align it as they do so.

When the open turn is done against a flat wall, swimmers have to plant the palm against the wall and then allow the arm to flex as they glide toward the wall and while they are pulling the legs down. The hand should make contact with the wall at water level, the fingers in toward the body at contact. They can then ride this arm in by letting the elbow bend as they flex the legs and bring them under the body. When the legs pass underneath the hips, swimmers should extend the contact arm to push the body away from the wall in the manner described for butterfly and breaststroke turns. After that, the mechanics of the turn are the same as those described for the same changeover turn with a gutter.

One advantage of the open turn is that swimmers can take a breath during the turn that will last them through the glide and underwater armstroke. They also seem to have an easier time maintaining a sense of orientation with an open turn. The major disadvantage is that the turn is slower than those methods that incorporate rolling or somersaulting actions. This is because swimmers have to stop the motion at the wall to change direction with an open turn whereas they can maintain momentum through the turn when they use a somersault.

Somersault Turn This method of changing over from the backstroke to the breaststroke is illustrated by the drawings in figure 8.23.

Upon approaching the turn, the swimmer in figure 8.23 dives back into the wall as he completes his last arm recovery. His contact arm swings straight over the top and touches fairly deep with his palm flat against the wall and fingers pointing down. He then pushes up and back against the wall with his contact arm to help him rotate his body around during the first half of the somersault. He releases his contact arm from the wall as his feet pass over his head and then brings that arm quickly upward under his body to meet his other arm overhead. He does this by flexing his contact arm and sliding it up under his chest and then extending it forward. He gets that arm overhead and in contact with the other before his feet reach the wall.

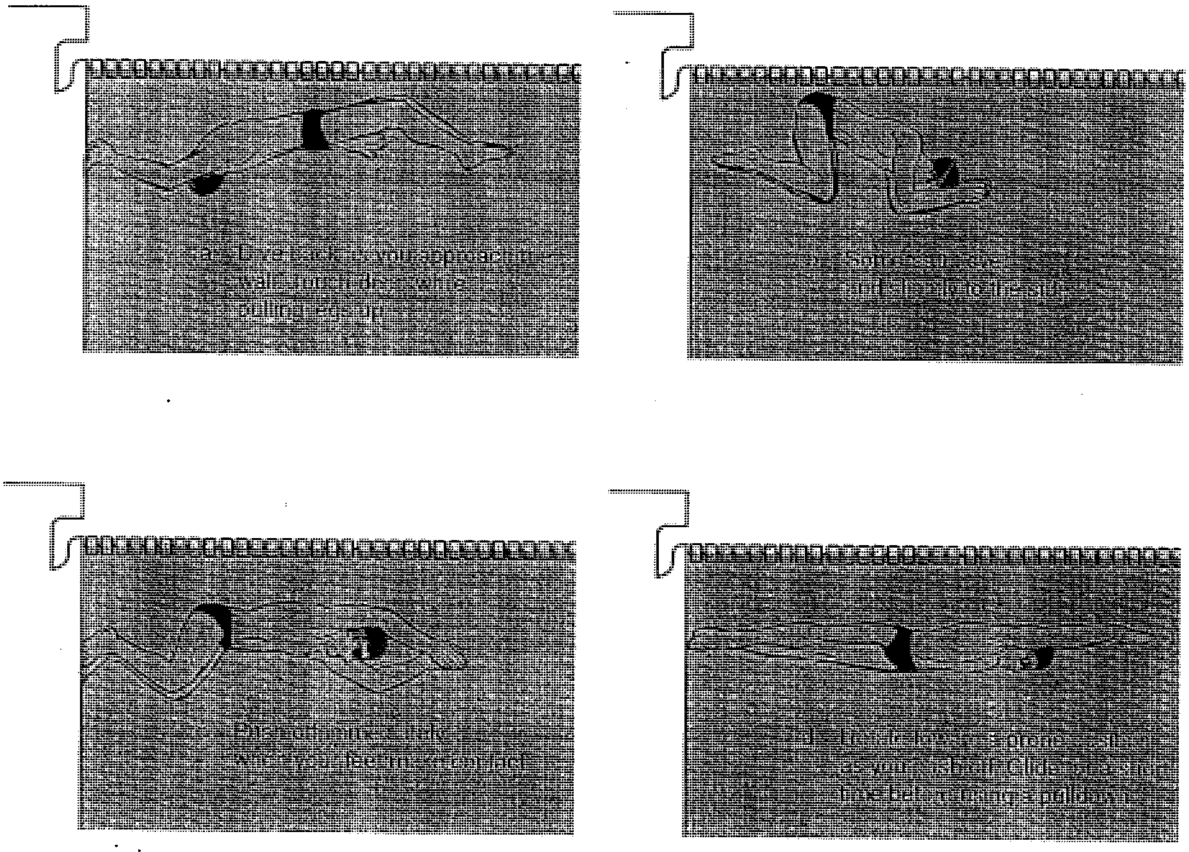


Figure 8.23 The somersault backstroke to breaststroke changeover turn.

In the meantime; his noncontact arm, which was back at his hip as his other arm made contact with the wall, is used to help complete the second half of his somersault into the wall. He does this by turning the palm of that hand up and pushing it toward his head to help pull his head and trunk into alignment with his legs for the push-off. The palm of that hand ends just above his head when the somersault has been completed (figure 8.23b) and then it is brought down in alignment with his other arm in preparation for the push-off.

Reaching back on the approach will cause his body to twist slightly during the somersault so that he ends up in a semi-prone position when his feet reach the wall. As a result, he plants his feet on the wall with his toes pointing to the side. His legs are flexed at the knees in preparation for the push-off (see figure 8.23c). Once his feet make contact, he pushes his body away from the wall without delay. The push-off is made partially on his side with his arms and legs extending simultaneously. As is the procedure with other turns, he rotates toward his abdomen while pushing off from the wall (see figure 8.23d). The push-off is angled slightly downward to get deep enough for the breaststroke underwater armstroke. After the push-off, he glides until he approaches race speed before starting that armstroke.

Modified Naber Turn The great backstroke swimmer John Naber popularized a style of backstroke turn. A combination of the spin and open turns, it allows swimmers to take a breath as in the open turn while using a faster spinning motion during the turn. The no-hand touch rule has made this turn obsolete in the backstroke, but a modification of it can be used effectively in the backstroke to breaststroke changeover. The techniques of the modified Naber turn are illustrated in figure 8.24.

Swimmers should make contact with the wall by reaching back over one shoulder and behind the other shoulder. The hand should make contact with the wall at a depth of approximately 15 to 20 cm (6 to 8 in) with the palm flat against the wall (see figure 8.24a). Swimmers should not grab the gutter, even if one is available.

The legs should start bending as swimmers reach for the wall so that the spin is already underway when they make contact with the hand. Once the touch has been made, swimmers ride into the wall by flexing the contact arm at the elbow. In the meantime, they continue lifting the legs out of the water by flexing them at the hips and knees (see figure 8.24b). The legs should be flexed as much as possible at the knees and hips and pulled into the gut, both to clear the water and speed their rotation into the wall. Leaning back while bringing the legs over the water will help in getting them out of the water. The heels may drag through the water somewhat, although swimmers should make every effort to avoid this. They should spin in a clockwise direction if contact is made with the right arm and in a counterclockwise direction if the left hand makes contact.

Swimmers should push the head away from the wall with the contact arm as the legs pass the midpoint in their trip toward the wall. That arm is then brought over and down into the water with a high elbow to meet the other arm in preparation for the push-off (see figure 8.24c). From there, the turn resembles the open turn described for the breaststroke. The head follows the arm over the water and swimmers should drop underwater on their sides with one shoulder directly above the other. The palm of the noncontact arm, which was back at the hip when the turn began, should be turned up, toward the surface, and used to help pull the head underwater when the body is dropping beneath the surface. Swimmers should push away from the wall on their sides and rotate toward a prone position during the push-off and glide that follows (see figure 8.24, d and e). To comply with the rules for the breaststroke, swimmers should be perfectly on the breast when they begin the first surface armstroke.

The major problem that swimmers have when learning this turn is a tendency to spin to the side too much. The turn should be made in the vertical plane. The legs should be pulled up tight during the spin to reduce their axis of rotation and swim-

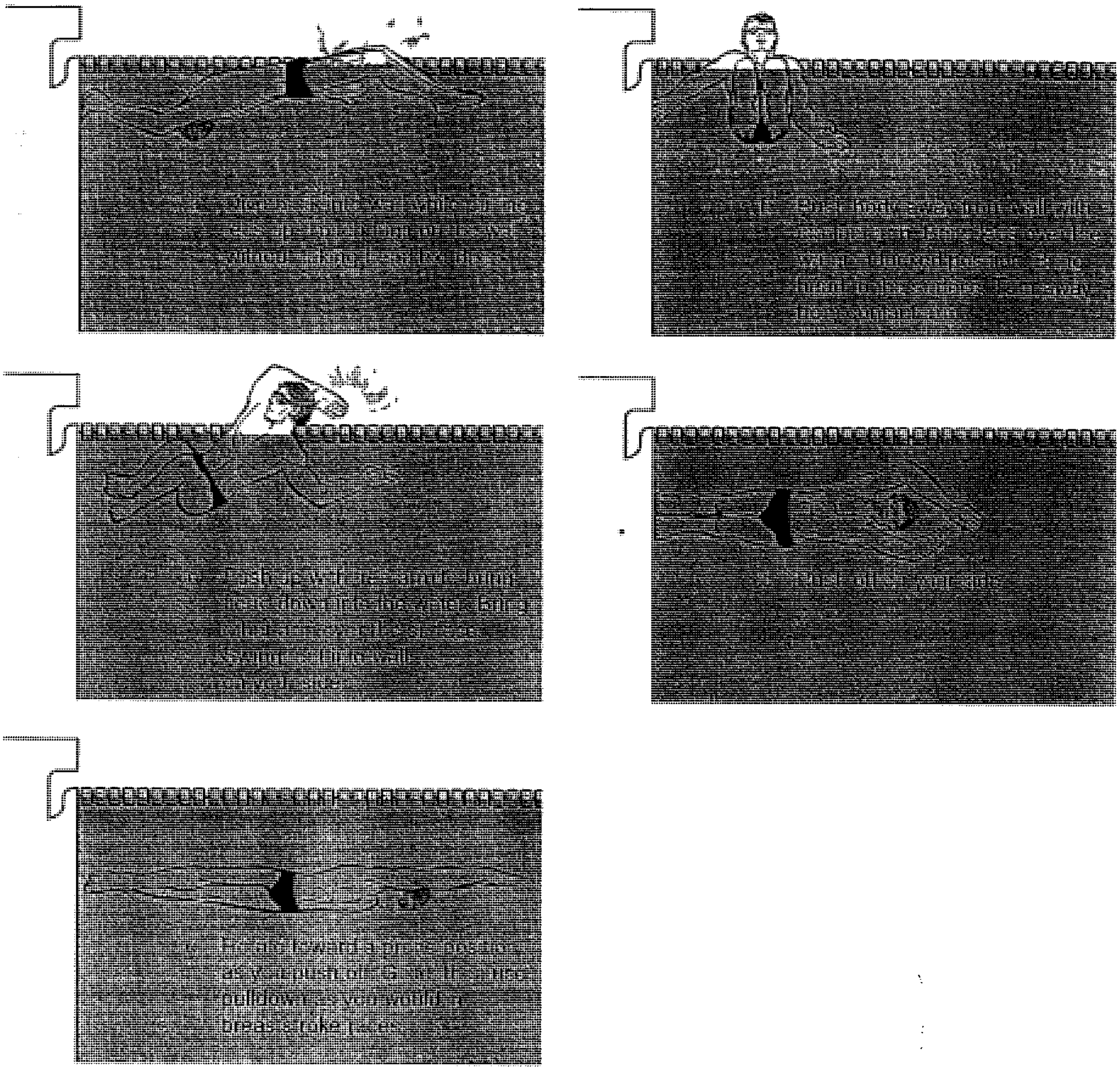


Figure 8.24 The modified Naber turn as it is used in the changeover from backstroke to breaststroke.

mers should lean back as they bring the legs into the wall for the same reason. When they push the body away from the wall with the contact arm, the head and trunk should travel almost directly back, toward the other end of the pool. They should not spin around in a wide circle.

Modified Roll Turn As mentioned earlier, the roll turn was the fastest method in backstroke swimming until recent rule changes eliminated the need for a hand touch. Because the hand touch is still required when changing from the backstroke to the breaststroke in the individual medley, however, the same roll turn, with slight modifications, should be the fastest changeover method. The modified roll turn is illustrated by the series of drawings in figure 8.25.

The swimmer in figure 8.25 rolls toward his side away from his contact arm (but not beyond a vertical position) as he reaches behind his head for the wall on his last arm recovery before starting his turn. The touch is made fairly deep, behind the opposite shoulder, with his palm flat against the wall and his fingers pointing diagonally down and out to the side. Once the touch is made, he continues to roll toward a prone position

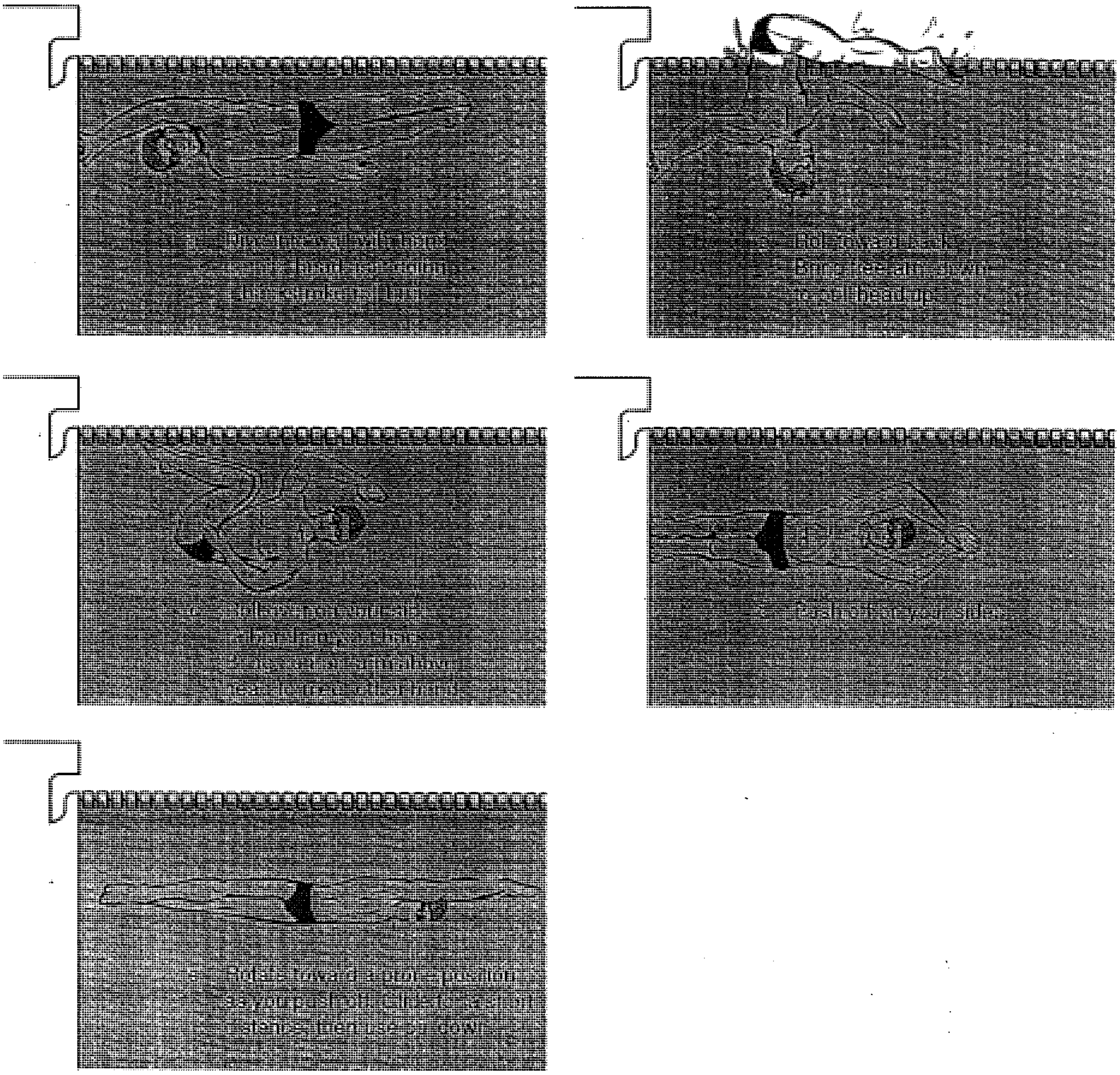


Figure 8.25 The modified roll turn as used for the changeover from backstroke to breaststroke in individual medley events.

as he somersaults his legs over into the wall (see figure 8.25, a, b, and c). Unlike the roll turn in the backstroke, the swimmer does not roll completely to a prone position as he somersaults. Instead, as his feet come into the wall, he corrects slightly backward so that his body is on its side as his feet reach the wall and his head is rising to the surface. This prepares him for a breaststroke push-off (see figure 8.25c).

As he rotates his body toward a prone position, he brings his noncontact arm back through the water, toward the wall and up to a position above his head. Once it is above his head, he uses that arm to assist in the turn by pushing down with his palm to bring his head toward the surface (figure 8.25, b and c). The contact arm is brought forward underwater to a position above his head while he is completing the roll so that his head is aligned with and between both arms as his feet reach the wall (see figure 8.25, c and d).

His feet are planted on the wall facing sideward and he pushes his body away from the wall on its side. The rotation to a completely prone position occurs when he is pushing his body away from the wall and during the glide, after which he executes an underwater armstroke and kicks his body to the surface, as shown in figure 8.25, d and e.

Changeover From Breaststroke to Freestyle

The techniques for this turn are shown in the series of drawings in figure 8.26. The breaststroke to freestyle changeover turn is almost identical to the turn described for the changeover from the butterfly to the backstroke until the body is pushed away from the wall. The obvious difference is that, in this turn, swimmers will rotate to a prone rather than a supine position during the push-off and the glide that follows.

When the feet leave the wall, and after gliding for a short time, the kick and pullout to the surface should be performed as described for a freestyle turn. Swimmers should take one or two dolphin kicks, followed by two to three flutter kicks, until they near the surface. At that time, they should take one arm pull that brings the body up through the surface traveling forward at race speed. Swimmers may breathe as they complete the first armstroke, provided they do so without disturbing their race rhythms.

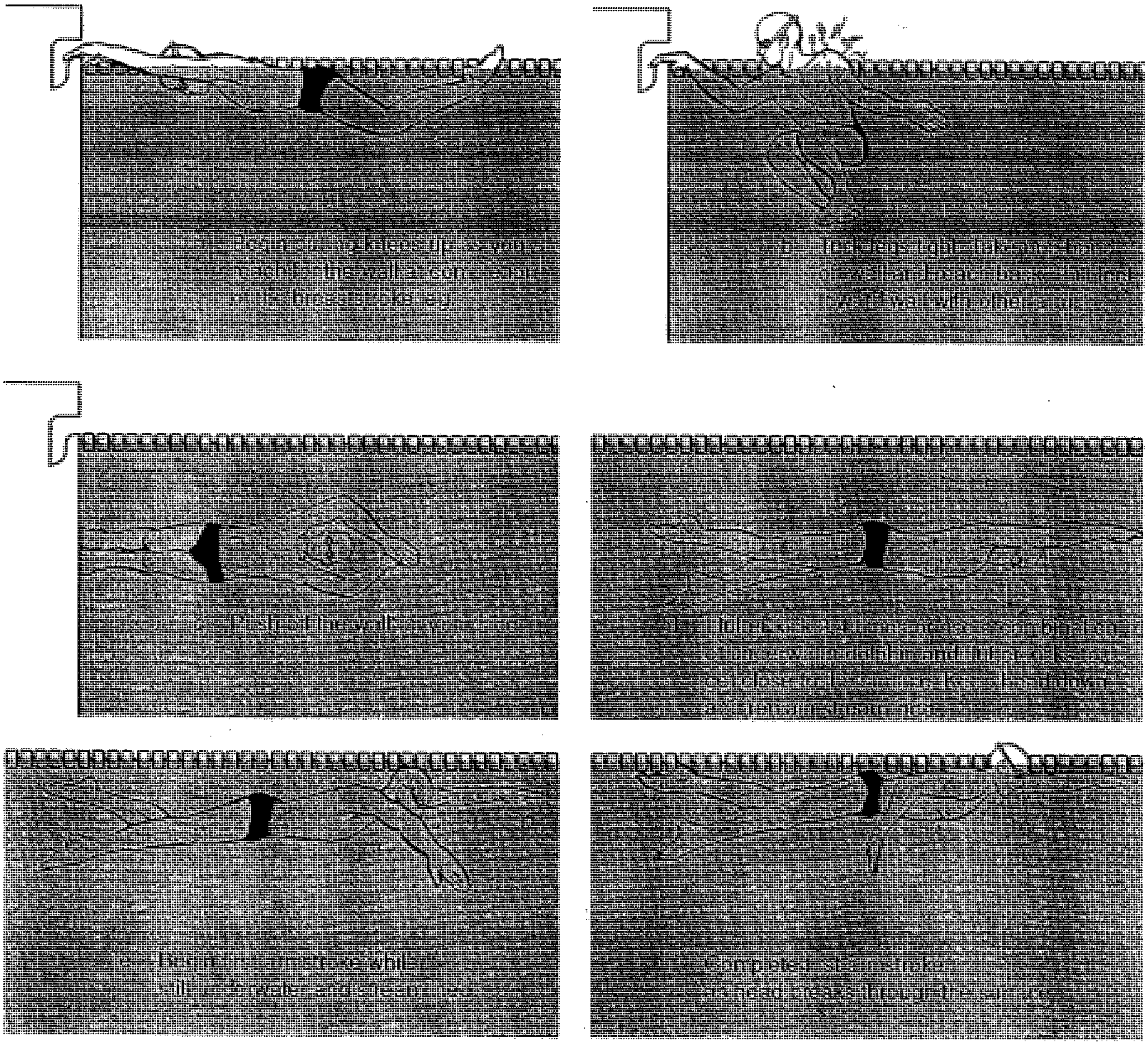


Figure 8.26 The changeover turn from the breaststroke to the freestyle.

Finishes

Many races have been lost because swimmers glide to the finish. Races have also been lost because they took more strokes than needed to reach the wall. The techniques of finishing races should be practiced until swimmers can consistently accelerate to the finish with a minimal glide and no extra strokes.

Freestyle Finish

The fastest way to finish freestyle races is to jab the hand straight forward into the touch pad. The drawings in figure 8.27 show a swimmer finishing a freestyle race in this manner.

When swimmers have judged that the next arm recovery will bring the hand into contact with the touch pad, they should accelerate the speed of that recovery and bring the arm rapidly over the water in normal high elbow style. They should not slide it down into the water and forward to the touch pad, however. Instead, after it passes the head, the arm should be extended quickly forward to hit the touch pad at water level with the fingertips. Swimmers should also roll away from the recovering arm to give it added reach as it travels toward the touch pad. This is done by looking toward the other side and stretching the body forward in the direction of the recovering arm. At the same time, they should be accelerating the body toward the touch pad as rapidly as possible with the underwater stroke of the other arm and with the kick.

The touch should be made with fingers outstretched rather than with a flat palm because, obviously, the fingertips can reach the touch pad before the palm. The face

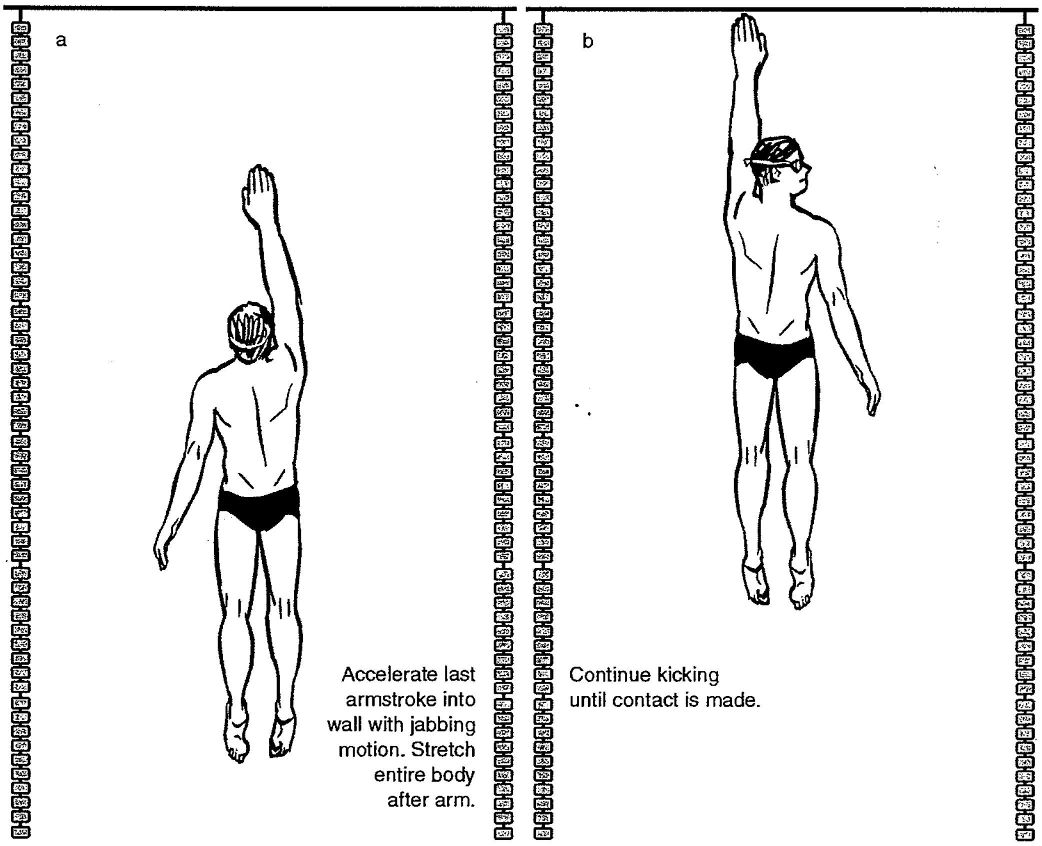


Figure 8.27 The finishing technique for freestyle races.

should remain in the water, looking to the side, during the reach. Lifting the head will shorten the reach and decelerate their speed into the wall.

Ideally, the touch should be made when the arm is at full extension. A touch that is made with a bent arm indicates that swimmers have probably taken one stroke too many. This will increase their time for the race by 0.20 to 0.30 sec. Swimmers should not glide into the wall if the arm does not make contact at full extension. Nor should they take another stroke if they are less than one arm's length from the wall. Instead, they should continue stretching and kicking until the hand reaches the touch pad. Kicking will get the hand to the touch pad faster than either gliding or taking another armstroke. In fact, using a quick dolphin kick may even increase the speed to the finish more than one or two flutter kicks when they have to stretch the arm forward to reach the touch pad. Of course, as mentioned, this advice holds true only when swimmers have misjudged the finish by less than one arm's length. It will be faster to take another stroke if they misjudge the finish by more than that.

Butterfly Finish

The finishing technique for butterfly races is illustrated by the photos in figure 8.28. Because a two-hand touch is required, the lunge must be made with both arms simultaneously and the body must remain in a prone position as they reach forward to touch the wall.

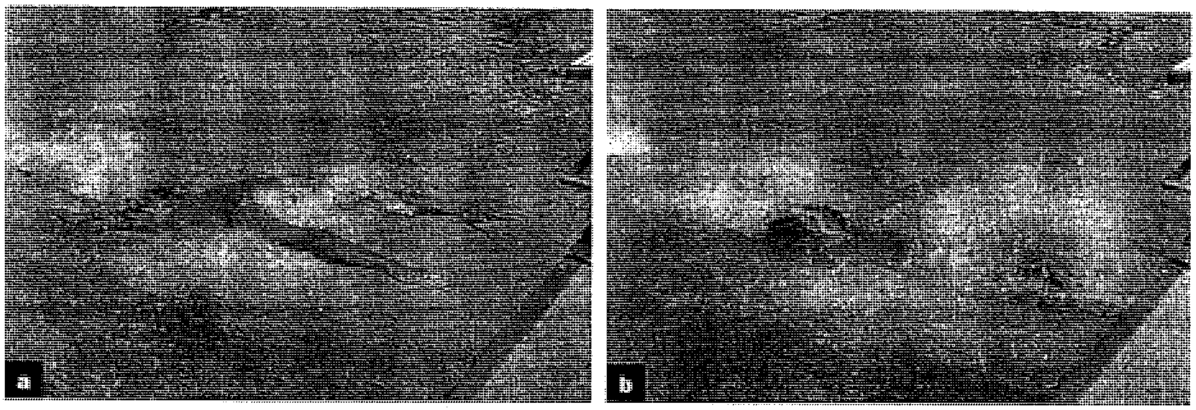


Figure 8.28 The procedure for finishing butterfly races. *(a)* Reach for wall (notice the arms outstretched and head down). *(b)* Touch at full extension (notice the head remains underwater).

The last few armstrokes should be the most powerful of the race and swimmers should accelerate the hands into the touch pad on their last recovery. They should also make this recovery with elbows flexed and jab the hands into the touch pad. This will shorten the distance the hands must travel. Swimmers should accelerate the kick to push the body forward at a faster speed than it would travel by simply gliding over the last few yd or m. The face should be in the water and they should be stretching every fiber of the body forward to reach the touch pad as quickly as possible.

Breaststroke Finish

A breaststroke finish is shown in the photos in figure 8.29. Swimmers of this stroke should also lunge for the finish with both hands simultaneously and they must remain in a prone position until they touch the wall. The final few armstrokes and the final arm recovery should be accelerated so that the arms can be sliced forward as quickly as possible when they reach for the finish. They should not breathe during the last armstroke before the finish so that they can accelerate into the wall even faster. They

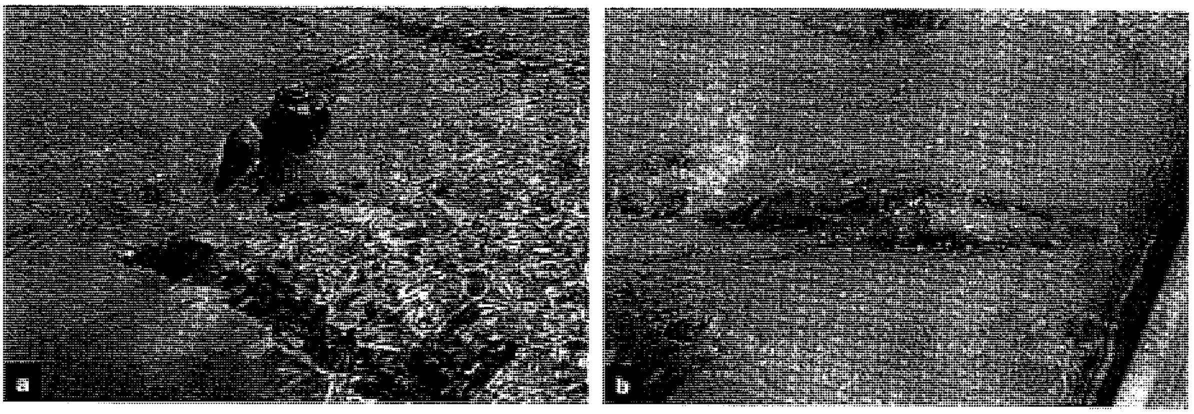


Figure 8.29 A finishing technique for breaststroke races. *(a)* Start of last recovery before finish. *(b)* Stretch for the finish (notice head is down and shoulders are level).

will gain several extra centimeters of reach if the face remains in the water as they stretch for the touch pad.

The final kick should be very strong to accelerate the body to the finish. If the reach is slightly short, swimmers should stretch for the wall. Another armstroke, even a partial one, will require more time than would simply stretching and gliding to the finish. They should only take an extra stroke if they find themselves so far from the wall that they will lose time by gliding. It seldom happens that breaststroke swimmers misjudge the finish by more than a few centimeters, however.

Backstroke Finish

In backstroke races, swimmers should count the number of strokes they will need to cover the distance from the flags to the wall. The two drawings in figure 8.30 illustrate the way swimmers should finish backstroke races.

When backstroke swimmers determine that one more arm recovery will bring the hand into contact with the touch pad, they should accelerate that recovery and jab the hand back into the pad. The jab is accomplished by flexing the arm forward after it leaves the water and then extending it rapidly into the touch pad at water level—not underwater. Reaching forward in this way takes less time than a normal vertical recovery with a straight arm. The body should be rotated toward the finishing arm to increase the reach and swimmers should stretch hard for the finish. The head should be stretched toward the wall and swimmers should be looking to the side, toward the finishing arm, to help the stretch. They should stroke powerfully with the other arm and execute one very powerful dolphin kick to accelerate their speed into the wall. Contact with the touch pad should be made with the fingertips near the surface.

Ideally, the hand should make contact with the wall at the instant it reaches full extension. If the hand touch is misjudged, however, the best strategy is to continue stretching and dolphin kicking until the fingers reach the touch pad. This advice, of course, applies only to finishes that have been misjudged by less than one arm's length.

Breathing While Finishing

Breathing during the final sprint to the wall should have no effect on speed in backstroke races, for obvious reasons. In the breaststroke, breathing seems to be necessary for maintaining stroke rhythm and, therefore, should not be restricted until the lunge for the finish takes place. The situation is quite different in butterfly and freestyle races, however. Turning or lifting the head for a breath will definitely slow speed during the final sprint. In these events, then, swimmers should swim as much of the final 25 yd/m as they can tolerate without taking a breath. The stress and fatigue they may experience

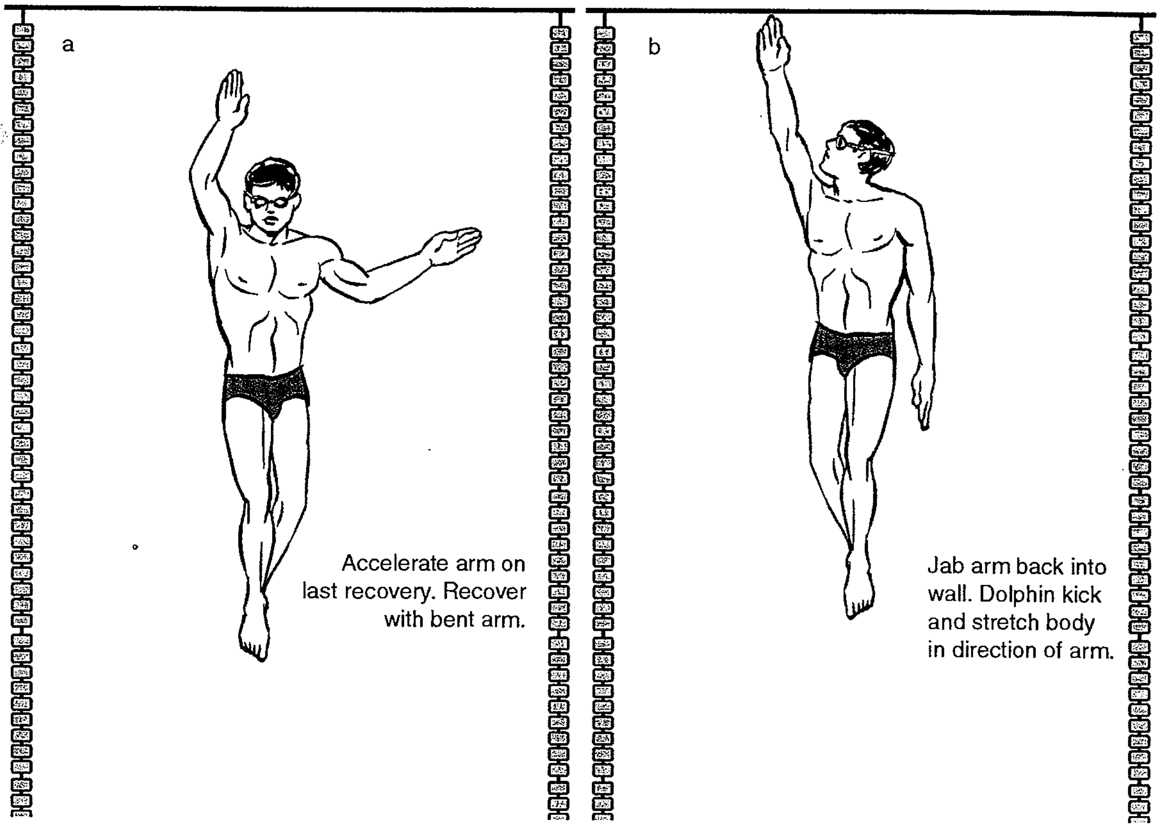


Figure 8.30 The procedure for finishing backstroke races.

when doing this should be disregarded in favor of the additional speed they achieve. At this point in the race, there is no longer any need to conserve energy. The only thing that is important is getting to the finish as fast as possible.

Butterfly and freestyle swimmers should hold their breath from, at least, the time they pass the backstroke flags until they finish the race. With practice, it may be possible to hold their breath for even longer periods with no loss in speed. But swimmers must never restrict their breathing on the final pool length for such a long period that they lose speed over the final few yards or meters of the race. They should practice holding their breath as they sprint to the finish during competitions and practices until they know how much of the final portion of the race they can sprint without breathing and without losing speed.

part II

Training

Research completed in the decade of the 1990s has provided significant new information about the topics covered in part II. I have completely rewritten some sections to present the large amount of new material; others I have merely revised to include new information.

The first two chapters, 9 and 10, are a review of exercise physiology as it relates to the training of competitive swimmers. These chapters provide background information that supports the methods of training presented in later chapters. Chapter 9 is concerned with muscular, circulatory, respiratory, and hormonal reactions to training and exercise. Information concerning the way different muscle fiber types are used during training and competition has been emphasized to set the stage for a revision of the anaerobic threshold theory of training presented in previous editions of this book.

The processes of aerobic and anaerobic metabolism are described in chapter 10, and the training effects that improve athletic performance are described in chapter 11. Scientists were just beginning to study the influence of one of these effects, the removal of lactic acid from muscles during exercise, when the previous revision of this book was completed. A great deal of additional information is now available about this important training effect. Consequently, discussion of the process of lactate removal during exercise and how it can be trained has been enlarged considerably in this edition.

Chapter 12 describes the principles of training. Most of the information in this chapter is similar to what I presented in the previous edition of this book, but I have included some additional principles here.

The most enlarged sections in this edition are in Chapters 13, 14, and 15. Endurance training is the topic for chapter 13, and sprint training is covered in chapter 14. Perhaps the most important change of emphasis in training has to do with the threshold and overload endurance categories. The importance of training at exactly the anaerobic threshold was overstated in previous editions of this book. I no longer believe that training at the anaerobic threshold is the best way to improve aerobic endurance. Nor do I believe that training at the anaerobic threshold will improve aerobic endurance as much as it can be improved. I present new information that explains why no single level of training will produce all the adaptations needed to increase aerobic endurance. Athletes need to train at intensities both slower and faster than anaerobic threshold speed to improve their endurance optimally.

The purpose for overload endurance training was not well understood when I wrote the previous edition of this book. Coaches did not know exactly what unique training adaptations it produced beyond those that could be produced by threshold training. In this edition I suggest a possible explanation for the value of overload endurance training that has to do with the unique effect of this form of training on the fast-twitch muscle fibers.

Chapter 15 is devoted to training athletes for different events. This is the pivotal chapter of this section because it offers practical suggestions about how to use the information from the previous two chapters on endurance and sprint training to prepare athletes for competition. The chapter also describes the training programs of several successful athletes.

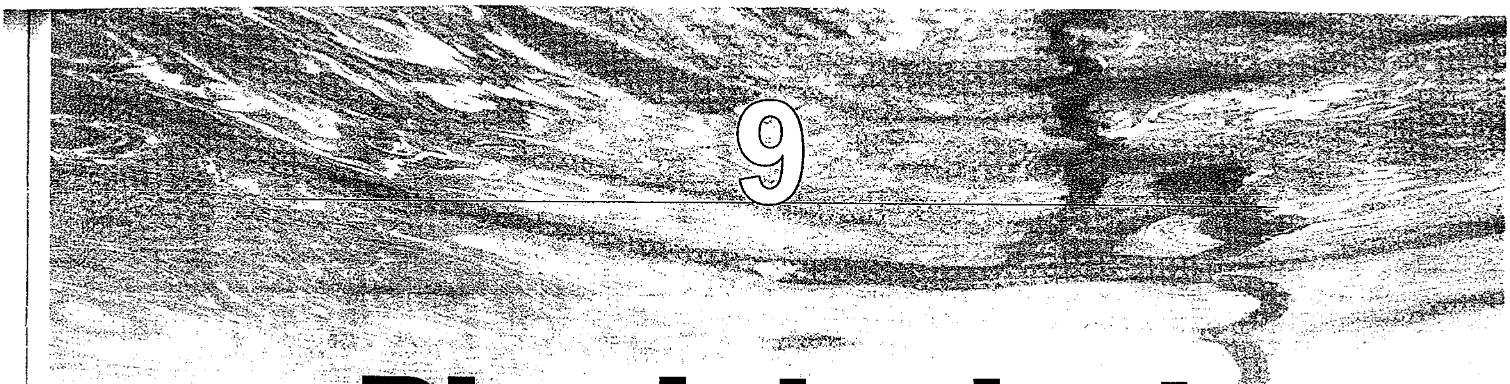
Chapter 16, on monitoring training, also contains a large amount of new information. I describe several new methods of blood testing and reexamine the importance of including measures of anaerobic power when interpreting blood tests. We coaches have known for some time that simply improving anaerobic threshold speed does not guarantee better performance. The relationship between shifts of the lactate-velocity curve at the anaerobic threshold and above had to be considered. Additional research can now help us interpret the meaning of these shifts. In this edition I describe the results of that research.

The information on using heart rates for monitoring training has been updated and clarified in this edition. I hope that this information will allow readers to use this useful procedure more effectively. Finally, I have included a section on using repeat sets for monitoring training. Most coaches find repeat sets their most available method for evaluating the reactions of individual swimmers to their training programs. Therefore, I have suggested some sets that coaches can use for this purpose and show how to interpret the results from those sets to evaluate the effects of training.

The chapter on planning training, chapter 17, has also been updated and enlarged. The various types of training cycles have been described in detail with the intent of providing readers with ideas they can use for planning their seasons.

Research from the 1990s has provided new information about tapering, the subject of chapter 18, and I have included it here. This research has focused on two areas. The first area concerns what happens physiologically during the taper, and the second has to do with the relationship between taper duration and training intensity that will produce the best results.

The last chapter in part II, chapter 19, covers the topic of overtraining. A discussion of the physiological basis for overtraining, how to treat it, and how to prevent it are the primary topics in this chapter.



9

Physiological Responses to Exercise

New in this edition:

- A reevaluation of the oxygen debt
- A discussion of the relationship between the respiratory and lactate thresholds
- The role of hormones during exercise has been expanded

One of my primary purposes in writing this book is to provide readers with a basic understanding of exercise physiology. I did this so that they could understand the scientific basis for present training methods and evaluate the potential benefits of new methods that will be developed in the coming years. For these reasons I will provide in this chapter a brief description of the responses of the muscular, circulatory, respiratory, and endocrine systems to exercise and training. In the next chapter I will review exercise metabolism.

Muscular System

The human body has three types of muscles—smooth muscles located in various organs, cardiac muscles located in the heart, and skeletal muscles that connect to and move the various bones of the body. The contractions of skeletal muscles produce the force that makes it possible for swimmers to move their limbs through the water. Consequently, their function and development should be of great interest to coaches and athletes.

Structure and Function of Muscles

Muscles contract when they receive messages from the central nervous system. Those messages come in the form of electrical impulses that travel along nerve fibers at lightning speed until they reach their point of connection to muscle fibers, where they cause the fibers to contract. Muscles are groups of muscle fibers that are connected to bones. They usually span a joint. When they contract or shorten, they pull the end attached to a particular bone, termed the *insertion*, toward its other end, the *origin*, which is attached to another bone. We often speak of muscles as contracting in total, but only some of the fibers within each muscle actually contract at any one time. When loads are heavy a large number of the fibers must contract to move that large amount of resistance. When the load is light only a small portion of the fibers may need to contract to move the resistance through a range of motion.

Muscles consist of thousands of tiny fibers, each of which is a single muscle cell. About as thick as a human hair, muscle fibers can vary in length from a few millimeters to several centimeters. Figure 9.1 shows the structure of a muscle. It consists of bundles of muscle fibers wrapped in connective tissue. The contractile elements of muscle fibers are *myofibrils*, which are composed of proteins called *actin* and *myosin*. When a nerve impulse of sufficient intensity stimulates the muscle fiber and energy is released from chemicals stored in the muscle fiber, the myosin filaments connect to the actin filaments and pull them inward, causing the fiber to contract.

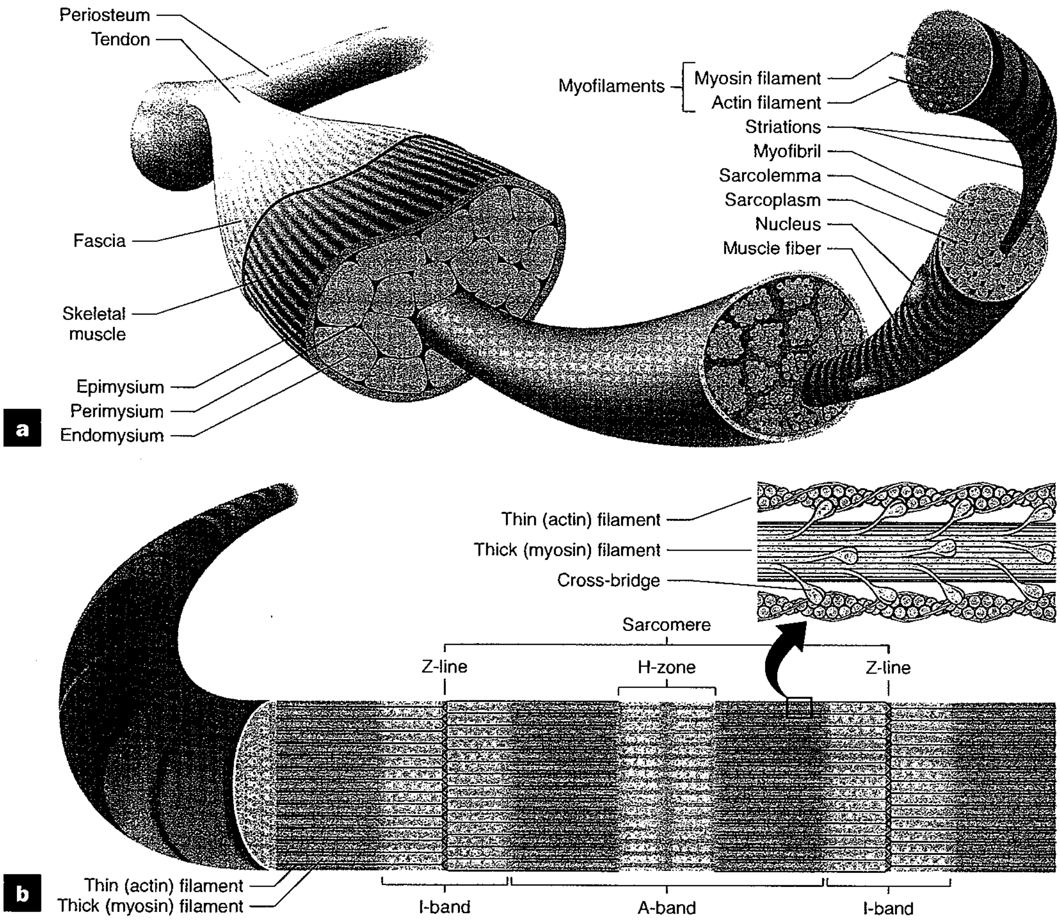


Figure 9.1 *(a)* The structure of a skeletal muscle. *(b)* A muscle fiber and its myofibrils.

Adapted from Behnke 2001.

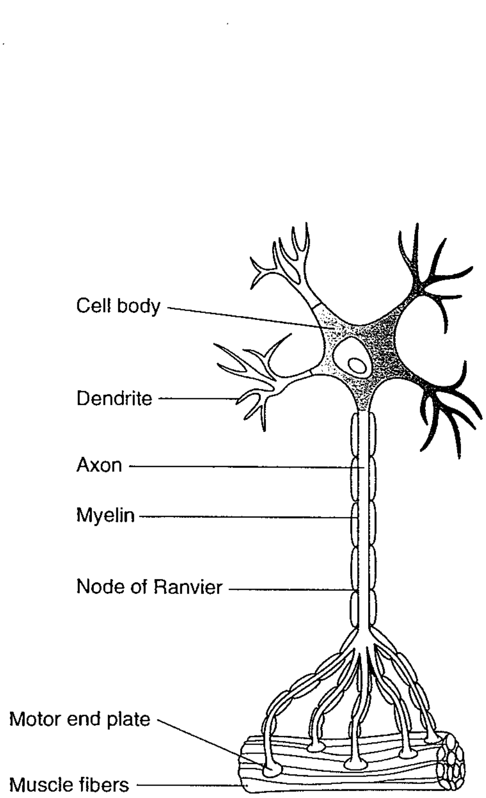


Figure 9.2 A motor unit, comprising a motor neuron and muscle fibers.

Adapted from Behnke 2001.

Muscle fibers are arranged within a muscle in *motor units.* A single motor nerve serves each motor unit through branches that reach all the fibers within the unit. Therefore, each muscle fiber has a nerve ending that relays messages from the central nervous system and tells it when to contract. Any impulse that comes over the nerve and its branches will cause all the muscle fibers within a motor unit to contract at once. This is known as the *all-or-none law.* When a nerve impulse with sufficient intensity travels to a motor unit, all the muscle fibers within that unit will contract. None of them will contract if the charge is not strong enough. A motor unit is pictured in figure 9.2.

The number of motor units that contract at any one time determines the contractile force of an entire muscle. Only a few motor units (a few hundred fibers) will contract when the demand for force is low, such as during easy swimming. A much larger number of the motor units will contract when the demand for force is high, as in sprinting. Our brains learn from experience how much force is needed to perform certain jobs. Then our nervous system stimulates the appropriate number of motor units to contract when we perform that work. This precise pattern of muscle fiber stimulation is called *motor-unit recruitment.*

One way that we maintain work for a long time is to rotate the effort among groups of motor units so that some contract while others rest. A certain number of the motor units within a muscle will perform the work until they become fatigued. When that happens, other motor units within the muscle that have been resting will be recruited to replace the fatigued units so that the desired amount of force can be maintained.

Most experts believe that we never use all the motor units in a muscle at one time, even during maximum efforts (Wilmore and Costill 1999). The nervous system inhibits us from doing so because the force would be so great that it might snap our bones. Muscle fibers must be used or they will atrophy. Light to moderate work must be continued long enough so that all the fibers within a particular muscle rotate in and participate in the work. Obviously, this sort of workout will improve the endurance of muscle fibers. The second point is to work at near-maximal effort so that the muscle will use all or almost all of its fibers to overcome the resistance. Work of this intensity can continue only for a short time, so the primary effect of such training will be to improve strength, power, and anaerobic capacity.

One factor that determines our ability to maintain a particular pace, in other words, our endurance, is the number of motor units that must contract at any one time within a muscle to maintain that speed. If a large number are required, fewer will remain to rotate in to the work later and we will fatigue earlier. If the task requires a small number of motor units, a greater number will be available to take up the work later and we will be able to maintain a certain pace longer.

The speed with which fibers can be recruited and the number that can be stimulated at any one time is probably an important determinant of an athlete's potential for sprinting. The pattern of recruitment may also affect maximum speed. That pattern determines whether motor units from many different muscles, and motor units from different areas within each muscle, can contract in a sequence that provides the desired amount of force in the correct sequence of contraction. Motor-unit recruitment patterns probably affect our endurance as well. That is, if the recruitment pattern is efficient, an athlete will need fewer motor units to maintain a particular swimming speed and will thus have more available to perform work later.

Slow-Twitch and Fast-Twitch Muscle Fibers

Humans have two categories of fibers in the skeletal muscles of their bodies. One type are known variously as slow-twitch fibers, slow oxidative (SO) fibers, red fibers, or Type I fibers. The second type are known as fast-twitch (FT) fibers, white fibers, or Type II fibers. I will use the terms *slow-twitch* (ST) and *fast-twitch* (FT) when discussing these two fiber types.

Fast-twitch (FT) muscle fibers, as their name implies, contract rapidly (30 to 50 times per sec). Slow-twitch (ST) muscle fibers contract at slower rates (10 to 15 times per sec). Fast-twitch muscle fibers also shorten more rapidly. They can shorten up to six fiber lengths per second, whereas slow-twitch muscle fibers shorten at a rate of only two fiber lengths per second (Faulkner et al. 1986). Another important difference between the two fiber types is in their capacity for endurance and power work. Slow-twitch muscle fibers have more endurance because they have a greater capacity for aerobic metabolism. They contain more of the substances that are important for aerobic metabolism, and they have a greater number of structures in which aerobic metabolism takes place. They have more *myoglobin,* the substance that transports oxygen across the muscle cell. The myoglobin in slow-twitch muscle fibers gives them their red appearance (myoglobin has a reddish pigment). Fast-twitch fibers are white (actually light pink) because they contain less myoglobin.

Another factor that makes slow-twitch muscle fibers more enduring is that they contain more *mitochondria,* the protein structures within muscle cells where aerobic metabolism occurs. Slow-twitch muscle fibers have two to five times more mitochondria than fast-twitch muscle fibers. Slow-twitch fibers also have a greater concentration of the aerobic enzymes that catalyze the release of energy during aerobic metabolism.

Although slow-twitch muscle fibers have a great capacity for providing energy aerobically, their capacity for anaerobic metabolism is limited. They have smaller concentrations of the anaerobic enzymes that catalyze the release of energy when oxygen is not available. Even when called upon to supply energy anaerobically, they cannot do so as rapidly as their fast-twitch counterparts can.

On the other hand, fast-twitch muscle fibers have a lower capacity for aerobic metabolism because they contain less myoglobin, fewer mitochondria, less fat, and fewer aerobic enzymes. They produce more lactic acid than slow-twitch muscle fibers at equivalent workloads and therefore fatigue more quickly. They also use their glycogen faster.

Most muscles contain a mixture of fast-twitch and slow-twitch fibers. A few are composed predominantly of slow-twitch fibers, and others contain a preponderance of fast-twitch fibers. For example, the soleus muscles of the legs contain between 25% and 40% more slow-twitch muscle fibers than other leg muscles. The triceps muscles of the upper arms contain between 10% and 30% more fast-twitch muscle fibers than the other arm muscles of humans (Saltin et al. 1977).

Effects of Training on ST and FT Muscle Fibers

Endurance training will increase the aerobic capacity of slow-twitch and fast-twitch muscle fibers. Trained fast-twitch fibers never reach the level of aerobic capacity of trained slow-twitch muscle fibers. An athlete can increase the aerobic capacity of fast-twitch muscle fibers, however, to a level that surpasses that of untrained slow-twitch muscle fibers (Saltin et al. 1977). Conversely, strength and sprint training will increase the size and contractile speed of fast-twitch and slow-twitch muscle fibers as well as their potential for rapid energy release (Tesch and Larsson 1982). Fast-twitch muscle fibers, however, possess a greater potential than slow-twitch muscle fibers for such increases. In support of this statement, the fast-twitch muscle fibers of a trained person are usually much larger than their slow-twitch fibers. Although an athlete can increase contractile speed and force in slow-twitch muscle fibers that have been sprint trained, they never reach the level of even untrained fast-twitch muscle fibers.

Subgroups of FT Muscle Fibers

Experts have identified subgroups within the fast-twitch group of human muscle fibers. Some fibers within this group appear to have the potential for greater aerobic metabolism than others do, although their aerobic capacity does not equal that of slow-twitch fibers in this respect. The fast-twitch subgroup of muscle fibers that has more aerobic capacity than other members of the fast-twitch group have been termed variously as *Type IIa, fast-twitch a (FTa),* and *fast-oxidative-glycolytic (FOG)* fibers. The second type of fast-twitch muscle fibers differs from the first type in that they have an extremely limited capacity for aerobic metabolism. Terms used to identify this subgroup are *Type IIb, fast-twitch b (FTb),* and *fast-glycolytic (FG)* fibers. The third group has been termed *fast-twitch c (FTc)* fibers, but a better concept is to consider them unclassified. They do not seem to fit into either the fast-twitch or slow-twitch categories but instead appear to be fibers in transition between the two main types of muscle fibers. Some experts believe that these FTc fibers can become either slow-twitch or fast-twitch fibers depending on whether they are trained for endurance or for speed and strength. Others do not accept this hypothesis. They point out that longitudinal studies have not demonstrated any change in the percentage of FTc muscle fibers. I will use the terms *FTa, FTb,* and *FTc* to identify the subgroups of fast-twitch muscle fibers because the physiological literature most frequently uses those terms.

The properties of the various fiber groups and subgroups are listed in table 9.1. The FTa fibers have more aerobic capacity than either of the other two subtypes of FT muscle fibers because they contain more and larger mitochondria, more myoglobin, and greater activity of aerobic enzymes. They also have more capillaries around them.

On the other hand, FTa muscle fibers can contract faster and with greater force and power than slow-twitch muscle fibers. FTa muscle fibers will shorten three to four times faster than slow-twitch muscle fibers. But they cannot shorten as rapidly as FTb muscle fibers, nor can they produce the same amount of power and force as FTb muscle fibers. FTb fibers can shorten at a rate that is five to six times faster than that of slow-twitch muscle fibers (Fitts and Widrick 1996). FTb fibers also contract with twice the power of FTa fibers and 10 times the power of slow-twitch muscle fibers. The ratio of peak power production for FTb, FTa, and ST muscle fibers is 10:5:1. The graph in figure 9.3 shows the differences in peak power production for slow-twitch, FTa, and FTb muscle fibers. The graph shows the peak power that each type of muscle fiber can produce at varying percentages of its maximum contractile force.

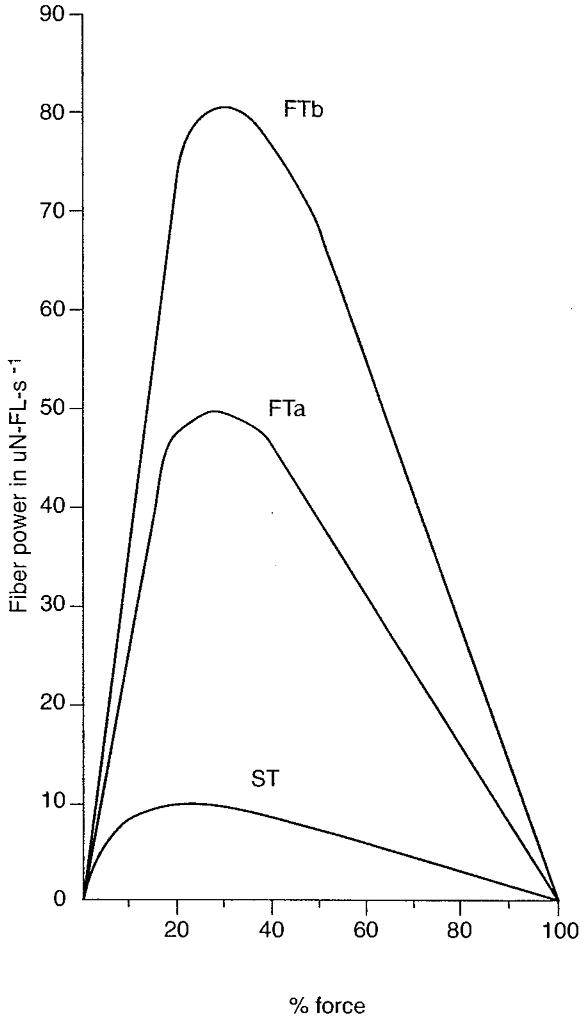


Figure 9.3 Power production of FTb, FTa, and ST muscle fibers. FTb fibers produce more power at all percentages of maximum force because they contract more rapidly than the others do. FTa fibers are the second most powerful type, and the power production of ST muscle fibers is well below that of the fast-twitch categories.

Adapted from Fitts and Widrick 1996.

Fiber Types and Athletic Ability

The muscles of most humans contain approximately equal amounts of fast-twitch and slow-twitch muscle fibers. Within the fast-twitch

Table 9.1 Properties of Fast-Twitch and Slow-Twitch Muscle Fibers

PROPERTY	FTa	FTb	ST
Contractile speed	Fast	Fast	Slower
Capacity for anaerobic metabolism	Greater	Greater	Less
Capacity for aerobic metabolism	Less	Least	Greatest
Size*	Larger	Larger	Smaller
Aerobic metabolism	Less	Least	Greatest
Power	Greater	Greater	Less
Mitochondria	Less	Least	Most
Capillaries	Less	Least	Most
Anaerobic enzyme activity	Greater	Greater	Less
Aerobic enzyme activity	Less	Least	Greatest
ATPase activity	More	More	Less
CPK activity	More	More	Less
Glycogen content	No difference		
ATP content	No difference		
CP content	More	More	Less
Fat content	Less	Less	More
Protein content	More	More	Less
Myoglobin content	Less	Least	Most
Calcium content	More	More	Least
Buffering capacity	More	More	Least

*FT fibers are larger in the average person. This relationship can easily be changed with training. Well-trained endurance athletes usually have larger ST fibers, while the FT fibers of sprint and power trained athletes are even larger than those found in the average population.

group, approximately 33% of the fibers are classified as FTa, 14% as FTb, and the remaining 3% as FTc fibers (Saltin et al. 1977). Some persons, however, have muscle that contains a much larger number of one fiber type than another. For example, Costill (1978) reported that the percentage of slow-twitch muscle fibers in the deltoid muscles can be as high as 80% for some swimmers and as low as 20% for others. The muscles of both males and females may contain extreme proportions of either fast-twitch or slow-twitch muscle fibers.

People have speculated that an athlete's potential for sprint or endurance performance is determined by the predominant type of fiber contained in his or her muscles. Athletes with an unusually high percentage of fast-twitch muscle fibers have a greater potential for success in sprint events because they have more fibers that can contract rapidly and with great force. But these athletes are at a disadvantage in endurance events. They have only a small number of slow-twitch fibers and therefore have reduced ability to supply energy aerobically. Consequently, they will tend to fatigue earlier because of the accumulation of lactic acid in their muscles.

The reverse is true for athletes with an unusually high percentage of slow-twitch muscle fibers. They have an advantage in endurance events but are ill equipped for sprinting because they have fewer fibers that can deliver large amounts of energy in a rapid manner.

Despite the obvious advantage that a preponderance of slow- or fast-twitch muscle fibers provides for endurance or sprint events respectively, research has not produced any high relationship between the percentage of either fiber type in the muscles of swimmers and their performance over certain race distances (Campbell, Bonen, Kirby, and Belcastro 1979; Komi and Karlsson 1978). In other words, swimmers with a high percentage of fast-twitch muscle fibers are not always the fastest sprint swimmers, nor are swimmers with a high percentage of slow-twitch muscle fibers always the fastest distance swimmers. This circumstance is probably because the range of competitive distances permits swimmers with less favorable fiber-type percentages to overcome their disadvantage through factors such as training, stroke mechanics, and racing ability. The difference between sprint and endurance events is not extreme in swimming when compared with other sports, particularly track and field. Our shortest event, the 50 freestyle, requires 19 to 25 sec for our fastest male and female swimmers, whereas track athletes run the 60 yd dash in 5 to 6 sec. Similarly, our longest event, the 1,500 m freestyle, requires 14 to 18 min, whereas the marathon of track and field takes several hours to complete.

A large percentage of fast-twitch muscle fibers may in fact be necessary for success in 50 m swimming events. In all other events, however, swimmers need both speed and endurance. Thus competitors have almost equal need for the two major types of muscle fibers. The case could be made that swimmers in 100 and 200 m events might have a slight advantage if they possess a high percentage of fast-twitch muscle fibers, just as 1,500 m swimmers with a high percentage of slow-twitch muscle fibers might have a slight advantage. Those advantages are so slight, however, that an athlete can easily overcome them by the factors mentioned earlier. Some people have suggested that swimmers should have muscle biopsies to determine what events they are best suited for, but there is no need to subject swimmers to that procedure.

FT and ST Muscle Fiber Recruitment During Work

A common misconception is that slow-twitch muscle fibers contract when athletes swim slowly and fast-twitch fibers contract when they swim quickly. The different fiber types contract according to the muscular force required to produce a movement, not the speed of the movement. Slow-twitch muscle fibers are the first to contract, and they perform most of the work for a muscle when the resistance is light, regardless of the speed of the movement. When the resistance increases, both the slow-twitch and fast-twitch muscle fibers will contract to overcome it, whether the movement is slow or fast.

Consequently, the slow-twitch muscle fibers do most of the work when athletes swim at slow speeds because they do not need to apply very much force against the water at those speeds. Both types of fibers contract during faster swims, however, when the demand for force is greater. The way your nervous system determines whether to recruit only the slow-twitch muscle fibers or both the slow-twitch and fast-twitch fibers of a particular muscle group is interesting.

Motor units contain all FTa muscle fibers, all FTb muscle fibers, or all slow-twitch muscle fibers. The nerve serving a particular motor unit determines what type of fiber it contains. The motor nerves that serve slow-twitch motor units have small cell bodies and a small number of muscle fibers, between 10 and 180, per motor unit. Fast-twitch motor units have large motor nerves and more fibers, 300 to 800 muscle fibers per motor unit. Surprisingly, the strength of contraction is similar for both slow-twitch and fast-twitch muscle fibers. The difference in the force generated by fast-twitch and slow-twitch motor units is due to the number of muscle fibers contained in those units, not the force generated by the individual muscle fibers.

Your central nervous system will stimulate the type and number of motor units appropriate to the amount of force required to swim at a particular speed. If the speed requires a small amount of force, the frequency of impulses from the central nervous system will be lower and only a small number of slow-twitch motor units will be

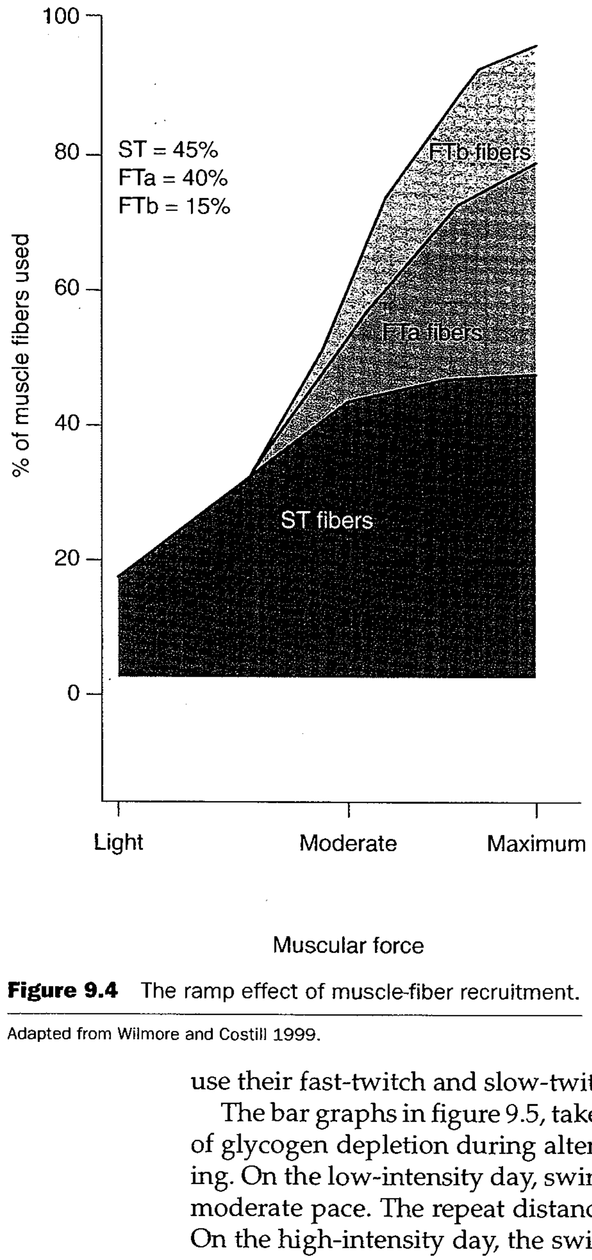


Figure 9.4 The ramp effect of muscle-fiber recruitment.

Adapted from Wilmore and Costill 1999.

stimulated to contract at any one time. When the pace and therefore the need for force increases, the frequency of nerve stimulation will also increase so that more slow-twitch motor units will be contracting. When that frequency reaches a critical point, the FTa motor units will also be stimulated to contract. If the frequency continues to increase, contraction of FTb motor units will occur. The pattern of muscle fiber recruitment during work is shown in figure 9.4, which depicts the so-called *ramp effect* of muscular contraction. As indicated, only slow-twitch motor units contract when the force required is light to moderate. They contract in ever-greater quantities as that force approaches maximum. Fast-twitch motor units do not begin contracting until the force is moderate. The number of fast-twitch motor units that are contracting also increases as the demand for force goes up. Within the fast-twitch group the FTa muscle fibers carry most of the load until the required level of force is near maximum. Then the FTb fibers rotate in. All fiber types (but not all motor units) will be contracting when you exert maximum force.

Researchers have used muscle biopsies to determine the amount of glycogen lost from each fiber type before and after exercise of different intensities. The fiber type that has lost more of its glycogen will be the one that supplied most of the energy during the training effort. The results of these studies generally support the concept of the ramp effect of muscle-fiber recruitment. They can provide additional insight into the way swimmers use their fast-twitch and slow-twitch muscle fibers in training and competition.

The bar graphs in figure 9.5, taken from a study by Houston (1978), show the pattern of glycogen depletion during alternating days of high- and low-intensity swim training. On the low-intensity day, swimmers completed 6.1 km of freestyle swimming at a moderate pace. The repeat distances varied from 50 to 400 m with short rest periods. On the high-intensity day, the swimmers warmed up with five 200 m swims at a low intensity. Then they swam and kicked 1.5 km of long rest repeats at distances of 25 to 100 m at near-maximum speed.

As expected, the tests for glycogen depletion showed that both slow-twitch and fast-twitch muscle fibers were used on both training days. More of the slow-twitch fibers, however, were depleted or partially depleted of glycogen on the low-intensity day, whereas both the slow-twitch and fast-twitch muscle fibers were equally depleted of their glycogen during the high-intensity day.

Note also that the fast-twitch muscle fibers lost more of their glycogen on the high-intensity training day. When both types of muscle fibers are used, the fast-twitch muscle fibers become depleted faster because they metabolize glycogen more rapidly. The results of this study suggest that fast-twitch muscle fibers are depleted of glycogen first during sustained efforts greater than 70% of maximum. Slow-twitch muscle fibers lose their glycogen first during slower swims.

Researchers believe that both slow-twitch and FTa motor units of humans are recruited at swimming speeds that demand more than 80% to 85% of a swimmer's maximal ability to consume oxygen (Henriksson 1992). This speed is roughly equivalent to swimming at 70% to 75% of maximum effort. FTb muscle fibers are not extensively recruited until athletes are swimming faster than speeds that produce maximal oxygen consumption.

Knowing the intensity of work at which the various subtypes of fast-twitch muscle fibers are recruited is important to the training process because it tells us how fast athletes must swim to improve the aerobic capacity of their fast-twitch muscle fibers. Studies by Harms and Hickson (1983) and by Dudley, Abraham, and Terjung (1982) provide some insight into this matter. Both studies used rats, rather than humans, as subjects.

If humans recruit their muscle fibers similarly to the way rats recruit theirs, and we have good reason to believe they do, these studies provide important insight into the training speeds that will improve the aerobic capacity of each muscle fiber type. To summarize, studies with rats, if applicable to humans, indicate that both slow-twitch and some FTa fibers are recruited at training speeds in excess of 50% of $\dot{V}O_2$max. Athletes can best improve the aerobic capacity of slow-twitch muscle fibers at low to moderate swimming speeds. Faster speeds may actually reduce the training effect. Training intensities between 85% and 100% of $\dot{V}O_2$max (maximal oxygen consumption) are probably required to bring about maximum recruitment of the FTa muscle fibers and improve their aerobic capacity. Training intensities that correspond to $\dot{V}O_2$max and greater are probably needed to produce maximum improvements of the aerobic capacity of the FTb fibers of humans.

Force is not the only factor that determines how fast-twitch and slow-twitch muscle fibers are recruited during exercise. Another interesting aspect is the manner in which one type of muscle fiber will assist another when fatigue sets in. During long periods of even, slow-speed training, slow-twitch muscle fibers will gradually fatigue, and more fast-twitch muscle fibers will be recruited to maintain the speed. Thus, a swimmer could improve the aerobic capacity of fast-twitch muscle fibers by simply swimming long periods at slow speeds.

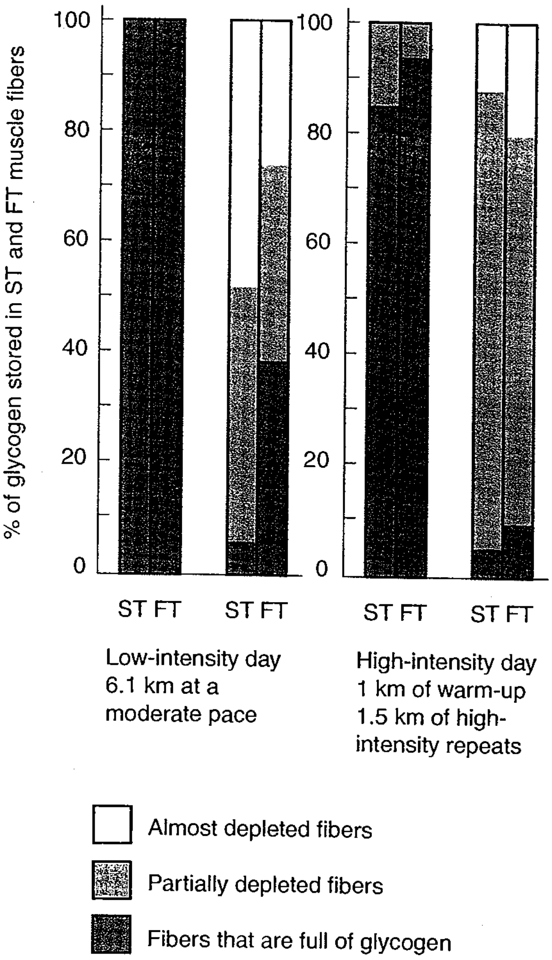


Figure 9.5 The effects of sprint and endurance swimming on muscle glycogen use in ST and FT muscle fibers.

Adapted from Houston 1978.

Can FT Fibers Be Converted to ST Fibers?

The prevailing, but not universal, belief in the scientific community is that the percentages of fast-twitch and slow-twitch muscle fibers cannot be changed with training (MacDougall et al. 1980). Sprint training, however, can increase the contraction speed and power of slow-twitch muscle fibers, and endurance training can increase the aerobic capacity of fast-twitch muscle fibers. At the same time, experts believe that a sprint-trained slow-twitch muscle fiber will never contract as fast nor produce as much power as a sprint-trained fast-twitch fiber. Similarly, endurance-trained fast-twitch fiber will never possess the aerobic capacity of an endurance-trained slow-twitch muscle fiber.

Training probably does not change the proportions of fast-twitch and slow-twitch muscle fibers, but the proportions of FTa and FTb muscle fibers do change. Training reduces the number of FTb muscle fibers and increases the number of FTa fibers. The feeling is that training increases the amount of myoglobin, the number of mitochondria, and the concentration of aerobic enzymes in FTb muscle fibers so they become FTa fibers, or at least function like them (Saltin et al. 1977).

Some recent studies suggest that the FTc muscle fibers may be the vehicle by which FTb fibers are converted to FTa fibers (Bottinelli et al. 1994). In one study the muscles of trained humans were found to contain few FTb fibers. At the same time the percentage of FTc fibers increased in proportion to the decrease in FTb fibers (Fitts and Widrick 1996).

Endurance training, sprint training, and weight training appear to increase the number of FTa muscle fibers in humans while decreasing the number of FTb fibers. This change could have a positive effect on the performances of middle distance and distance swimmers. Their endurance should improve by increasing the aerobic capacity of FTb muscle fibers simply because those fibers have the most potential for improvement. As I indicated earlier, the aerobic capacity of FTb muscle fibers should be improved best by swimming endurance repeat sets at a high intensity because fast speeds are required to activate those fibers. At the same time, swimmers may also be able to improve their aerobic capacity by swimming very high mileage at low to moderate intensity. This method will take considerably longer, however, and the approach may not be foolproof because an hour or more would be required to deplete energy from the slow-twitch fibers and FTa fibers before the FTb fibers would be called upon.

Another side to this story is relevant to sprinters. Training that increases the endurance of fast-twitch muscle fibers, particularly the FTb fibers, may also reduce their contraction speed and force. Fitts, Costill, and Gardetto (1989) reported a loss of contractile speed in fast-twitch muscle fibers after just 10 days of endurance training. In addition, several studies suggest that endurance training reduces the activity of certain enzymes that control the rates of anaerobic metabolism (Sjodin 1976). The effect of a decrease in the activity of those enzymes would be to reduce the rate of anaerobic energy release in fast-twitch muscle fibers, which would in turn prevent athletes from generating fast speeds over short distances.

The issue of whether sprint training can improve the contraction speed of slow-twitch muscle fibers is not settled. Endurance and sprint training alike seem to increase the rate of contraction of slow-twitch fibers, at least initially. Evidence suggests that long periods of endurance training could reverse the process and slow the contraction speed of slow-twitch muscle fibers. Fitts and Widrick (1996) reported that continued endurance training produced an initial improvement in the contraction speed of slow-twitch muscle fibers followed by a reduction in contraction speed.

Circulatory System

The purpose of the circulatory system is to transport blood throughout the body. This function is important because blood carries oxygen, glucose, and other nutrients to the tissues and carries lactic acid, hydrogen ions, and carbon dioxide away from them. Thus, circulation is the delivery system for substances athletes need in their muscles to continue exercise and the removal system for substances that would cause fatigue if they remained in the muscles.

The circulatory system is essentially like the filtering system of a swimming pool. The pool is like the tissues of the body, principally the muscles. The heart is the pump. The arteries and veins are the pipes going to and from the pool, respectively. The blood is like the water that is pushed out to the pool after being cleaned and then pulled back from the pool for subsequent cleaning. A drawing of the circulatory system is shown in figure 9.6.

The left side of the heart pumps blood out to the muscles and other tissues of the body through the *arteries* and *arterioles*. The arteries and arterioles are like branching sets of pipes that become smaller in diameter until they reach their destinations in the tissues. Arteries are the large branches, and arterioles are small vessels that branch off

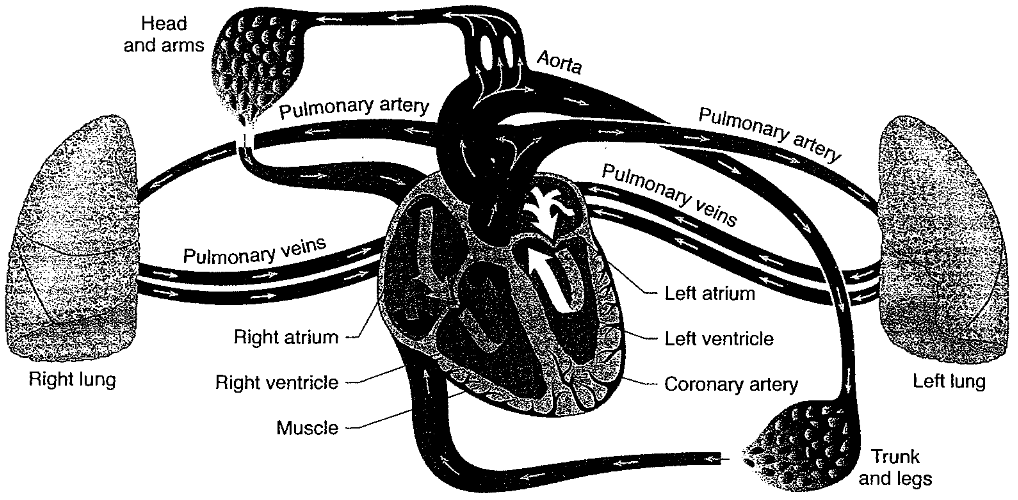


Figure 9.6 Anatomy of the heart and circulatory system.

Reprinted from Jackson et al. 1999.

them. Arterioles end in *capillaries,* which are the smallest vessel units. Capillaries surround individual muscle fibers.

The blood delivers oxygen, glucose, and other substances to the capillaries. At that point, blood is at its greatest proximity to muscles, and some of these substances diffuse out of the capillaries and into the muscle fibers they surround. At the same time the carbon dioxide, lactate, and hydrogen ions produced in the muscles during exercise diffuse and are transported out of them into the capillaries. Blood then leaves the tissues through the same capillaries and travels through another set of progressively larger tubes, called the *venules* and *veins,* back to the right side of the heart. From there the heart pumps the blood out to the lungs through pulmonary arteries and arterioles, ending in pulmonary capillaries that surround small sacs in the lungs called *alveoli.* Carbon dioxide diffuses out of the blood and into the alveoli when it reaches the lungs, where it is exhaled. At the same time, oxygen inhaled into the lungs diffuses into the capillaries, and blood transports it back to the left side of the heart through venules and veins. Once it reaches the heart, the blood is pumped out to the muscles, and the process begins again.

The lactic acid picked up from the muscles will be dropped off at several locations as the blood makes its way back to the heart. Some of it will be dropped off at other muscle fibers and the liver, where it will be converted back to glycogen for use later as a source of energy. Some of the remaining amount will be picked up by the heart muscles and used as fuel or converted to glycogen and stored for later use.

The features of the circulatory system most important for delivering blood to and from the tissues during exercise are heart rate, stroke volume, and cardiac output. The following sections discuss each of these topics in detail.

Heart Rate

The number of times your heart contracts during each minute is your heart rate. Actually, both the right and left sides of the heart (the ventricles) contract simultaneously, but these two contractions count as one beat. The left ventricle of the heart fills with blood from the lungs during its rest period between beats. When the heart beats, it pumps that blood, with its oxygen and nutrients, out to the muscles. The right ventricle fills with blood returning from the muscles during the rest period and then pushes that blood, with its carbon dioxide, out to the lungs.

Resting heart rates are in the neighborhood of 60 to 80 beats per minute (bpm) for most untrained persons. The resting heart rates of trained athletes tend to be considerably lower, frequently between 30 and 50 bpm, because the resting heart rate declines with training. The cardiac muscles of the heart become larger and stronger from training, and they can push more blood out with each beat. Consequently, the heart requires fewer beats to supply the usual quantity of blood the athlete needs at rest.

For accuracy, resting heart rates should be counted for 60 sec. You can take a count by palpating the carotid artery in the neck or the radial artery in the wrist, or you can count the beats with your hand over your heart.

Each of us also has a maximum heart rate, that is, a maximum number of times our hearts will beat each minute. That rate is usually between 180 and 220 bpm. Heredity probably determines an individual's maximum heart rate, and training produces little if any change.

The maximum heart rate tends to decline with age, showing a slight but steady decrease of one beat per year beginning at 10 to 15 yr of age. A rule-of-thumb procedure for estimating the maximum heart rate is to subtract your age from 220. This method gives a crude estimate. The range of maximum heart rates actually varies considerably among persons as they become older. For example, according to the formula, the maximum heart rate should be 180 at 40 yr of age. Maximum heart rates for 40 yr olds, however, range between 156 and 204 bpm (Wilmore and Costill 1999). Therefore, estimates of maximum heart rates are not precise enough for use in training swimmers. When used to monitor training, the maximum heart rate should be determined experimentally for each person.

One method for doing this is to swim a set of 100 repeats on short rest (5 to 15 sec). You would start at a speed that elicits a moderate heart rate and increase your speed a few seconds with each swim until you are swimming faster but experience no increase in heart rate. Another method is to count your heart rate during several all-out training efforts over a period of days. The highest rate you achieve is your maximum heart rate. To reduce the possibility of error, you should have achieved the same maximum rate several times during the testing period. A maximum rate that you achieve only once may not be your true maximum.

A commercial heart-rate counting device that calculates maximum heart rate by determining the time between beats is more accurate than counts that take place over several seconds. The latter method will tend to produce a result lower than the true maximum. The heart rate of well-trained persons will begin slowing immediately after they complete an effort; therefore, a heart-rate count taken for 30 to 60 sec after exercise will undoubtedly be slower than the true maximum rate.

In the absence of a device for calculating the maximum heart rate, athletes should count their heart rates for 10 sec immediately after they finish a maximum effort. This count will not be exactly accurate either. The error in such measurement could be as great as plus or minus 6 bpm because the 10 sec count is multiplied by six to get a 1 min count. This amount of error is still likely to be less than the error that could result from a 30 or 60 sec count.

Stroke Volume

The amount of blood pushed out of the ventricles of the heart with each beat is termed *stroke volume.* A normal range of values at rest is between 60 and 130 ml per beat. These amounts can increase to between 150 and 180 ml per beat during exercise. These values refer only to blood pumped out of the left ventricle. An equal amount of blood will simultaneously be pumped out of the right ventricle.

Stroke volume increases with endurance training. Many factors contribute to the increase, including increased strength of the cardiac muscle fibers, an increase in ventricle size, and a decrease in the thickness of the blood. The stroke volumes of athletes are usually greater after training than before, which explains why they have a lower resting heart rate. They can supply the same amount of blood to their bodies by pushing more blood out of their hearts with each beat; therefore, their hearts do not need to beat as fast. For the same reasons, training will also reduce the heart rates of athletes by

10 to 15 bpm during identical submaximal swimming efforts. Training will also increase the maximum stroke volumes that athletes can attain. Maximum values may be in the range of 120 to 140 ml per beat for the untrained person, but it can increase to between 160 and 180 ml per beat after training.

Cardiac Output

The amount of blood ejected from the heart during each minute is referred to as *cardiac output*. Again, we consider only the amount ejected from the left ventricle when citing values for the cardiac output. The right ventricle will eject an equal amount of blood during the same time.

Cardiac output is calculated by multiplying the heart rate by the stroke volume. Normal cardiac output for a person at rest is between 5 and 6 L per minute (L/min). The bodies of females and males contain between 4 and 6 L of blood; therefore, each red blood cell usually makes one round-trip from the lungs to the muscles and back again in approximately 1 min when athletes' bodies are resting.

Untrained athletes can increase their cardiac output fourfold during exercise, to approximately 20 L/min. They do this by increasing their heart rates and stroke volumes during exercise. Athletes can increase their cardiac outputs even more than untrained persons can because training increases the athletes' maximum stroke volumes. During maximum exercise, the cardiac output of trained athletes will be six or seven times greater than their resting cardiac output. Consequently, each red blood cell can travel from the lungs to the muscles and back again six or seven times, instead of only once, during each minute. This greater cardiac output is important because it increases the amount of oxygen and blood glucose that the blood can deliver to the muscles during each minute and the amount of carbon dioxide and lactic acid that the blood can carry away.

Resting cardiac output does not increase with training, but the heart becomes more efficient in the way it supplies the blood. As mentioned earlier, stroke volume increases and heart rate decreases, so when a person is resting the heart does not have to work as hard to push the same 5 L of blood out to the body each minute.

Training does not increase an athlete's cardiac output during similar submaximal efforts because there is no need for it. The demand for oxygen is the same, whether trained or untrained; therefore, there is no need for larger cardiac output. A trained athlete's stroke volume will increase during submaximal efforts so that the heart will not have to beat as fast to supply the same cardiac output. For that reason a trained athlete's heart rate decreases during submaximal efforts.

Athletes can increase their maximum cardiac output by training. Maximum cardiac output values of 30 and 35 L/min are not unusual for trained endurance athletes. The box on the right lists typical resting and maximum cardiac outputs calculated for trained and untrained persons.

Typical Cardiac Output Values for Trained and Untrained Persons

Cardiac Output for Trained Athletes

At rest:
40 bpm + 125 ml/b = 5,000 ml/min or 5 L/min
During exercise:
200 bpm + 150 ml/b = 30,000 ml/min or 30 L/min

Cardiac Output for Untrained Persons

At rest:
73 bpm + 70 ml/b = 5,100 ml/min or 5.1 L/min
During exercise:
200 bpm + 100 ml/b = 20,000 ml/min or 20 L/min

The relationships between an athlete's heart rate, stroke volume, and cardiac output largely determine how rapidly blood circulates through the body. Other aspects of circulatory function are also important to the delivery of oxygen and nutrients and the removal of carbon dioxide and lactic acid during exercise. These factors are the amount of blood in the body, the number of red blood cells, the number of capillaries around the muscles and lungs, and the difference in oxygen content between the arteries and veins around working muscle fibers. In addition, the pressure of the blood and its distribution throughout the body play important roles during exercise. Consequently, the student of training should be familiar with these functions as well.

Red Blood Cells and Blood Volume

Blood is made up of *plasma* (the liquid part) and solid substances including red blood cells *(erythrocytes)*, white blood cells *(leukocytes)*, and platelets *(thrombocytes)*. Plasma, which is primarily water, makes up 55% to 60% of the total blood volume. Red blood cells, white blood cells, and platelets make up the rest. Red blood cells make up by far the greatest amount of solid material in blood, with white blood cells and platelets constituting less than 1% of the total.

Red blood cells are important because they contain *hemoglobin*, an iron-containing protein substance that binds with and transports oxygen in the blood. The iron in hemoglobin, the *heme* portion, combines with oxygen and transports it until it is released to various tissues.

An increase of red blood cells will increase the oxygen supply to muscles and increase endurance, whereas a reduction in the normal hemoglobin concentration of blood will reduce oxygen consumption and lessen endurance. A reduction in hemoglobin results in a condition known as anemia.

Research has been contradictory concerning the effects of training on red blood cells. Some studies have reported no increase, and others have reported only a small improvement during training at sea level. Training at various altitudes above sea level seems to increase hemoglobin more than training at sea level.

When the number of red blood cells increases, their hemoglobin content causes the blood to become thicker (more viscous) and more resistant to flow through the body. A slower rate of blood flow could conceivably reduce the rate of oxygen and glucose delivery during exercise. It is beneficial, then, that the fluid in blood tends to increase relatively more than its hemoglobin concentration with training. The additional fluid prevents the extra hemoglobin from thickening the blood so that a fast rate of flow can be maintained. Endurance training can increase blood volume by as much as 10% (Wilmore and Costill 1999).

Capillaries

The heart sends blood to the muscles by means of large arteries or tubes. These branch into progressively smaller groups of arteries called arterioles. Arterioles branch into even smaller end units called capillaries. These capillaries surround the tissues of the body. Those that surround muscle fibers are called, for obvious reasons, *muscle capillaries.* They bring oxygen in close proximity to the muscles, where it can diffuse into muscle fibers and be used for aerobic metabolism. These capillaries also pick up the carbon dioxide and lactic acid produced in the muscle cells and carry them away to other locations. The capillaries in the lungs are called *alveolar capillaries* because they surround the tiny air sacs, the alveoli, that are the end points of the bronchiole tubes through which air and oxygen enter the lungs. Oxygen diffuses out of the alveoli and into the blood through the capillaries so that it can be transported back to the heart and then out to the tissues of the body. Carbon dioxide diffuses out of the capillaries and into the alveoli where it can be expelled.

Training can increase the number of capillaries that surround each muscle fiber. Capillaries are quite small and will admit only one molecule of a particular substance at a time. Therefore, an increase in the number of capillaries around muscle fibers will allow the delivery of more oxygen and glucose to the muscles and the removal of more carbon dioxide and lactic acid from them during each minute of exercise.

Capillaries play an important role because they are in proximity to muscle fibers and because they slow the rate of blood flow as it passes by the muscles. Their proximity shortens the distance between blood and muscle fibers, and the slowing of the blood flow allows more time for oxygen and glucose to diffuse out of the blood and into the

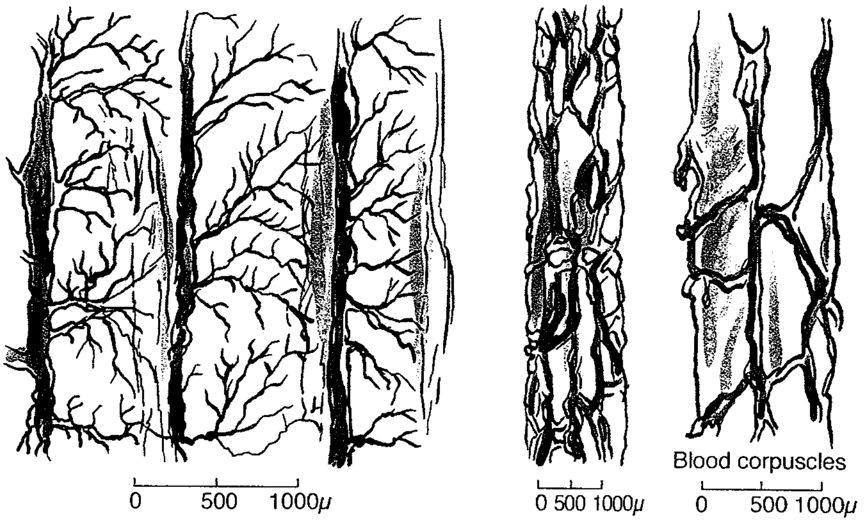


Figure 9.7 The arrangement of capillaries around muscle fibers.

muscles and for carbon dioxide and lactic acid to diffuse out of the muscles and into the blood. The blood then travels from the capillaries to larger branches called venules and finally to very large tubes called veins, which pour into the heart.

The location of capillaries around muscles is shown in figure 9.7. The three illustrations in figure 9.7a show arterioles and venules branching off common arteries and veins. The two illustrations in part figure 9.7b show the arrangement of capillaries around individual muscle fibers, with blood coming into the capillaries on the arterial side and leaving them on the venous side.

The drawing in figure 9.8 of the structure of a single capillary illustrates how capillaries can become more efficient at delivering oxygen and glucose and removing carbon dioxide and lactic acid during exercise. A preferential channel borders the capillary and serves as a direct connection between the arterial and venous circulation. A system of several smaller tubes called *true capillaries* connects the arterial and venous sides. In a body at rest, blood usually travels through the preferential channel, passing the muscle fiber quickly and giving up only a small portion of its oxygen. During exercise, an increase in blood pressure will cause blood to flow through the true capillary channels as well. This flow will put blood in proximity to more area of the muscle fiber so that more oxygen can diffuse in and fatigue-producing products can diffuse out.

Training can increase the number of capillaries around muscle fibers. A larger number of capillaries will increase the area for diffusion around each muscle fiber, allowing them to pick up more oxygen and eliminate more carbon dioxide and lactic acid.

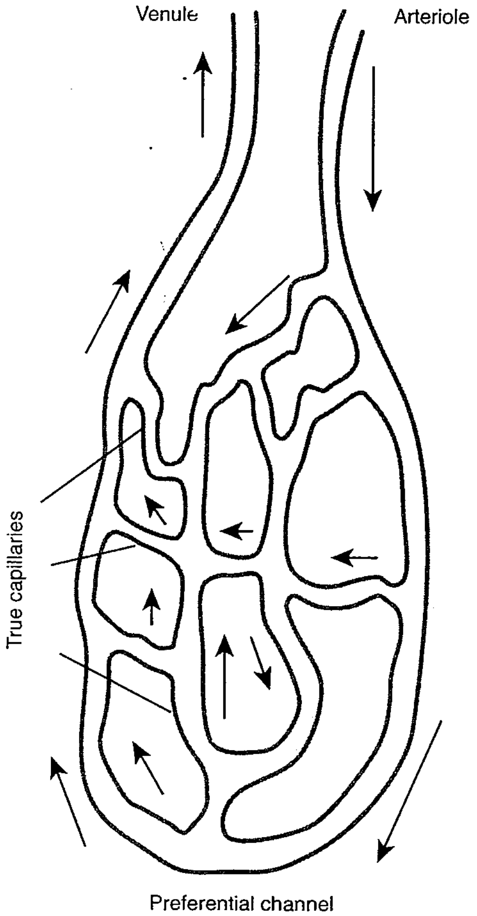


Figure 9.8 The structure of capillaries around muscle fibers.

Arterial-Venous Oxygen Difference

As I stated earlier, some of the oxygen in the blood diffuses into muscle fibers as that blood makes its way from the

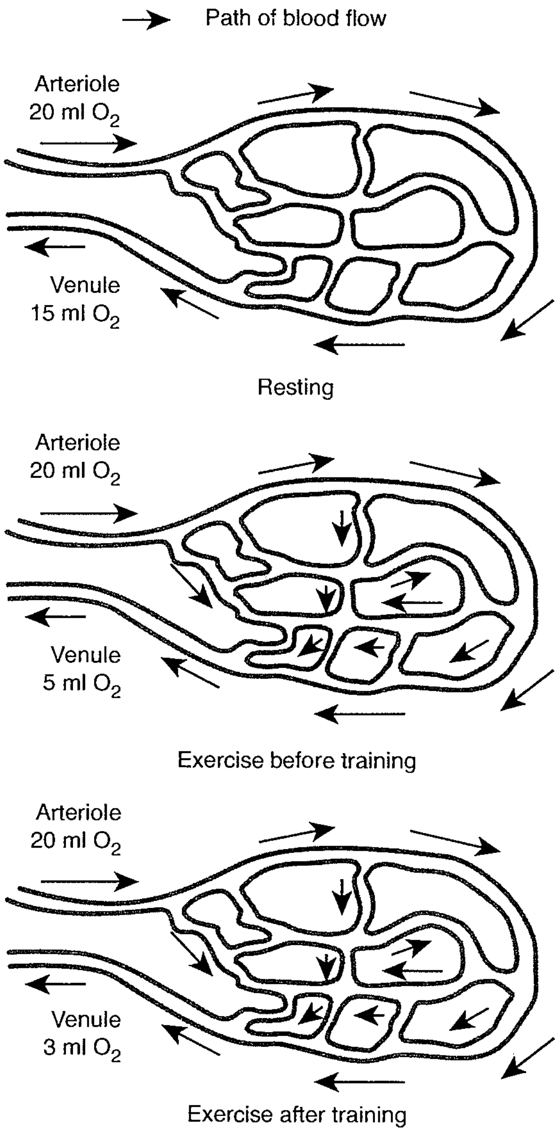


Figure 9.9 The a–v O_2 difference at rest, during exercise before training, and during exercise after training.

arterioles to the venules by way of the capillaries that surround those fibers. The difference between the oxygen content in the arterioles and the content of that same gas in the venules is, for obvious reasons, referred to as the *arterial-venous oxygen difference* (a–v O_2 diff). This measurement tells us how much of the oxygen delivered to a muscle fiber was taken in by that fiber. As mentioned earlier, the quantity of oxygen in the arterial blood when it leaves the heart is usually 20 ml of oxygen per 100 ml of blood during resting conditions. That blood usually loses between 4 and 5 ml of that oxygen to the muscles as it travels around the body so that the quantity of oxygen in the venous blood is reduced only slightly to 15 or 16 ml per 100 ml of blood during rest. The large amount of oxygen that remains in the blood provides a *reserve* that the muscles can call upon during exercise. During intense exercise as much as 15 ml of the oxygen in each 100 ml of arterial blood that reaches the capillaries may diffuse into the muscles, leaving a concentration of only 5 ml of oxygen on the venous side. This happens because exercise increases oxygen use within the muscles, which in turn lowers the pressure of that gas in the muscles so that a greater pressure differential exists between blood and muscles. Thus more oxygen diffuses from the capillaries into the muscles as the blood passes by.

Short-term endurance training (55 days) can increase the amount of oxygen delivered to the muscle by the blood by approximately 11%. In one study (Saltin 1973) the amount of oxygen extracted during intense exercise increased from 15 ml of oxygen per 100 ml of blood to 17 ml of oxygen. The reasons for this improvement probably involve both an increase in muscle capillaries and the diversion of additional oxygen-rich blood to the working muscles. The illustrations in figure 9.9 show the a–v O_2 differences at rest and during maximum exercise both before and after training.

Blood Shunting

The human body contains between 4 and 6 L of blood. At rest, the total volume is equally distributed to all tissues. During exercise, however, a greater amount of blood will be sent to the working muscles, while the supply to nonworking muscles and other tissues is reduced. For example, at rest only 15% to 20% of the total blood volume goes to the skeletal muscles, whereas during exercise that amount increases to 85% or 90% of the total (Fox and Mathews 1981). This process, termed *blood shunting*, has the effect of supplying more blood where it is needed so that more of its oxygen and other nutrients become available to working muscles and more fatigue-producing products can be carried away from them.

Blood shunting occurs because arteries that supply the working muscles dilate (expand), and those serving inactive areas of the body constrict (contract). When this happens, greater quantities of blood flow through the larger arteries where the pressure and resistance to flow is less while less blood will flow through the restricted areas. Training can improve the efficiency of blood shunting.

Blood Pressure

No discussion of the circulatory system would be complete without a description of the effects of exercise on blood pressure. Blood flowing through vessels exerts pressure on the walls of those vessels. This pressure is measured by the number of millimeters that the blood causes a column of mercury (Hg) to rise. Two measurements of pressure are needed to identify the force of blood flow: (1) the pressure when the heart beats and (2) the pressure when it is resting between beats. The pressure in vessels when the heart beats is called *systolic* because the scientific term for a heartbeat is *systole*. The pressure between beats is called *diastolic* because the rest period of the heart is termed a *diastole*. Typical resting systolic and diastolic blood pressures are 120 and 80 mm Hg, respectively.

Systolic blood pressure increases in proportion to the intensity of work because a larger amount of blood is present in the vessels at any one time. That amount of blood could increase to levels that would cause rupturing if the vessels were not elastic. They are able to stretch as more blood enters to reduce the pressure. Nevertheless, systolic pressure will rise to values in excess of 200 mm Hg when work is strenuous. That increase in pressure, however, is small relative to the 500% to 700% increase in blood flow that occurs during maximum effort. Diastolic blood pressure does not increase as dramatically because the amount of blood in the vessels subsides somewhat between beats. Under normal conditions diastolic blood pressure generally increases to only 100 or 110 mm Hg during exercise.

Endurance training reduces both systolic and diastolic blood pressure by 6 to 10 mm Hg at rest and by an equal amount during submaximal exercise. This reduction in pressure probably occurs because the elasticity of blood vessels increases through constant expansion and constriction that occurs in training.

Over the years many researchers have attempted to predict athletic success and monitor the effects of exercise and training with blood pressure measurements. Carlile (1963) reported that swim training caused an average increase of 10 mm Hg in resting systolic blood pressure and a decrease of 5 to 9 mm Hg in resting diastolic blood pressure. The reason for the increase in systolic blood pressure was difficult to interpret, but the author believed it might have reflected an increased stroke volume during each heartbeat that was out of proportion to the improved elasticity of the blood vessels. Therefore, a net increase in blood pressure occurred each time the heart would beat. The decrease in diastolic blood pressure was easier to understand. The decrease probably reflected the increased elasticity of the blood vessels, which reduced the pressure in them when the heart was not beating. Most of the increases in systolic and decreases in diastolic blood pressures took place during the first 6 weeks of training.

Other experts have suggested that sudden unexplained elevations in both resting systolic and diastolic blood pressures may be associated with overtraining (Costill 1986). These increases may be a sign that vessel elasticity decreased or did not keep pace with the increased blood flow during exercise.

Despite these observations, blood pressure measurements have not been particularly reliable for measuring responses to exercise and training. Blood pressure responses to exercise and training seem to vary considerably from person to person and, therefore, have not been particularly reliable indicators of performance (Cureton 1951; Costill 1967).

Respiratory System

The two primary purposes of respiration are to provide our bodies with oxygen and to remove carbon dioxide. This process makes life possible. We could not live more than a few minutes without oxygen. A lesser-known but almost equally important function of respiration is to regulate the acid-base balance of the blood.

The respiratory system consists of the lungs and a set of branching tubes that transport air and oxygen from outside the body to the bloodstream. During inhalation we take air from the outside into the mouth and nose, down the pharynx or throat, and into each lung by means of two large tubes called the *bronchi.* Within the lungs air travels through an ever smaller system of branching tubes called *bronchioles* until these finally end as small sacs called *alveoli.* Capillaries surround the alveoli. Figure 9.10 illustrates the anatomy of the respiratory system.

The inhalation phase of respiration allows us to take in oxygen as a component of the air that comes into our bodies. Some of that oxygen remains in our bodies when we exhale the air. With the air we expel during the exhalation phase, we also expel carbon dioxide and some water vapor that our bodies produced.

We take in air through the nose and mouth. It travels down the pharynx through the bronchi, the bronchioles, and lastly to the alveoli, where it inflates these small elastic sacs. From there, some of the oxygen in that air diffuses from the alveoli into the bloodstream by way of the pulmonary capillaries. At the same time, carbon dioxide produced in the muscles diffuses in the opposite direction, that is, out of the capillaries and into the alveoli. The carbon dioxide is then transported through the bronchioles and finally exhaled into the air from the nose and mouth.

The term for the amount of air exchanged per breath is the *tidal volume.* The amount of air exchanged per minute is termed the *minute volume.* Average tidal volume is between 500 and 700 ml of air per breath, and we breathe 12 to 15 times per minute. The average minute volume is thus 6 to 10 L of air.

With training, athletes tend to adopt a breathing rate that provides the greatest minute volume with the least breathing effort during submaximal exercise. They learn how to

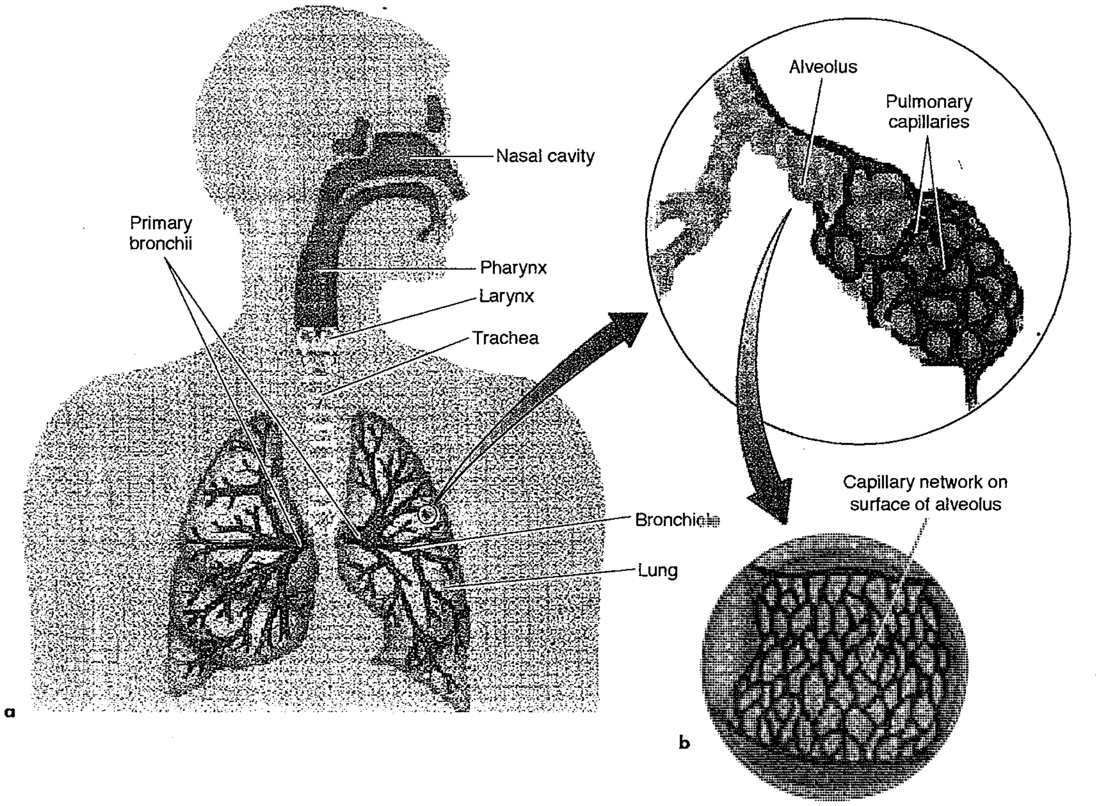


Figure 9.10 *(a)* The anatomy of the respiratory system. *(b)* An enlarged view of the alveolus, showing the regions of gas exchange between the alveolus and pulmonary blood in the capillaries.

Reprinted from Wilmore and Costill 1999.

adjust the relationship between their breathing rate and tidal volume naturally with exercise and do not require any special training that involves deep-breathing exercises or restricted-breathing drills to accomplish this purpose. They learn to breathe more slowly and deeply during exercise but not so slowly and deeply that they increase the work of breathing unnecessarily. Swimmers learn this skill particularly well because they must regulate their breathing to match their stroke rhythms.

The air we breathe is made up of 21% oxygen and 79% nitrogen, with a negligible amount of carbon dioxide (0.03%). At rest, we inhale and exhale between 7 to 9 L of air during each minute. Because 21% of that air is oxygen, we take between 1.5 and 1.9 L of oxygen into our bodies each minute. However, we only extract between 0.25 and 0.30 L of that amount for use in our bodies. We exhale the rest along with the carbon dioxide that diffused into our lungs from the bloodstream.

Oxygen Consumption and Swimming Performance

Oxygen consumption refers to the amount of oxygen used during exercise. That amount is equal to the amount of oxygen taken in during exercise minus the amount exhaled. Oxygen consumption is usually expressed according to the number of liters or milliliters of oxygen used by the body during each minute of exercise. For example, if a person inhales 10 L of oxygen and exhales 6 L in 1 min, oxygen consumption would be 4 L per minute.

The amount of oxygen used by the muscles each minute will be directly related to the intensity of the exercise until a maximum rate is reached. That maximum rate will be between 2 and 3 L per minute for average nonathletic females and males, respectively. The rate can be as high as 4 to 6 L per minute for female and male endurance athletes. The term for the maximum amount of oxygen that a person can take in during 1 min of exercise is *maximal oxygen consumption,* more commonly referred to as *$\dot{V}O_2max$.* Values for $\dot{V}O_2max$ are a direct expression of a person's ability to supply energy for muscular contraction through aerobic metabolism. The relationship between oxygen consumption and performance in endurance events is so important that we must discuss it in detail.

Maximal Oxygen Consumption

We calculate maximal oxygen consumption, $\dot{V}O_2max$, by measuring oxygen consumption during repeated intervals of exercise at progressively faster speeds until the athlete reaches a plateau where a further increase of speed does not cause an increase in oxygen consumption. When that happens, the athlete has reached his or her maximum ability to consume oxygen.

One aspect of $\dot{V}O_2max$ difficult for many people to understand is that athletes will reach it when they are swimming slower than their maximum speed. Athletes can continue to increase their speed even after they have reached their maximum ability to consume oxygen because of their capacity for anaerobic metabolism. Anaerobic capacity makes it possible for them to continue supplying energy to their muscles even though not enough oxygen is available to metabolize the chemical sources of that energy. They will only be able to do this for a short time, however, because the chemicals that were not completely metabolized, principally lactic acid and more specifically the hydrogen ions in that compound, will accumulate in the muscles and change their pH from neutral to acidic, which will slow the speed and force of muscular contraction and in the process slow the swimming speed.

During submaximal exercise, oxygen consumption will increase from its resting rate of approximately 0.25 L/min to some level that will sustain the contractile energy needed by the muscles. It will usually take between 1 and 3 min to reach this level of increased oxygen consumption because the need for additional oxygen must first be created in the muscles before the respiratory and circulatory adjustments that will deliver more of this gas can occur.

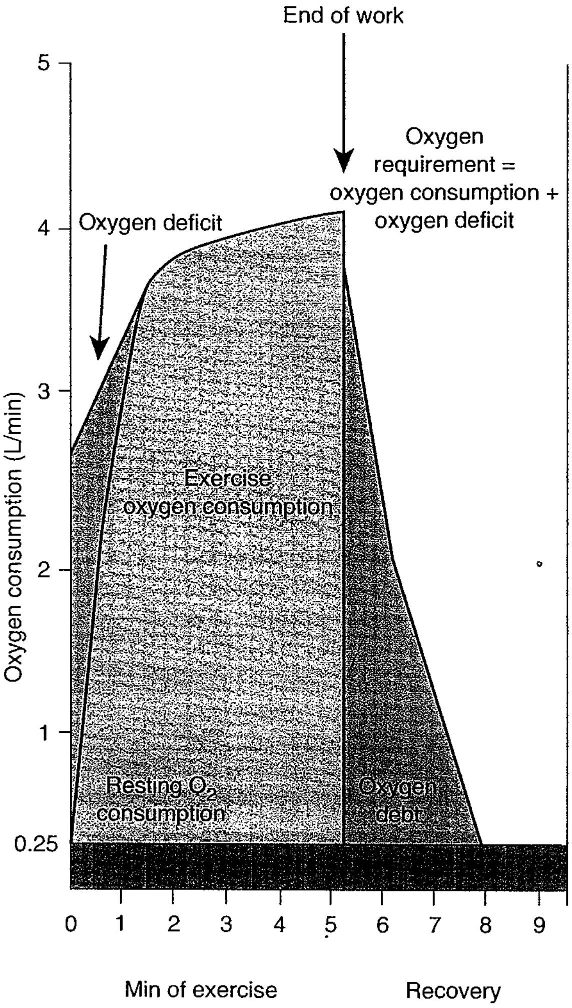


Figure 9.11 Results of a typical test of maximum oxygen consumption.

An *oxygen deficit* occurs during this period of adjustment. The oxygen deficit represents the oxygen that was needed but not available during the first few minutes of exercise. The athlete can repay the deficit during the remainder of the exercise if the intensity of work is low. To repay the deficit, the body can make available for a short time more oxygen than it needs to provide energy for work. The amount of oxygen consumed during the exercise period plus the oxygen deficit is termed the *oxygen requirement* for the task at hand.

If the demand for oxygen exceeds the amount that the athlete can repay during exercise, it will continue to build. The athlete will repay it after exercise by maintaining a high level of oxygen consumption for a short period. This period of additional oxygen consumption after exercise has become known as the *oxygen debt.* Although this term is in common use by members of the sporting community, it has become obsolete in the scientific community because sophisticated evaluation techniques have shown that the increased consumption of oxygen after exercise does not correspond directly to the oxygen deficit that occurred in the first few minutes of exercise. I will discuss recent interpretations of the oxygen debt concept later in this chapter. For now, I want to return to a discussion of oxygen consumption.

The graph in figure 9.11 shows a typical pattern of oxygen consumption during exercise. Once exercise begins, the amount of oxygen consumed increases during the first 2 min of work until it reaches a level that supplies the oxygen the athlete needs to perform the work. The graph also shows the oxygen deficit that occurred during those minutes. Notice, however, that the oxygen deficit continues to grow throughout the exercise period because more oxygen was needed than could be supplied. In this case, the *oxygen requirement* of the exercise was in excess of 5 LO_2/min of work, whereas the maximum amount of oxygen that the athlete could consume was slightly less than 4 LO_2/min. The repayment of the oxygen deficit produced during the task is represented, in part, by the additional amount of oxygen consumed after exercise, which for now we will term the oxygen debt.

Oxygen consumption can be misleading when reported in liters per minute because that measure is biased toward large persons. Large athletes will usually have higher $\dot{V}O_2$max levels than smaller athletes simply because their large lungs allow them to exchange more air and thus more oxygen with each minute of exercise. Of course, larger bodies require more oxygen. For this reason, oxygen consumption is also reported according to the amount available for each kilogram of body weight. This relative method of expressing oxygen consumption provides a representation of oxygen supply unbiased by size.

With the relative method, oxygen consumption is expressed according to the number of milliliters of oxygen a person can consume per kilogram of body weight during each minute of exercise (ml/kg/min).

Average values for relative $\dot{V}O_2$max are 40 and 46 ml/kg/min for untrained women and men, respectively. World-class female and male swimmers have been tested as high as 66 and 80 ml/kg/min, respectively (Van Handel et al. 1988). The highest value recorded for a female athlete was 74 ml/kg/min, for a Russian cross-country skier. The highest value recorded for a male athlete was 94 ml/kg/min, for a Norwegian cross-country skier (Wilmore and Costill 1988).

Methods of Measuring $\dot{V}O_2max$ To reflect an athlete's aerobic capacity accurately, tests of $\dot{V}O_2$max should be conducted in the athlete's sport. Runners should be evaluated by running, cyclists by cycling, and swimmers by swimming. Tests that involve other activities will yield false results.

Measuring the maximum oxygen consumption of swimmers in a swimming pool is not a simple procedure. The swimmer must wear a mask over the mouth and nose. The mask is connected to a two-way valve so that the swimmer takes air in from the atmosphere through one valve and exhales air into a collecting device through the other valve. A long hose must extend from the face mask to the collecting device on the deck of the swimming pool. The collecting device must be moved back and forth on a cart in time with the swimmer. The hose must not be placed under strain or become tangled. The swimmer must also perform some artificial skills. The athlete cannot turn the head to breathe and must do open turns at the ends of the pool and gentle surface push-offs to keep the hose from becoming tangled. The quantity of air the swimmer exhales into the collecting device must be measured accurately, and its oxygen content must be calculated with great precision. Both procedures are fraught with potential error.

An easier method for measuring oxygen consumption is to conduct the test while the athlete is swimming in a swimming flume. The athlete and collecting equipment can remain stationary, which makes collection and gas measurement much easier to accomplish. The photo in figure 9.12 shows a swimmer being tested for oxygen consumption in a swimming flume at the USA Swimming Center for Aquatic Research.

Measures of oxygen consumption taken in flumes and with movable carts have been criticized for producing false results. Detractors feel that swimming with the mask and tubes will increase the workload so that swimmers consume more oxygen at a given speed than they would when swimming without the equipment. They also argue that the equipment may inhibit performance and prevent the athlete from reaching true maximum levels of oxygen consumption. In this respect, tests in a swimming flume should produce less error than those taken during actual swimming. Nevertheless, concern remains that the use of a mask and collecting tube will produce false measurements in the swimming flume.

Another procedure developed to reduce these sources of error involves estimating an athlete's oxygen consumption during a swim from oxygen collected immediately after the swim ends (Costill et al. 1985; Montpetit et al. 1981). This method does not require masks or hoses, so athletes can swim and turn normally during the work period. Immediately after finishing a swim, an athlete must hold his or her breath while a mask is put in place. The swimmer then exhales into a collecting device for 20 sec. After collection, the amount of air and the amount of oxygen in that air are determined. The value for oxygen consumption is extrapolated backward to the last minute of the swim and is presumed

Figure 9.12 A photo of an athlete being tested for oxygen consumption in the flume at the USA Swimming Center for Aquatic Research, Colorado Springs, Colorado.

to be equivalent to the athlete's rate of oxygen consumption per minute during the swim. This test can be repeated several times at progressively faster speeds until the athlete's maximum rate of oxygen consumption has been determined.

Critics of the backward extrapolation method believe that the potential for error is too great when measurements are taken from such small samples of air immediately after a swimming effort. They emphasize that a time mismeasurement of 0.1 sec or a mistake of just a few milliliters in the amount of air collected could skew the results considerably. Despite these criticisms, research indicates that immediate postexercise collection of expired air for 20 sec in the field produces results very similar to those of continuous measurements of $\dot{V}O_2$max (Carre et al. 1994). Costill and associates (1985) have used this backward extrapolation procedure with swimmers and found it more practical and accurate than collecting expired air with a moving cart.

$\dot{V}O_2$max and Work Intensity Scientists frequently use $\dot{V}O_2$max measurements to equate the intensity of exercise within and between groups of subjects. They speak in terms of work being performed, for example, at a speed that elicits oxygen consumption that is 70% of a person's $\dot{V}O_2$max. By doing so, they can quantify the level of effort relative to each person's individual maximum oxygen consumption and provide a more accurate representation of the work intensity. This method of standardizing workloads is excellent for scientific purposes, but it has limited value for coaches. We seldom know the $\dot{V}O_2$max of our swimmers and almost never know how much oxygen they are consuming during training. We prefer instead to refer to efforts subjectively as a percentage of maximum. To help equate the two, information from studies in which work intensity has been reported as a percentage of $\dot{V}O_2$max can be translated to percent efforts as follows:

1. Efforts of 50% to 60% of $\dot{V}O_2$max are probably equivalent to subjective feelings that the effort is 30% to 40% of maximum.
2. Efforts of 70% to 90% of $\dot{V}O_2$max are probably equivalent to subjective feelings that the effort is 60% to 80% of maximum.
3. Efforts of 100% of $\dot{V}O_2$max are probably equivalent to subjective feelings that the effort is 80% to 90% of maximum.
4. Efforts of 90% to 100% of maximum are probably equivalent to values that are between 110% and 130% of $\dot{V}O_2$max.

The distance of swimming repeats has a considerable effect on these crude estimates. During short repeats the athlete may sense a lower percentage of maximum effort than the actual percentage of $\dot{V}O_2$max at which he or she is swimming because the duration of the swimming will not cause intense fatigue. Subjective feelings of percent effort will correspond more closely to the percentage of $\dot{V}O_2$max I indicated when the repeats are longer.

Heart rates, if counted correctly and interpreted properly, can provide a more accurate method than subjective percentages of maximum effort for estimating the percentage of $\dot{V}O_2$max during work. For most athletes who have been training for several weeks, a heart rate between maximum and 10 beats less than maximum usually corresponds to a swimming speed that will produce a value for oxygen consumption that is 100% of maximum. Heart rates 15 to 20 beats below maximum correspond to speeds that will result in levels of oxygen consumption that are between 85% and 90% of maximum. Heart rates 25 to 30 beats below maximum generally represent swimming efforts that require persons to consume oxygen at 70% to 80% of their maximum rate, and heart rates 40 to 60 beats below maximum correspond to rates of oxygen consumption between 50% and 60% of maximum. I must caution that these heart rates are only estimates of the effort required to produce a certain percentage of maximum oxygen consumption.

$\dot{V}O_2max$ and Performance Although a person can improve $\dot{V}O_2max$ by training, research shows that heredity sets limits on the amount of improvement each person can achieve. Studies have shown that identical twins have almost identical maximal oxygen consumption capacities (Bouchard 1990; Klissouras 1971). Athletes can generally improve their absolute maximum oxygen consumption values in L/m by 15% to 20% and their relative values in ml/kg/min of body weight per minute by 20% to 40%.

For many years, the capacity to consume oxygen maximally was considered the most valid measure of an athlete's ability to perform in endurance events. We believed that a person who could supply more oxygen to his or her body during every minute of exercise would be able to get more energy from aerobic metabolism. Thus, the person would fatigue at a slower rate because he or she was less dependent on anaerobic metabolism. We believed that a large $\dot{V}O_2max$ would provide an athlete with a distinct advantage in endurance events and, for that reason, endurance training emphasized improving this physiological measure. It was true that improving $\dot{V}O_2max$ would improve endurance performance, but we discovered that it was only one of many physiological mechanisms that could do so. Consequently, although many researchers have reported a reasonably strong relationship, 0.75 to 0.80, between $\dot{V}O_2max$ and performance in endurance events, persons who are able to consume large quantities of oxygen during races do not always defeat those with smaller maximum consumption rates. Other factors are also involved, one of which I will discuss in the next section.

Percentage Utilization of $\dot{V}O_2max$

In recent years another measurement of oxygen consumption has proved to be more predictive of performance in endurance events than $\dot{V}O_2max$ (Sjodin and Jacobs 1981; Bishop, Jenkins, and MacKinnon 1998). That measurement is the *fractional percentage of maximum oxygen consumption (%$\dot{V}O_2max$).* It refers to the highest rate of work that a person can perform for a long period, that is, 20 to 40 min, without becoming fatigued. The rate is designated by the percentage of a person's maximum oxygen consumption ability it produces. It is determined by measuring an athlete's oxygen consumption during a maximum effort swim of 20 to 40 min and then determining what fraction of the athlete's maximum oxygen consumption rate it represents. For example, let us assume an athlete has the ability to consume oxygen at a maximum rate of 70 ml/kg/min. If the highest rate of oxygen consumption that the person can maintain for a long time without becoming fatigued is 60 ml/kg/min, then the person is able to work at 85% of $\dot{V}O_2max$.

For untrained persons, the highest fractional utilization of $\dot{V}O_2max$ that will not cause fatigue is usually between 50% and 70% of maximum. Training can improve this value to between 75% and 90% of maximum. As with $\dot{V}O_2max$, heredity seems to play a role in determining the highest percentage of maximum that athletes can reach. A more common term used to identify the highest fractional utilization of $\dot{V}O_2max$ that can be maintained for a long period is the *anaerobic threshold* (Wasserman et al. 1973).

This terminology was unfortunate because it suggests that anaerobic metabolism does not begin until a person has exceeded a particular percentage utilization of $\dot{V}O_2max$. In fact, anaerobic metabolism begins at the onset of exercise and continues until it ends. The anaerobic threshold does not indicate the rate of work at which anaerobic metabolism begins. Instead, it represents a manageable level of anaerobic metabolism that a person can sustain for a long period without experiencing severe fatigue. At that rate, oxygen consumption and other aerobic mechanisms are sufficient to oxidize most of the energy-liberating substances in muscles; therefore, lactic acid is produced at a slower rate and fatigue is delayed. I will explain this process more thoroughly in the next chapter.

You might be wondering why an athlete cannot work for a long period at 100% of $\dot{V}O_2max$. A common, but erroneous, belief is that people do not become fatigued until they exceed their maximum rates of oxygen consumption because they do not begin to produce lactic acid until their oxygen supply has peaked but is no longer adequate to meet their energy needs. As I indicated in the previous paragraph, however, they will be producing lactic acid long before they reach a work level that corresponds to 100% of $\dot{V}O_2$max. This occurs for several reasons. For one, it takes some time to stimulate oxygen consumption to maximum, and the athlete's oxygen supply will be inadequate until that happens.

Athletes will not be able to consume oxygen at a maximal rate until they have stimulated to the greatest extent possible all the respiratory, circulatory, and muscular mechanisms that participate in the delivery of oxygen. That usually does not happen until they have completed 1 to 2 min of a race and until they have accumulated some lactic acid in their muscles and blood (Serresse et al. 1988).

A second reason is that the rate of work required to stimulate the circulatory and muscular reactions that result in a maximum rate of oxygen consumption requires more energy than oxidation alone can supply. Therefore, those work rates produce an oxygen deficit, causing lactic acid to accumulate in the muscles.

Advantages of Increasing %$\dot{V}O_2$max Most athletes can only maintain speeds that require them to consume oxygen maximally for 1 to 3 min of continuous effort before they are forced to slow their pace because of fatigue (Hill and Rowell 1997). In long races and long training sets, athletes must select speeds that require less than a maximum rate of oxygen consumption so that they do not accumulate too much lactic acid in their muscles too early. For example, most runners can complete a marathon (42 km, or 26.2 mi) at an average pace that requires them to use 75% to 80% of their maximal oxygen consumption capacity. You should be able to understand now why the ability to use a larger fraction of $\dot{V}O_2$max in these races would be a decided advantage. Athletes who can train themselves to use 85% to 90% of $\dot{V}O_2$max without becoming fatigued should be able to run their long races at a faster average pace.

The ability to compete at a higher percentage of $\dot{V}O_2$max should also be advantageous in shorter events. In middle distance and distance swimming races, the pace at which athletes must compete always exceeds the pace that would produce maximum oxygen consumption. Let us assume that two athletes with identical maximum oxygen consumption ability are swimming a race that requires each of them to work at a rate equivalent to 130% of $\dot{V}O_2$max. Let's assume also that one athlete is able to work at 85% of $\dot{V}O_2$max without becoming fatigued whereas the other can work at only 80% of $\dot{V}O_2$max without becoming fatigued. It should be easy to see that the athlete who can swim closer to 100% of $\dot{V}O_2$max will be producing less lactic acid at race pace and should therefore be able to maintain that pace longer.

Athletes with a smaller $\dot{V}O_2$max can sometimes excel over competitors who have larger values through their ability to compete at a higher percentage of maximum. For example, Alberto Salazar, former world-record holder in the marathon, had a $\dot{V}O_2$max of 70 ml/kg/min, which was lower than that of many of his competitors. But he was able to run the marathon at a pace that used 86% of his maximum, a much higher percentage utilization of $\dot{V}O_2$max than most athletes can sustain for that distance. This circumstance probably explains why he was able to defeat his competitors and set a world record. The calculations in the box on page 343 illustrate how a swimmer with a smaller $\dot{V}O_2$max could maintain a faster pace in a distance race than a teammate who has a larger $\dot{V}O_2$max.

If both swimmers were similar in stroke efficiency, swimmer A would have a definite advantage in any race that has an oxygen requirement of 48 ml/kg/min or greater because swimmer A can release more energy through aerobic metabolism and thus should be able to maintain a faster pace without becoming fatigued.

The results of several research studies suggest that the ability to use a greater percentage of $\dot{V}O_2$max than one's competitors has a strong relationship to performance in middle distance and distance races, and even in races as short as 100 m. In a study with runners (Sjodin 1982) the relationship between a measure of the percentage utilization of $\dot{V}O_2$max and performance was very high, 0.86, for a 400 m run, a race that corresponds to 100 m in swimming. A 400 m run requires 44 to 60 sec for most people, which is in the same time frame as 100 yd and 100 m swimming races. The relationship between %$\dot{V}O_2$max and performance was 0.90 for a 1,000 m run, which requires approximately the same time as swimmers need to complete 200 m.

Comparison of Percentage Consumption of Oxygen for Two Swimmers With Different $\dot{V}O_2$max Values

Swimmer A

$\dot{V}O_2$max = 60 ml/kg/min

Swimmer A can swim at 92% of maximum without becoming fatigued; therefore, swimmer A can consume oxygen at a rate of 55.2 ml/kg/min.

60 × .92 = 55.20

Swimmer B

$\dot{V}O_2$max = 65 ml/kg/min

Swimmer B can swim at 75% of maximum without becoming fatigued; therefore, swimmer B can consume oxygen at a rate of only 48.75 ml/kg/min.

65 × .75 = 48.75

As I indicated, training can improve by 20% to 30% the percentage of maximum oxygen consumption that a person can use without becoming fatigued. But some people believe that the percentage utilization of oxygen and maximum oxygen consumption are so closely linked that they cannot be considered separate physiological phenomena. In other words, an increase in the percentage utilization of $\dot{V}O_2$max cannot occur without a concomitant increase in maximum oxygen consumption (Saltin 1973). The results of a study by Hurley and associates (1984), however, demonstrated that %$\dot{V}O_2$max could be increased without also increasing maximum oxygen consumption. In their study the %$\dot{V}O_2$max required to produce a blood lactate concentration of 2.5 mmols/L increased with training whereas maximum oxygen consumption did not. Before training, an exercise intensity that caused a rate of oxygen consumption that was 65% of maximum resulted in a blood lactate concentration of 2.5 mmols/L. After training, a work intensity requiring 75% of $\dot{V}O_2$max was required to produce that same blood lactate concentration.

These results demonstrate that the percentage of maximum oxygen consumption that a person can use during exercise can improve independently of improvements in $\dot{V}O_2$max. The primary reason for an improvement in %$\dot{V}O_2$max without a corresponding increase in maximum oxygen consumption could have something to do with the rate at which lactic acid is being removed from the muscles and blood after training. If lactic acid was being removed at a faster rate after training, athletes could work at a rate closer to one that requires $\dot{V}O_2$max without producing acidosis. With no change in $\dot{V}O_2$max, a higher rate of work would cause the production of more lactic acid in the muscles. But if that lactic acid was being removed faster, it would not remain in the muscles where it could cause fatigue. Thus, training that increases the rate of lactic acid removal from muscles may be just as valuable, if not more valuable, for improving endurance than training that increases maximum oxygen consumption during exercise. I will discuss this topic more thoroughly in chapter 13 of this book.

Determining the Anaerobic Threshold The highest percentage of maximum oxygen consumption that a person can maintain for a long period without becoming fatigued has been termed the anaerobic threshold. A more accurate term is the *respiratory anaerobic threshold*, or simply the *respiratory threshold*. To determine the respiratory threshold, oxygen consumption must be measured during exercise. Taking this measurement is a complex, difficult procedure. Consequently, Mader and his associates (Mader, Heck, and Hollmann 1976) developed another method for determining the anaerobic threshold, which involved measuring the lactic acid content of blood samples taken after various intensities of exercise. Because it provides an easier way to calculate the anaerobic threshold, this method is used more frequently in the training of athletes, including swimmers, than are measures involving oxygen consumption. I will have much more to say about determining the anaerobic threshold with blood measurement in chapter 16 on monitoring training.

Respiratory and blood determinations of the anaerobic threshold have much in common, but they are not identical. They are supposed to measure the same thing, but training speeds that correspond to the respiratory threshold are not always the same as the anaerobic threshold speeds that have been calculated from blood measurements. Despite these discrepancies in measurement, the concept of the anaerobic threshold is a valid one that has a great deal of meaning for the training process. The next set of chapters will discuss that meaning in more detail.

New Thoughts on the Oxygen Debt

At one time oxygen debt was the most popular concept in exercise physiology. Nobel Prize scientist A.V. Hill originated the term. Oxygen debt was identified as the additional oxygen consumed after exercise over and above the amount that would normally have been consumed at rest. The explanation for oxygen debt was that it occurred when the oxygen requirement of a particular bout of exercise exceeded the amount of oxygen that the athlete could consume during the performance of the exercise. Therefore, athletes breathed faster and deeper for a time after finishing the exercise to provide (to pay back) the additional oxygen their bodies needed but were not able to take in during the exercise. The belief was that the additional oxygen repaid the oxygen deficit produced by anaerobic metabolism during the exercise. Figure 9.11 (page 338) illustrates the concept of the oxygen debt as extra oxygen consumed during the recovery period following exercise.

Although this was an attractive theory to explain the deep and rapid breathing that continued after athletes had completed work, research never validated it. The additional amount of oxygen consumed during recovery did not equate with the oxygen deficit. In fact, it was generally greater than the calculated oxygen deficit because metabolizing lactic acid after exercise required more energy than was required to produce it during the exercise (Vandewalle, Peres, and Monod 1987). Several studies have shown that the oxygen debt is 50% to 100% larger than the oxygen deficit (Bangsbo et al. 1990; Hughson 1984; Powers et al. 1987; Rose et al. 1988).

We now understand that the extra oxygen consumed after exercise does not entirely represent the repayment of a debt incurred during the exercise. For this reason, scientists have suggested other terms for the additional oxygen consumed during recovery. One of these terms is *excess post-exercise oxygen consumption (EPOC)*. A simpler term is *recovery oxygen uptake*, a term I will use in this book.

To this point, no one has been able to provide a complete explanation of the role of recovery oxygen uptake in energy metabolism. Several possible explanations have been offered, however, and I will detail these in the next few paragraphs.

Typically, recovery oxygen uptake has fast and slow components. About half of the total amount of excess oxygen consumed during recovery will take place within 30 sec to 3 min after completion of the exercise, depending on the length and intensity of the exercise. This portion is termed the *fast component* for obvious reasons. At one time, the fast component was believed to represent the oxygen needed to replace the ATP and CP depleted during exercise. However, Bangsbo and coworkers (1990) demonstrated that no more than 20% of the fast portion of recovery oxygen uptake could be attributed to this process. Since this discovery, several other mechanisms have been proposed for the remainder of the recovery oxygen uptake. One possibility is that it represents the oxygen needed to replace the amount stored in muscle mitochondria and blood hemoglobin before exercise. Another is that it is a normal reaction of the respiratory system to exercise in that the respiratory rate will remain elevated until all the additional carbon dioxide produced during exercise has been removed from the person's body.

The slow portion of recovery oxygen uptake refers to the slightly elevated breathing rate that can continue for several minutes or even several hours after exercise. Several explanations have also been provided for this phenomenon. One is that the additional oxygen is probably used to metabolize the lactic acid produced during exercise. Another is that an increase of body temperature keeps the respiration rate elevated. Body temperature increases during intense exercise and does not return to normal for some time afterward. A person's respiration rate may remain elevated until body temperature returns to normal. Still another explanation has to do with the secretion of hormones. Intense exercise causes a large increase in the secretion of certain hormones, particularly *norepinephrine* and *epinephrine* (adrenaline) during exercise. Perhaps the respiration rate remains elevated until the blood concentration of those hormones returns to normal.

Second Wind and Stitch in the Side

Athletes always have questions about second wind and stitch in the side. A brief discussion of each follows.

Second Wind

A feeling of relief that occurs during strenuous exercise is known as *second wind.* Labored breathing becomes easier and painful work becomes tolerable after athletes experience a second wind. We currently have no definitive explanation for this phenomenon, but the following explanation is most frequently advanced. The distress athletes feel during the early stages of exercise may be associated with a temporary increase in the rate of anaerobic metabolism. This condition continues until oxygen consumption increases and aerobic metabolism provides a larger percentage of the energy for work. Once that happens, the rate of anaerobic metabolism slows and the athlete experiences a feeling of reduced effort.

The fact that second wind only occurs during endurance efforts offers some support for this explanation. In addition, athletes generally experience the sensation of second wind only when they are just beginning a training program after a long layoff. Well-trained athletes rarely experience this phenomenon, probably because their respiratory and circulatory systems adjust more rapidly after they become conditioned.

Stitch in the Side

During exercise, athletes sometimes experience a sharp pain in the side, just underneath the lungs, referred to as a *stitch in the side.* Although no scientific proof is available to explain the reasons for a stitch in the side, the popular theory is that it is caused by a temporary lack of oxygen that takes place in the diaphragm or intercostal (breathing) muscles during endurance efforts. That oxygen deficiency is believed to occur because the circulatory and respiratory systems cannot adjust rapidly enough to the increased demand for oxygen during exercise. Like second wind, stitches in the side are usually experienced by athletes who are poorly conditioned. They no longer occur after athletes become trained. Like second wind, the stitch in the side probably disappears because training increases the rate of adjustment of the respiratory and circulatory systems to exercise.

Do Deep-Breathing Exercises Improve Performance?

The act of inhaling and exhaling air provides oxygen and removes carbon dioxide, so respiration is extremely important to exercise. Despite this, athletes and coaches do not need special deep-breathing drills to improve this exchange of air. Adaptations that improve respiratory function during endurance and sprint races occur as a by-product of all the other training procedures that athletes engage in. Special training will not improve them further. Additionally, the respiratory system does not limit the exchange of oxygen and carbon dioxide during exercise. Even in moderately trained athletes, more oxygen is available to the blood than it can carry. Evidence for this is that a large portion of the oxygen taken into the lungs is expired before it leaves them. The factors that limit an athlete's ability to consume oxygen take place in the circulatory and muscular systems, not the respiratory system. Consequently, performing deep-breathing exercises to increase tidal volume has no real value. Although many athletes practice deep-breathing exercises, such exercises will not improve vital capacity, and even if they did they would not improve performance.

Role of Hormones in Training and Competition

Hormones are chemical substances produced in the endocrine glands. The endocrines are ductless glands that secrete their hormones directly into the bloodstream. The hormones they produce are poured into the blood and transported throughout the body to tissue receptor sites where they can serve a large number of purposes. Cells contain between 2,000 and 10,000 receptor sites where specific hormones can attach themselves and perform their functions. Of particular concern to coaches and athletes are the functions involved with (1) enhancing the energy supply during exercise and (2) replacing that energy during recovery.

Hormones do not pour into the blood at a constant rate. They are released in bursts when stimulated by certain events. The autonomic (unconscious) nervous system largely regulates the secretion of hormones. The autonomic nervous system has two parts, known as the *sympathetic* and *parasympathetic* nervous systems. The sympathetic nervous system regulates energy mobilization for exercise through the well-known *fight-or-flight* reaction. The parasympathetic system governs the replacement of fuels during recovery. The most prominent hormones and their functions are listed in table 9.2.

A negative feedback system regulates the secretion of hormones. That is, the secretion of a particular hormone will cause some specific change in the body, which in turn inhibits the secretion of that hormone. For example, when the concentration of blood glucose is higher than normal, the pancreas will release insulin. Insulin increases the movement of glucose out of the blood and into the cells of the body. When glucose leaves the blood and enters the cells, the blood glucose level drops, inhibiting the release of additional insulin. When blood glucose levels increase again, more insulin is secreted and the process begins again.

Hormonal Responses During Exercise

Hormones play important roles in providing energy to the muscles and nerves. They are also involved in replacing that energy. In addition, they play roles in repairing and building tissues. The following are some of the most important functions that hormones perform for athletes.

Endurance work increases the use of glucose by muscles. The following hormones facilitate the use and replacement of muscle glucose. An increase in secretion of the hormone glucagon facilitates the movement of glucose from the liver to the blood, which carries it to the working muscles. The hormones epinephrine (adrenaline) and norepinephrine are also secreted in additional amounts. They aid in the movement of liver glucose to the blood. Secretion of another hormone, *cortisol*, facilitates the conversion of liver glycogen to glucose. As mentioned previously, an increased secretion of the hormone insulin is directly involved in transferring blood glucose into working muscle fibers.

The hormones cortisol, epinephrine, norepinephrine, and growth hormone also facilitate the conversion of triglycerides that are stored in the liver to free fatty acids and glycerol that the blood can carry to the muscles. There the free fatty acids can be used for energy.

The hormones secreted by the adrenal gland have received the most attention from athletes and coaches. Epinephrine and norepinephrine, known collectively as the *catecholamines*, are responsible for the fight-or-flight mechanism. They stimulate the circu-

Table 9.2 Hormones and Their Functions

LOCATION	HORMONE	FUNCTION
Pancreas	Insulin	Stimulates glucose and free fatty acid uptake by cells.
	Glucagon	Stimulates release of glucose from the liver. Also encourages formation of glycogen from protein in the liver.
	Somatostatin	Decreases the secretion of insulin and glucagon.
Adrenal glands		
Medulla	Epinephrine (Adrenaline)	Stimulates breakdown of muscle glycogen and triglycerides. Also stimulates heart rate, nerve impulse conduction, and muscle contraction.
	Norepinephrine	Stimulates heart rate and blood flow by raising blood pressure. Stimulates release of free fatty acids from adipose tissue.
Cortex	Cortisol	Stimulates release of amino acids from muscle and free fatty acids in adipose tissue.
	Aldosterone	Regulates sodium retention and thus, water and electrolyte balance.
Pituitary gland		
Anterior	Growth hormone	Stimulates tissue building and fat metabolism.
	Thyroid-stimulating hormone	Controls the amount of thyroxin produced and released by the thyroid gland.
	ACTH (Adrenocorticotropic hormone)	Stimulates release of adrenal hormones.
	Follicle-stimulating hormone (FSH)	Initiates growth of follicles in the ovaries and promotes secretion of estrogen from the ovaries.
	Luteinizing hormone (LH)	Promotes secretion of estrogen and progesterone and causes the follicle to rupture releasing the ovum.
Posterior	ADH (Anitdiuretic hormone)	Stimulates water retention and reduces urine output.
Thyroid gland	Thyroxine	Increases cell metabolism increasing oxygen consumption, fat and glycogen breakdown, and tissue repair.
	Calcitonin	Controls calcium concentration in blood.
Parathyroid gland	Parathormone	Stimulates bone growth through its effect on calcium. Also responsible for development of strong teeth.
Gonads	Testosterone	Stimulates tissue building and repair.
	Estrogen	Promotes development of female sex organs. Provides for increased fat storage. Assists in regulating the menstrual cycle.
	Progesterone	Assists in regulating the menstrual cycle.

latory system so that it responds to the need for oxygen and glucose more quickly after exercise begins. In fact, an increased secretion of these hormones can take place before exercise begins. This phenomenon is known as an *anticipatory response.* Anticipatory responses are important because they shorten the response time for various physiological adjustments that facilitate the delivery of energy and the removal of fatigue-producing products during exercise. Some experts have proposed that repeated stress over a long period can weaken the catecholamine response and reduce performance. I will discuss this topic at greater length in the chapter on overtraining.

Growth hormone, produced in the anterior pituitary gland, promotes muscle growth. At rest, a releasing factor regulates the amount secreted, but the amount secreted increases considerably during physical exercise. The way that growth hormone and exercise interact to stimulate muscle growth is not completely understood. Some athletes supplement the body's supply of growth hormone with synthetic growth hormone to increase muscle size and power. Although they may achieve this effect, supplementation is both dangerous and unethical.

Effects of Training on Hormones

The general effect of training is to reduce the rate of hormonal secretion during exercise while at the same time sustaining those secretions for a longer time. This mediates their effects so that exercise can continue longer with less interference from energy imbalances. A few examples of the effects of training on some of these hormones may help you understand their effect on performances in practice and competition.

For example, training will reduce the rate of secretion of insulin during exercise. This change will maintain a higher blood glucose level over a longer period and reduce muscle glycogen use during exercise. Instead of a sudden spike of insulin followed by an equally sudden drop in the supply of this hormone, the effect will be to provide a smaller amount over a longer period. Athletes will thus be able to train more intensely for longer periods because they can supply blood glucose to the muscles for a longer time. Similarly, after an athlete becomes well trained, glucagon and the catecholamines, epinephrine and norepinephrine, will respond less actively during exercise. Consequently, the rate of glycogen use will decrease while the rate of fat metabolism will increase so that endurance exercise can continue longer before muscle glycogen becomes depleted.

10

Energy Metabolism and Swimming Performance

New in this edition:

- An expanded discussion of the role of lactate removal in competition and training
- An expanded discussion of the factors that limit performance at various competition distances and in training

The contractions of muscles make it possible to swim from one end of a pool to the other. The release of energy present in chemical compounds within muscles is what makes contraction possible. Thus, energy provides the power for swimming. Without it, muscles could not contract. This chapter describes the physiological mechanisms that provide energy for muscular contraction.

The complex process that supplies energy within the human body is called *metabolism.* During the past three decades scientific information about energy metabolism has been largely responsible for the improvements we have seen in training methods. Serious students of training should therefore understand the metabolic process. This chapter begins with a description of energy and proceeds to a discussion of the physiological mechanisms of metabolism that make it available to the muscles for contraction.

Energy and Its Sources

Energy is usually defined as the capacity to do work. The universe contains many different kinds of energy. Chief among these are radiant energy, heat energy, light energy, chemical energy, and mechanical energy. The first law of thermodynamics tells us that each form of energy is capable of being transformed into one of the other forms when the situation demands it (Lehninger 1973).

The ultimate source of our energy is the sun, which radiates energy to the earth. When that energy strikes plants, it is transferred to them and stored as chemical energy through the process of photosynthesis. When we eat plants or the flesh of animals that have eaten plants, we take the energy into our bodies and store it for later use. Both plants and animals store energy as carbohydrates, fats, and proteins. These foods store energy as parts of various chemical substances. Energy becomes a source of power for various physiological mechanisms when it is released from those chemicals and converted to other forms. We transform the chemical energy in our bodies to electrical energy for the transmission of nerve impulses. We transform it to mechanical energy for powering the work of muscular contraction. The speed of sprinters and the ability of middle distance swimmers and distance swimmers to maintain a certain pace are determined by the capacity of their bodies to release chemical energy and transform it into mechanical energy for work.

Because energy availability is the factor that governs the speed and pace of swimmers, the purpose of training should be to make more chemical energy available to the muscles at faster rates and to replace the energy lost from those chemicals as rapidly as possible. Training does this through a process called *adaptation.* When swimmers continually expend large amounts of energy at rapid rates during training, their bodies store more substances that contain energy and release that energy more rapidly when they need it during races. Their bodies also learn to replace the energy more rapidly after they release it. In other words, the body's physiological mechanisms adapt to the specific demands that training places on them so that more energy is available to perform more work with less fatigue. The adaptations that make the release and replacement of energy possible are many and varied and involve, among other functions, the delivery of oxygen and foods to the muscles and the removal of carbon dioxide and lactic acid from them by the respiratory and circulatory systems. They also involve the movement of these substances within muscles and the enzymatic reactions in those muscles that both release and replace energy.

Energy is measured in *calories.* The caloric content of foods indicates the amount of energy we receive from them. The term *calorie* with a lowercase *c* identifies these small calorie units. One thousand calories is equal to one *kilocalorie,* which is equal to 426.85 kg/m, or 3,087.4 foot-pounds of work. The term *Calorie* with a capital C is often used as a substitute for the term *kilocalorie.*

Storage Forms of Energy in the Body

Energy is stored in our bodies in combination with the following chemical compounds: *adenosine triphosphate (ATP), creatine phosphate (CP), carbohydrates, fats,* and *proteins.* Combinations of chemical molecules form all these substances.

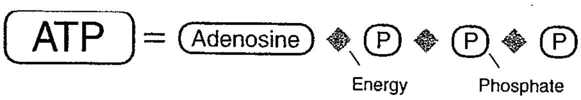


Figure 10.1 The chemical structure of adenosine triphosphate.

Adenosine Triphosphate

ATP consists of a protein molecule, adenosine, and three molecules of phosphate. The chemical structure of ATP is illustrated in figure 10.1. The diamond-shaped symbols connecting the four components represent energy. That energy binds the four smaller molecules together to form the larger ATP molecule. The bonds between these molecules are sources of chemical energy available for use.

ATP is the only source of energy that our bodies can use for muscular contraction. All the other energy-containing chemicals are used to recycle ATP after its energy has been used for muscular work. The energy from ATP becomes available for muscular contraction in the following manner. When muscle fibers contract, they activate an enzyme, *adenosine triphosphatase (ATPase)*, that causes one of the phosphate molecules to split away from the ATP molecule and in the process release the energy that bound it to that molecule. What is left is *adenosine diphosphate (ADP)*, a compound that contains adenosine and two phosphate molecules. The process of ATP splitting, the release of energy, and the formation of ADP are illustrated in figure 10.2. Enzymes are small proteins that have a specific function in the body. One enzyme is associated with each of the thousands of chemical reactions that occur in the body. Enzymes accelerate these reactions without being consumed or changed in the process.

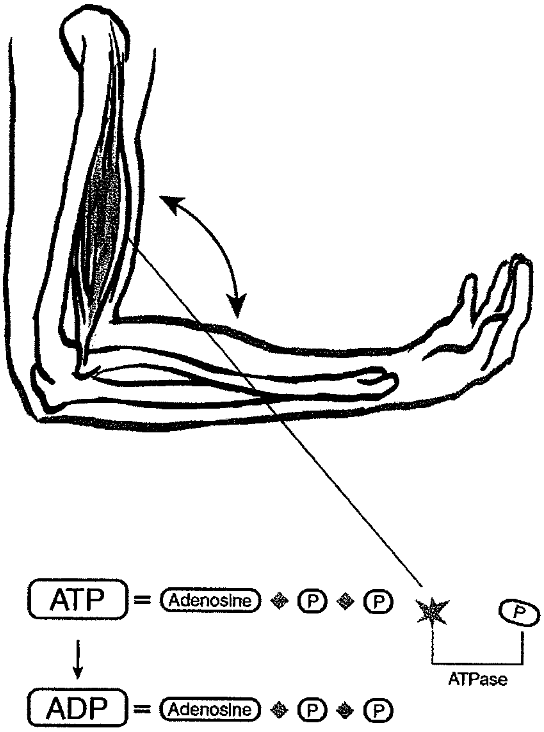


Figure 10.2 The splitting of energy and one phosphate molecule from ATP, which leaves the compound ADP.

ATP cannot be transported to working muscle fibers from other parts of the body. Therefore, when the amount in a particular muscle fiber loses some of its energy and phosphate, other sources of energy within the same fiber must replace it almost immediately or the fiber will not be able to release enough energy to continue contracting. This is no simple task. Our muscles contain such small amounts of ATP (6.2 mmols/kg of wet muscle, Bangsbo et al. 1990) that it can be depleted in the first few seconds of exercise if it is not replaced rapidly. It is amazing, therefore, that even when severely fatigued, a swimmer's muscles will still contain almost 70% of their original ATP supply (Bangsbo et al. 1990).

The recycling of ADP back to ATP requires that another phosphate molecule and energy be made available. The other sources of energy that can be used as phosphate and energy donors are the remaining four chemicals in muscles: creatine phosphate (CP), carbohydrates, fats, and proteins. Enzymes begin breaking these substances down immediately at the onset of exercise so that their energy will be instantly available for recycling ATP. Let me describe the role of each of these chemical compounds in recycling ATP, starting with creatine phosphate.

Creatine Phosphate

The chemical creatine phosphate provides the most rapid source of energy and phosphate for ATP recycling. As its name implies, it is composed of one molecule of creatine and one molecule of phosphate. Energy binds the two molecules together. The chemical structure of creatine phosphate is illustrated in figure 10.3.

Figure 10.3 The chemical structure of creatine phosphate.

The enzyme *creatine kinase* (*CK*) catalyzes the splitting of the phosphate molecule from creatine, which also releases the energy that bound these two molecules together. That energy and the phosphate then combine with ADP to reform ATP. The enzyme *myokinase* catalyzes that combination. The process of reforming ATP from ADP and CP is illustrated in figure 10.4.

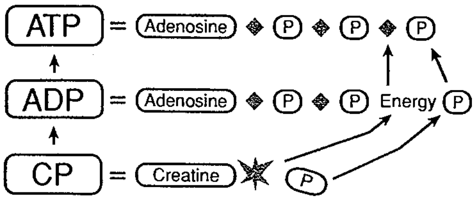


Figure 10.4 The replacement of ATP through the splitting of creatine phosphate.

The process of replacing ATP with phosphate and energy from CP requires only two steps: the splitting of CP and the combination of its phosphate and energy with ADP. These two steps can occur so rapidly that no delay will occur in the process of releasing energy from ATP. Consequently, athletes can maintain a maximum rate of muscular contraction as long as sufficient CP is available to restore the energy provided by ATP. Fast-twitch muscle fibers have a higher concentration of this chemical than do slow-twitch muscle fibers.

Unfortunately, the amount of creatine phosphate that can be stored in either type of muscle fiber is quite small, between 11 and 23 mmols per kg of wet muscle (Lehninger 1973). But humans can use only about 60% of their stored creatine phosphate for recycling ATP (Bangsbo et al. 1990; Henriksson 1992) before their bodies sense the diminishing supply and the process slows. Consequently, CP can only be used to recycle ATP for approximately 4 to 5 sec of all-out effort (di Prampero 1971). The significance of this is that humans can only maintain a maximum rate of muscular contraction for 4 to 6 sec.

Little CP can be replaced during exercise because all the available phosphate and energy will be needed to replace ATP. But when exercise is completed and all the ATP has been reformed, the excess phosphate molecules will find energy and rebind with creatine to restore the creatine phosphate supply of muscles.

When half of the muscles' CP supply has been used, athletes must rely on the metabolism of carbohydrates, fats, and proteins for the energy and phosphate they need to recycle ATP. This circumstance will slow the rate of muscular contraction because several additional steps are required to release energy from these foods. In the absence of sufficient creatine phosphate, the next most rapidly available source of energy and phosphate is carbohydrates in the form of glycogen stored in the muscles.

Carbohydrates

Carbohydrates are made up of simple sugars and starches, which supply the energy for all body functions, including thinking and exercise. *Glucose* is the simple sugar used for ATP recycling. Foods that contain simple and complex sugars and starches are reduced to glucose during the digestive process. After entering the bloodstream, they are carried to the cells of the body and used immediately for energy or stored for later use. The storage form of *glucose* is termed *glycogen*. The body stores glycogen in two principle reservoirs, in the muscles and in the liver. As indicated earlier, some of the glucose that diffuses into working muscle cells can also be used to recycle ATP immediately. I will describe the roles these three sources of energy—muscle glycogen, liver glycogen, and glucose—play in replacing ATP in the following sections.

Muscle Glycogen

Muscle glycogen, which consists of a chain of glucose molecules, is the primary source of energy. When combined with phosphate, it results in the rapid recycling of ATP in all but the shortest swimming events. Muscle glycogen is thus the next fastest source of energy and phosphate for recycling ATP when the muscle's creatine phosphate supply diminishes. The process takes place in the following manner.

When exercise begins, the glycogen stored in muscles is converted back to glucose. That glucose is then metabolized in a long, complex chain of events termed *glycolysis*. Energy and phosphate for ATP recycling is released at several points during the process. The energy and phosphate released most quickly come from *anaerobic glycolysis*, which does not require oxygen for release to take place. The longer, slower process, termed *aerobic glycolysis*, requires oxygen.

Liver Glycogen and Blood Glucose

The liver and blood also contain supplies of glucose that can be mobilized and transported to the muscles when they are needed for energy. The glucose that previously entered the liver was stored there as glycogen. It must be converted back to glucose before it can be transported to the muscles and used to supplement their glycogen supply. The reconversion process occurs whenever the blood glucose supply drops below normal. So when muscles are contracting and glucose is diffusing into them from the blood, liver glycogen will be converted to glucose and poured into the bloodstream to replenish the supply of glucose in the blood.

Blood glucose is more commonly known as blood sugar. The digestion of food causes glucose to pour into the blood from the stomach. At rest, blood glucose is transported to the muscles and the liver, where it is stored as glycogen. When swimmers are training, glucose that was circulating in the blood can diffuse into the muscle cells and enter the metabolic process without first being converted to glycogen. It is apparent, therefore, that glucose from the blood helps athletes maintain a high level of glucose in the muscles during exercise. Blood glucose may supply 30% to 40% of the total amount of energy used during training (Felig and Wahren 1971). But both liver glycogen and blood glucose can provide only small amounts of energy during most swimming races. The process of converting liver glycogen to blood glucose is too slow to provide energy for recycling ATP at fast or even moderate swimming speeds. Similarly, the diffusion of blood glucose into muscle cells requires too much time to sustain fast swimming speeds, although this process can probably provide a small amount of the energy athletes use in the longer competitive races. So both liver glycogen and blood glucose can serve only as supplements, not substitutes, for muscle glycogen and then only in a significant way during long training sessions. Nevertheless, they play an important role in training because they allow swimmers to do more work at a higher intensity before becoming fatigued because of a loss of energy.

Both blood glucose and liver glycogen play important roles in replacing the glycogen supplies of muscles during the recovery period following exercise. In addition, glucose that is circulating in the blood can replace the glycogen supply in the liver when it is low. Another important function of liver glycogen and blood glucose is to maintain an adequate blood glucose supply to the brain and other nervous tissues. Nerve cells, like other cells in the body, use glucose for energy, but unlike muscles cells they cannot store it as glycogen. Therefore, they need a constant supply of glucose from circulating blood.

Fats

Fats are also an important source of energy for ATP recycling during exercise. More ATP can be replaced with fat than with carbohydrate. A molecule of fat can resynthesize 457 ATP molecules, whereas a molecule of glucose can reform only 36 ATP molecules. Unfortunately, however, the process of metabolizing fats is entirely aerobic, which means that energy can only be released slowly.

Even when the process is entirely aerobic, nearly twice as much time is required to replace ATP with energy from fat as to replace it with energy from glucose. Thus, although the metabolism of fatty acids supplies abundant energy, it is released so slowly that swimmers could not sustain an adequate pace during races if this were their only source, or their primary source, of energy for ATP recycling. Consequently, little if any of the energy during races comes from fat metabolism. The release of energy from fat is even slower because only small amounts of this food, approximately 12 mmols/kg, are stored in the muscles where they are readily available for use. The greater amount is stored under the skin as adipose tissue. The bodies of most athletes contain enough adipose tissue to supply energy for several days. The total amount of energy available from fat is in the neighborhood of 70,000 to 110,000 kilocalories in lean adults. In contrast the total amount of energy available from the body's carbohydrate reserves is less than 2,000 kilocalories (McArdle, Katch, and Katch 1996).

Let me explain the process by which fats are converted to a form that allows them to release the energy, which, when combined with phosphate, allows ATP to be recycled. *Triglycerides* are the storage form of fat in the body. Triglycerides must first be transformed into *glycerol* and three fatty acid molecules (*free fatty acids*, or *FFA*) in a process called *lipolysis* before they can release energy. The enzyme *lipase* catalyzes that transformation. Once the conversion takes place, the blood can transport the glycerol to the liver, where it can be converted to glucose and glycogen. At the same time, the blood transports the fatty acids to working muscle fibers, where they can be absorbed and transported to the mitochondria. Once they arrive, fatty acids are transported into the mitochondria with the aid of another enzyme, *carnitine transferase (CT)*. In the mitochondria, they release carbon acetyl fragments in a process called *beta oxidation*. The acetyl joins with *coenzyme A* (*A* stands for acetic acid) to form *acetyl-coenzyme A (acetyl-CoA)*. The enzyme *acetyl-CoA synthetase* catalyzes the process of joining acetyl and coenzyme A. Acetyl-CoA then enters Krebs cycle, where it can participate in the recycling of ATP in the same way that glycogen does. Once it enters Krebs cycle, each fatty acid molecule can form 147 molecules of ATP (McArdle, Katch, and Katch 1996).

Adipose tissue supplies about one-half of the fat that is metabolized for energy during exercise. The fat stored in the muscle cells furnishes the other half. Slow-twitch fibers are better suited for fat metabolism than fast-twitch fibers because slow-twitch fibers have more fat stored within them, have a greater blood supply, and can transport additional fat from adipose tissue more rapidly. Slow-twitch muscle fibers also have more mitochondria, where fat from both the circulation and muscles can be metabolized. The rate of fat metabolism in slow-twitch muscle fibers has been estimated to be 10 times greater than the same rate in their fast-twitch counterparts (Brooks and Fahey 1984). Consequently, distance swimmers, who generally have a higher percentage of slow-twitch fibers, burn more fat (and less muscle glycogen) for energy during training. Thus, distance swimmers should deplete their muscle glycogen supply more slowly. This may be one of the reasons why they seem to tolerate successive days and weeks of hard training better than sprinters do.

The major role that fat metabolism plays in replacing the ATP of swimmers occurs during training. Fat metabolism can provide a significant amount of energy during long repeat sets swum at moderate speeds, thus reducing the rate of muscle glycogen use and delaying fatigue. Fat metabolism probably supplies between 30% and 50% of the total energy used during typical 2 hr training sessions that includes a significant amount of endurance training (Ahlborg, Hagenfelder, and Wahren 1974). The energy supply for sprinting and fast endurance repeats is another matter. The process of fat metabolism is simply too slow to supply any but a small amount of the energy needed to support fast swimming speeds. Consequently, the contribution of fats to ATP recycling falls dramatically when athletes swim at speeds that approach and exceed their anaerobic thresholds. Therefore, most of the energy for these swims must come from glycogen and glucose.

I should mention that the amount of energy donated by muscle glycogen decreases as the duration of training continues because the glycogen supply of muscles declines considerably after the first hour of training.

Proteins

Proteins are synonymous with strength because they are the basic structural elements of muscles and are intimately involved in the repair and rebuilding of those tissues. What is less known is the role they play in endurance. Many of the structural components of muscles that are involved in aerobic metabolism are built from protein. Principal among these are the *mitochondria* where aerobic metabolism takes place. Hemoglobin and myoglobin, the oxygen-carrying components of blood and muscle, also contain proteins. Enzymes are built from proteins, as are hormones. Proteins are also one of the most important buffers in the body. Accordingly, they play a role in regulating the balance between acidity and alkalinity of body fluids (acid-base balance) during exercise.

Proteins are composed of carbon, hydrogen, oxygen, and nitrogen arranged in a variety of ways to form a large combination of amino acids. The body has no storage depots of protein. All of it is contained in the body as important parts of tissues, blood, hormones, and enzymes. The structural components of the body that contain these amino acids are continually undergoing a process of breakdown and replacement.

Besides their other functions, proteins can donate small amounts of energy for recycling ATP during exercise. This occurs when some of the nitrogen in certain amino acids, principally leucine and isoleucine, is removed and passed to other proteins to form new amino acids. The carbon portions that remain from the old amino acids can then be converted to acetyl-CoA so that they can enter Krebs cycle and be metabolized for energy in the same manner as glucose is.

Like the recycling of ATP from fat, the recycling of ATP from protein is a slow, aerobic process that requires many steps before the carbon portions of degraded amino acids can even enter Krebs cycle. Protein metabolism is the slowest and least economical method for recycling ATP.

You might wonder why athletes would need to recycle ATP by metabolizing protein when they have fat available. They do so because muscles must contain a certain amount of glucose to metabolize fat for energy (McArdle, Katch, and Katch 1996). When free fatty acids are converted to acetyl-CoA, they must combine with oxaloacetic acid to enter Krebs cycle and be oxidized. Oxaloacetic acid is produced primarily by glucose metabolism. Thus, sufficient glucose must be available to produce oxaloacetic acid before fat can be metabolized in Krebs cycle. Consequently, when an athlete's glucose supply is very low, he or she has no choice but to rely more heavily on the muscles' own protein to recycle ATP.

Because it is an extremely slow process, protein metabolism does not contribute any substantial amount of energy during competition, but it does contribute to the energy supply for training. Protein catabolism (breakdown) has been estimated to supply between 10% and 15% of the total energy requirement during a 2 hr training session (McArdle, Katch, and Katch 1996). Athletes should maintain adequate supplies of glycogen and glucose in their muscles during training so that they do not use excessive amounts of protein for energy. Doing so will cause muscles to lose some of their protein content and thus some of their strength and endurance.

The small amount commonly used can generally be replaced overnight, so training adaptations should not be adversely affected. But when athletes train when muscle glycogen supplies are low, negative effects can become significant. For example, if an athlete's muscle glycogen is low from days of previous training, the amount of energy derived from protein catabolism could increase from 15% to 45% (McArdle, Katch, and Katch 1996). The energy for ATP recycling donated by protein will also increase significantly during long continuous training sessions if the glycogen supplies in muscles and the liver become depleted. When the amount of protein metabolized for energy becomes so great that athletes cannot replace it on a regular basis, they may literally cannibalize the structural components of the contractile proteins, mitochondria, myoglobin, and metabolic enzymes within their muscles. Over time, the loss may become so severe that they lose strength and endurance (Lehmann et al. 1996).

When protein is metabolized, the remaining nitrogen portions of the amino acids used to provide energy for ATP recycling must be eliminated from the body. In humans, the nitrogen is excreted in the urine as urea. For this reason, some researchers have suggested using measures of urea as a guide to excessive protein use. I will discuss the use of urea for this purpose in more detail in the chapter on overtraining later in this book.

Three Stages of Energy Metabolism

The human body recycles ATP using three different biochemical systems. Two of these do not require oxygen and are therefore considered *anaerobic* (meaning without oxygen). A steady supply of oxygen must be available to operate the third, so it is called *aerobic* (meaning with oxygen). These metabolic systems go by various names. The simplest and fastest of the anaerobic systems in terms of ATP recycling is usually referred to as the *ATP-CP system*, the *nonaerobic system*, or the *alactacid system*.

The various terms used to identify the other anaerobic system are *anaerobic metabolism*, the *lactacid system*, and *anaerobic glycolysis*. I will use the term *anaerobic metabolism* when referring to it in this text. The final phase of metabolism, the one requiring oxygen, has been called the *aerobic system*, *aerobic metabolism*, or *aerobic glycolysis*. I will use the term *aerobic metabolism* when referring to it.

Each of these systems recycles ATP at different rates of speed, the rate being largely determined by the number of intermediate steps they must undergo before ATP is reformed. As mentioned earlier, the ATP-CP system is the fastest of the three, anaerobic glycolysis is the next fastest, and aerobic metabolism is by far the slowest method for recycling ATP. The rate of ATP recycling by anaerobic metabolism is approximately half the rate of the ATP-CP system, and the rate of aerobic metabolism is half again slower than the rate of anaerobic metabolism.

ATP-CP System

The ATP-CP phase of the metabolic process refers to the rapid recycling of ATP through the breakdown of creatine phosphate. When a nerve impulse stimulates a muscle fiber to contract, the protein filaments of that fiber, *myosin* and *actin*, combine. They activate the enzyme *ATPase*. This enzyme, with water, causes one of the phosphate bonds to split from the ATP molecule. In the process the chemical energy in the phosphate bond is released and converted, in part, to mechanical energy that the muscle fiber can use to perform the work of contraction. This process is very rapid so that contraction can occur immediately and the muscle fiber can exert maximum force. Therefore, the ATP-CP system does not limit the total amount of force a muscle exerts. Instead, the number of fibers that are contracting at any one time determines the total amount of force a large muscle can exert.

The breakdown of one molecule of ATP liberates 7.3 Calories of chemical energy (McArdle, Katch, and Katch 1996). Some of this is converted to mechanical energy and used by the muscles for contraction, and the rest is converted to heat energy. The percentage of the total energy used for work determines the efficiency of that work. For example, when a swimmer's efficiency is listed as 14%, a typical efficiency for front-crawl stroke swimming (Pendergast et al. 1978), only 14% of the chemical energy released is used for the work of muscular contraction. The remaining 86% is converted to heat energy.

Although it has been widely reported that human muscle fibers contain enough creatine phosphate to recycle ATP for 10 to 15 sec, it appears that only about half this amount can be used in the rapid conversion of ADP to ATP before the formation of lactic acid slows the process (di Prampero 1971). Therefore, as mentioned earlier, muscle fibers can contract at a maximum rate of speed for only 4 to 6 sec because the CP supply in muscles declines in two stages. It drops rapidly during the first 4 to 6 sec of effort and then more slowly for the remainder of the race (Hasson and Barnes 1986). The graph in figure 10.5 illustrates this process.

Because it is in such short supply, most of the energy for replacing ATP is provided by creatine phosphate only during the first few seconds of exercise. As the supply diminishes, muscle glycogen becomes an increasingly greater source of energy. Ten seconds into the effort, creatine phosphate and muscle glycogen will be providing equally to the replacement of ATP. Muscle glycogen becomes the major source of energy for

ATP replacement after approximately 5 sec, with creatine phosphate continuing its participation at a diminishing rate. After 20 sec of exercise, the contribution of creatine phosphate to the replacement of ATP becomes negligible (Greenhaff and Timmons 1998).

Anaerobic Metabolism

Approximately 5 sec after the start of a race and for the duration of the event, muscle glycogen becomes the principal source of energy and phosphate for ATP recycling. The process has two phases. The first phase is anaerobic and releases energy and phosphate rapidly, whereas the second phase is aerobic and recycles ATP at a slower rate. Let me describe the anaerobic process first. The term *anaerobic metabolism* is commonly used when referring to this metabolic phase. Technically, however, it should be referred to as *anaerobic glycolysis* because it refers to the first 11 steps in the metabolism of muscle glycogen to glucose and finally to pyruvate or lactic acid.

The rate of ATP recycling by this process is about half that of the ATP-CP system, so the speed and force of muscles will necessarily become slower and athletes will not be able to maintain maximum speed when it becomes the major source of energy. Estimates are that a person's power output will decrease by approximately 35% after the first 5 sec of exercise when anaerobic glycolysis becomes the principal source of energy for ATP recycling (Hultman and Sjoholm 1986).

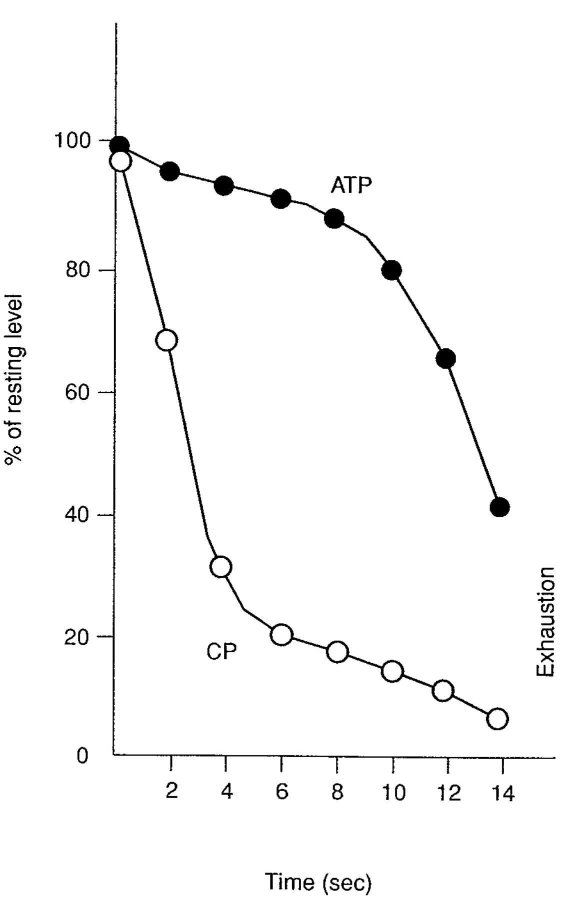


Figure 10.5 The pattern of ATP and CP use during short sprint events.

Adapted from Wilmore and Costill 1999.

A group of enzymes catalyzes anaerobic glycolysis and controls its rate. Sprint training can increase the activity of these enzymes and thus the rate of anaerobic glycolysis. Figure 10.6 lists the steps involved in anaerobic glycolysis as well as the enzymes involved.

In most cases the process begins with the conversion of muscle glycogen to glucose, a procedure catalyzed by an activated form of the enzyme *phosphorylase*. After this initial step the metabolism of glucose proceeds through 10 additional stages, ending with the formation of *pyruvic acid* from phosphophenylpyruvate. Phosphophenylpyruvate immediately dissociates to *pyruvate* ($C_3H_4O_3$) by losing one of its hydrogen ions. The enzyme *pyruvate kinase* catalyzes this procedure. All these reactions take place in the protoplasm (cytoplasm) of the muscle cell and, as indicated earlier, they do not require oxygen.

Hydrogen ions (H^+) are also released continuously from glucose at an earlier stage in the process of anaerobic glycolysis. Hydrogen ions are electrically charged atoms that contain energy in the electrons (+) they carry. The anaerobic phase of glycolysis ends with the formation of pyruvate and hydrogen ions. At that point both of these substances will continue to be metabolized in the aerobic phase of glycolysis if sufficient oxygen is available for that purpose. When the oxygen supply is insufficient, however, as is always the case during intense swimming, some of the pyruvate and hydrogen ions will combine to form *lactic acid* ($C_3H_6O_3$). The enzyme *lactate dehydrogenase (LDH)*, particularly the muscle form of that enzyme, catalyzes this reaction. Lactic acid causes the pH of muscle cells to decrease from its resting neutral value of 7.0 and causes the

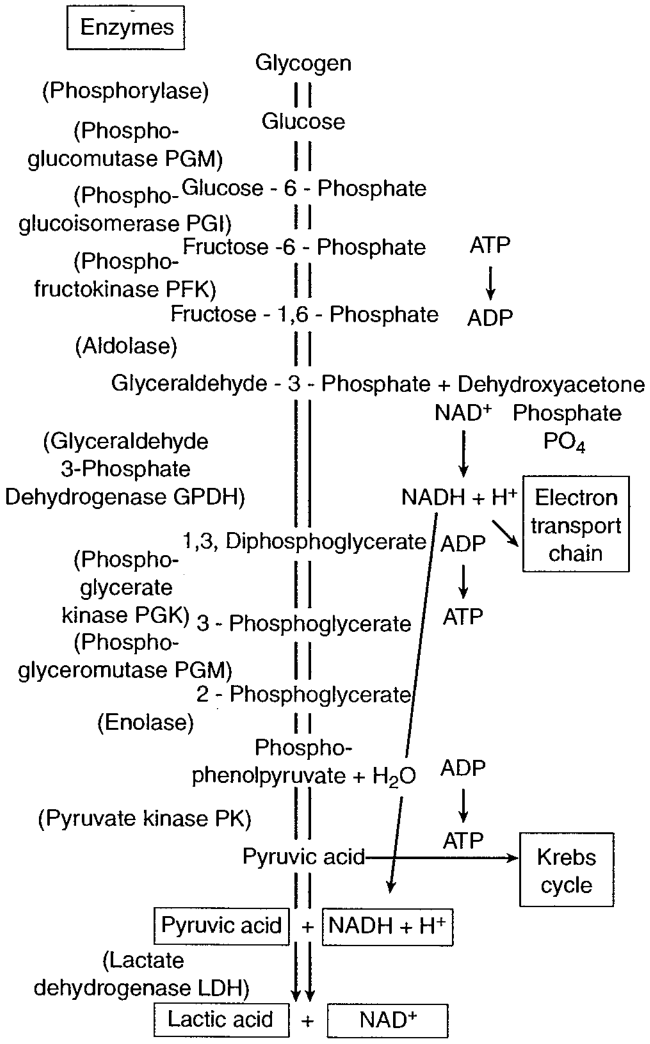


Figure 10.6 The process of anaerobic glycolysis, including the enzymes that catalyze the process.

interior of the cell to become acidic. Lactic acid is obviously acidic, and when it accumulates in muscles, they develop a condition known as *acidosis*. Acidosis is believed to be the principal cause of fatigue in all events longer than 20 to 30 sec. Later in this chapter I will have more to say about acidosis and the role it plays in fatigue during exercise.

Aerobic Metabolism

When sufficient oxygen is available, the end products of anaerobic glycolysis, pyruvate and hydrogen ions, will enter the aerobic phase of that same process, where they can be metabolized further to provide energy for ATP replacement. Hydrogen ions can provide the energy for ATP recycling when oxidation removes them in the electron transport chain, and pyruvate can provide phosphate when it is metabolized in Krebs cycle. Aerobic glycolysis is the most efficient method for recycling ATP because it does not produce any end products that cause fatigue. The products of aerobic metabolism are carbon dioxide and water, both of which are easily eliminated from the body during exercise. That process requires oxygen, so it is considered aerobic in nature. When a large supply of oxygen is available, more of the pyruvate and hydrogen ions will be oxidized and less will combine to form lactic acid. Consequently, less lactic acid will be produced, and acidosis will be delayed.

Every athlete has an upper limit of ability to metabolize pyruvate and hydrogen ions, determined by the athlete's maximum ability to consume oxygen ($\dot{V}O_2$max). Athletes can swim for a long time without suffering acidosis as long as their oxygen supply is sufficient to metabolize nearly all the pyruvate and hydrogen ions they produce to carbon dioxide and water. Two of the major goals of training are to improve stroking efficiency and increase the oxygen supply of the muscle. The first adaptation, improved stroking efficiency, will reduce the energy cost of swimming so that athletes can swim faster without greatly increasing the amount of oxygen they need. The second adaptation, increasing the oxygen supply, allows them to metabolize more pyruvate and hydrogen ions so that they can swim faster without producing greater amounts of lactic acid.

The aerobic phase of glycolysis is much more efficient than the anaerobic phase because it allows a much larger number of ATP molecules to be recycled. Each molecule of glucose can produce 39 molecules of ATP when the glucose is metabolized aerobically, but each molecule of glucose can produce only 3 molecules of ATP when the anaerobic process stops with the formation of pyruvate and hydrogen ions (Shephard 1982). The disadvantage of the aerobic phase of glycolysis is that the process is hundreds of steps longer than the anaerobic process and thus slower. Releasing energy from glucose through this process takes twice as long as anaerobic glycolysis does for the same purpose.

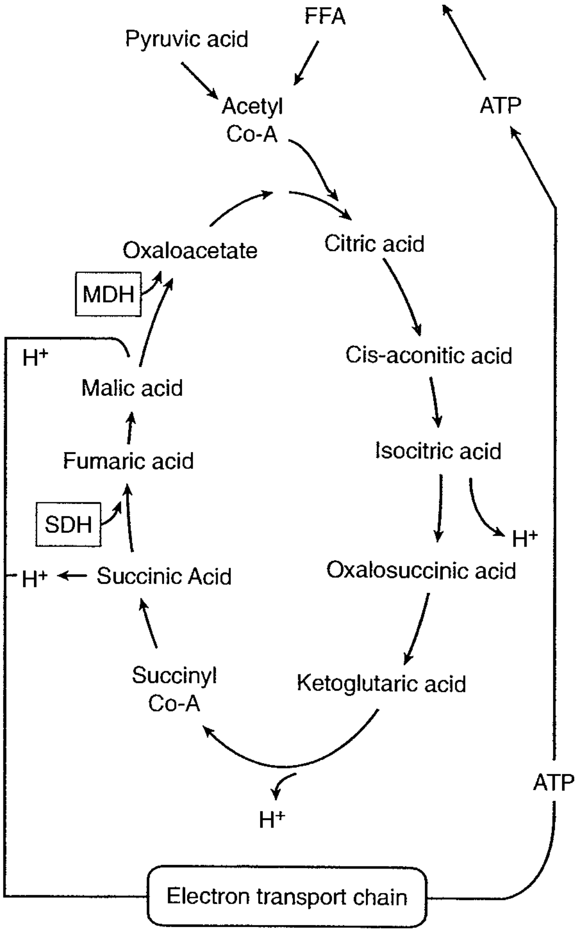


Figure 10.7 Krebs cycle.

Adapted from Costill 1978.

As indicated earlier, the body can also metabolize fats and proteins aerobically. But they must first be converted to an intermediate by-product of glycogen metabolism so that they can enter Krebs cycle and the electron transport chain. Fats and proteins do this when they are transformed to acetyl-CoA, a compound that can enter Krebs cycle.

Aerobic metabolism consists principally of two processes: Krebs cycle and the electron transport chain. Pyruvate is metabolized to carbon dioxide in Krebs cycle, and hydrogen ions and their electrons are metabolized to water in the electron transport chain. Both processes release a large amount of energy and phosphate for ATP recycling.

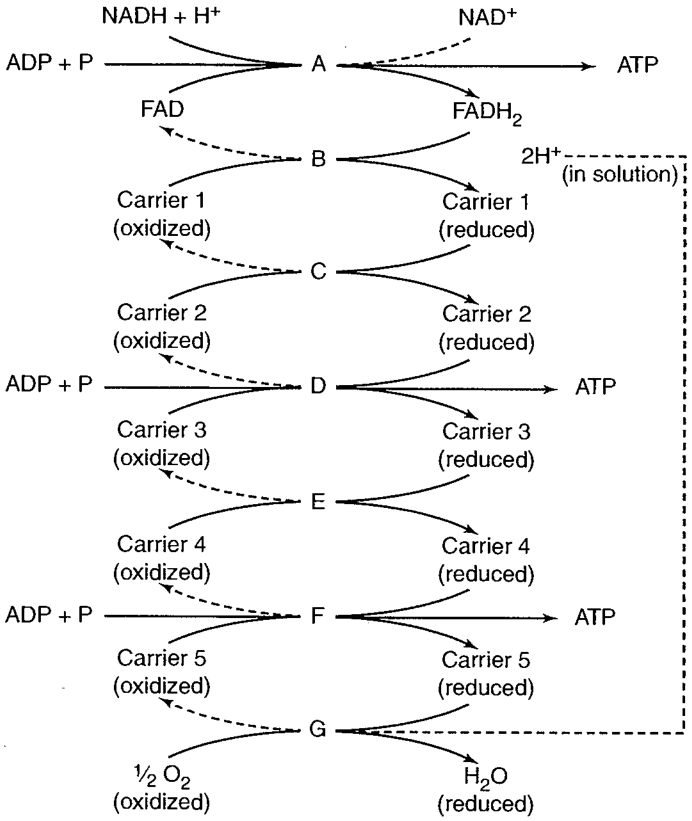
Krebs Cycle

Figure 10.7 shows a diagram of Krebs cycle. This process is also known as the *citric acid cycle* and the *tricarboxylic acid (TCA) cycle.* Some of the pyruvate that was produced in the first 11 steps of glycolysis enters Krebs cycle by joining with coenzyme A to form acetyl-CoA. Within Krebs cycle, acetyl-CoA joins with oxaloacetic acid to form citric acid, the same citric acid found in citrus fruits. The breakdown of citric acid then takes place in a whirling circular fashion until the acetyl-CoA is dissociated to carbon dioxide and hydrogen atoms. The hydrogen atoms and their electrons combine with *nicotinamide adenine dinucleotide (NAD$^+$)* and *flavine adenine dinucleotide (FAD)* so that they can enter the electron transport chain, where they will be reduced to water. Most of the hydrogen ions combine with NAD$^+$. FAD plays a smaller role in the process.

A large number of enzymes regulate Krebs cycle, the most important of which are also shown in figure 10.7. Endurance training increases the activity of these enzymes so that more pyruvate can be taken into Krebs cycle during each minute of exercise.

Electron Transport Chain

Figure 10.8 shows a schematic of the electron transport chain. The hydrogen atoms released during the anaerobic phase of glycolysis and those released within Krebs cycle will ultimately combine with oxygen to form water during this phase of the aerobic process. As mentioned previously, the hydrogen ions produced during anaerobic metabolism are passed to the coenzyme NAD$^+$ to form *NADH* (NAD$^+$ and one hydrogen ion), where they can be reduced to water (H_2O) through the electron transport chain. The hydrogen ions that were released in Krebs cycle combine with NAD$^+$ to form NADH, and they combine with FAD to form *FADH$_2$* (FAD plus two hydrogen ions) within the mitochondria of the muscle fiber so that they can enter the electron transport chain. Within the electron transport chain, both NADH and FADH$_2$ are passed through in bucket-brigade fashion to coenzyme Q and then to a series of enzymes called the *cytochromes.* The cytochromes are composed of iron and protein. The iron (ferric) portion can remove the hydrogen electrons from NADH and FADH$_2$ and transfer them to the next cytochrome in the chain. The energy contained in the hydrogen electrons is released at several points of transfer along the chain and bound to ADP to form ATP. The hydrogen that remains combines with oxygen to form water. This frees the NAD$^+$ and



Summary: $\frac{1}{2} O_2 + 2_e^- + 2H^+ + 3\ ADP + 3P \longrightarrow H_2O + 3\ ATP$

Figure 10.8 The electron transport chain.

Adapted from Lamb 1978.

FAD to join with more hydrogen ions and continue the process of recycling ATP. Over 90% of the recycling of ATP takes place in the electron transport chain.

The process for removing hydrogen ions is important because it is the primary procedure that delays acidosis. The hydrogen ions in lactic acid, not the lactic acid per se, reduce muscle pH. Therefore, it is important to remove as many hydrogen ions as possible during exercise so that they do not combine with pyruvate to form lactic acid. Removing hydrogen atoms is much more difficult after lactic acid has formed.

Roles of Myoglobin and Muscle Mitochondria in Aerobic Metabolism

Anaerobic metabolism takes place in the cytoplasm (protoplasm) of muscle cells. Aerobic metabolism takes place in the mitochondria of muscle cells. Mitochondria are rod-shaped bodies embedded within the cytoplasm of muscle cells. They are commonly known as the powerhouses of the cell because over 90% of the ATP replaced during endurance exercise is formed from events occurring in the mitochondria.

The products of anaerobic metabolism, pyruvate and hydrogen ions, must enter the mitochondria before they can be metabolized aerobically. Oxygen must also be transported to the mitochondria for aerobic metabolism to take place. The oxygen diffuses through the cell membrane, where *myoglobin* picks it up and transports it to the mitochondria. Figure 10.9 is a schematic drawing of a muscle fiber showing the location of mitochondria and the oxygen diffusing into the muscle cell from capillaries, after which myoglobin transports it to the mitochondria. Endurance training can increase the quantity of myoglobin in muscles so that more oxygen can be transported across the muscle cell. Additionally, endurance training will increase both the size and number of mitochondria within muscle cells so that more and larger areas are present for aerobic metabolism to take place. I want to describe the role of oxygen in aerobic metabolism more thoroughly because of its importance to endurance.

Role of Oxygen in Aerobic Metabolism

Oxygen is a principal regulator of the rate of energy release from aerobic metabolism because it is the final acceptor of hydrogen in the electron transport chain. Consequently, when oxygen is available in the mitochondria, many of the hydrogen ions produced during anaerobic metabolism are prevented from combining with pyruvate to form lactic acid.

If a middle distance or distance swimmer's oxygen consumption increases, he or she will be able to maintain a particular pace while producing less lactic acid. So the swimmer can delay the effects of acidosis on performance until the final sprint. Sprinters can also profit from an increase in oxygen consumption, although not to the extent that middle distance and distance swimmers can. An increase in a sprinter's oxygen consumption will make a small amount of additional oxygen available in the time it takes to swim 100 yd or m. With more oxygen available, the swimmer can operate anaerobic metabolism at a faster rate without increasing the production of lactic acid.

Roles of Lactic Acid and Muscle pH in Fatigue

A decline in muscle pH, or acidosis, is believed to be the principal cause of fatigue in all swimming events of 50 m and longer. Acidosis interferes with mental focus and energy metabolism in a number of ways that make it impossible for swimmers to maintain their speed. The effect of acidosis on swimming speed will be discussed in detail later in this chapter. For now, let me continue describing the mechanism of lactic acid accumulation.

Lactic Acid and Fatigue

Muscle lactic acid levels are between 1.0 and 2.0 mmols per kg of wet muscle tissue (1.0 to 2.0 mmols/kg) during rest and can increase to between 25 and 30 mmols/kg during all-out efforts that are 1 min or more in length (Bangsbo et al. 1990). Blood lactate concentrations are also between 1.0 and 2.0 mmols/L during rest and may increase to between 10 and 20 mmols/L during all-out efforts. Sprinters can usually reach levels of muscle lactic acid that are in the upper portion of the range between 10 and 20 mmols/kg during all-out efforts, whereas distance swimmers are usually in the lower portion of that range.

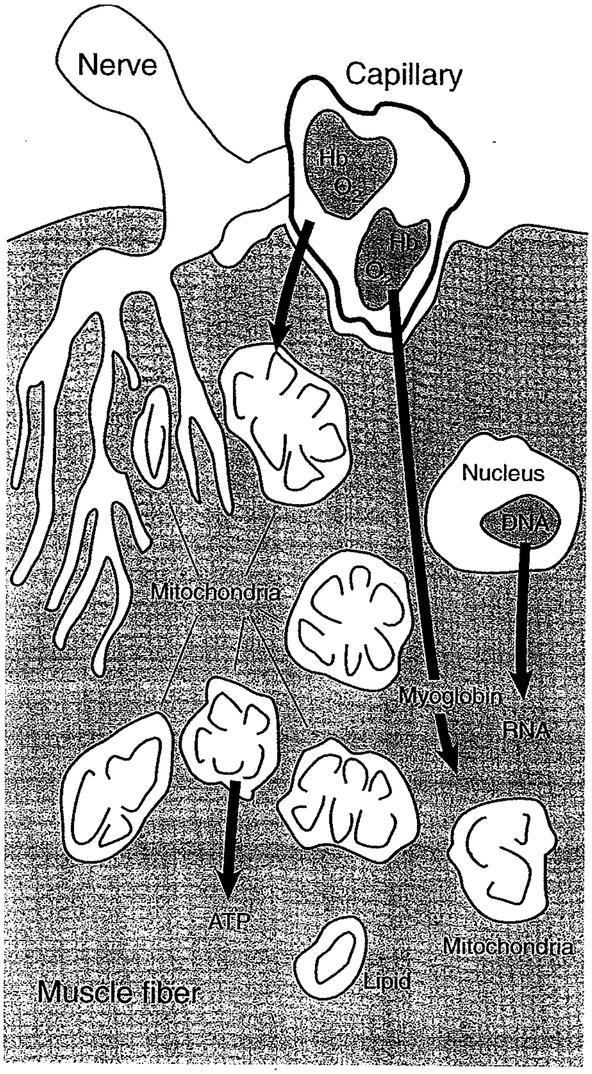


Figure 10.9 A muscle fiber, showing the path of oxygen diffusion from capillaries to mitochondria.

Adapted from Edington and Edgerton 1976.

When sufficient oxygen is not available, anaerobic metabolism will cause lactic acid to accumulate in muscles. As indicated earlier, some of the excess pyruvate will combine with ammonia to form alanine. Most of the excess, however, will combine with hydrogen ions that could not enter the electron transport chain to form lactic acid. Once formed, lactic acid immediately splits into lactate and hydrogen ions. Because of their acidity, the accumulation of hydrogen ions in muscles will lower their pH. A reduction in pH will cause a loss of muscular force and speed.

At one time scientists believed lactic acid was not produced until the CP supply of muscles had been depleted. We know now, however, that anaerobic metabolism occurs concurrently with the breakdown of CP so that lactic acid is being produced from the first second of exercise. Lactic acid has been shown to increase in the muscles and blood of subjects within 2 sec after the start of exercise (Margaria, Cerretelli, and Mangill 1964), and the production of this substance accounts for nearly 50% of the energy released for ATP recycling within 2 sec after exercise begins (Hultman and Sjoholm 1986).

Despite its effect on muscular contraction, lactic acid actually benefits performance. The production of lactic acid enables the body to perform beyond speeds that it can support entirely by aerobic metabolism. An athlete would not be able to maintain a competitive speed in any race if it were not for the ability of the muscles to supply energy anaerobically, which, of course, leads to the production of lactic acid and acidosis.

Success in competition results from controlling the rate and extent of acidosis to maintain the fastest possible average speed for the entire race.

Factors That Affect the Rate of Lactic Acid Accumulation The amount of lactic acid that accumulates in muscles is determined by the balance between its rate of production and its rate of removal. These two rates are generally in equilibrium during exercise of low to moderate intensity. Therefore, little or no additional lactic acid accumulates in the muscles. At faster speeds the rate of production will exceed the rate of removal so that additional lactic acid will accumulate in muscle fibers. The rate of lactic acid production in muscle fibers depends on

- swimming speed,
- rate of oxygen consumption, and
- type of muscle fiber.

Faster speeds require more muscle fibers to contract at a more rapid rate. The release of energy from rapidly recycled ATP makes those contractions possible. Thus, pyruvate and hydrogen ions combine at a faster rate than they can be metabolized aerobically, leading to an increase in the rate of lactic acid production.

Regarding aerobic capacity, the oxygen consumption of muscle fibers relates directly to the rate at which lactic acid will be produced in them. With more oxygen available, more of the pyruvate and hydrogen ions produced during anaerobic metabolism can be oxidized, leaving less available to become lactic acid. Thus, when more oxygen is consumed, lactic acid will accumulate at a slower rate at any exercise intensity. For this reason, improving oxygen consumption is important to endurance performance.

With regard to muscle-fiber types, slow-twitch muscle fibers have more mitochondria in them and more capillaries around them, so they can use more of the oxygen that is consumed. Fast-twitch muscle fibers, on the other hand, have fewer mitochondria and capillaries. As a result, they use less of the oxygen consumed and produce more lactic acid than slow-twitch fibers at any given exercise intensity.

One additional mechanism that affects the rate of lactic acid accumulation is the ability to remove lactate during exercise. In previous years scientists assumed that lactic acid could not be eliminated during exercise. They believed that once it was produced it stayed in the muscle fibers until the exercise was completed, after which it diffused out of them and into the blood, where it was carried away. It appears now that lactic acid can be removed from muscle fibers while exercise is ongoing. Recent research indicates that the process of removing lactic acid from muscles during exercise may reduce the rate of lactate accumulation in those muscles as much or even more than it can be reduced by oxygen consumption (Brooks et al. 1996).

Lactic Acid Removal Some scientists have suggested that human muscle fibers contain a system of protein transporters whose function is to remove lactic acid from muscle fibers (Bonen, Baker, and Hatta 1997; Bonen et al. 1998; Wilson et al. 1998). These transporters can move lactic acid from the protoplasm of working muscle fibers where it was produced into the mitochondria of the same muscle fibers so that it can be converted back to pyruvate and oxidized (Brooks et al. 1996). They can also transport lactic acid out of muscle fibers where it is being produced into adjacent muscle fibers that are better suited to metabolize this substance. This means of disposal is most prevalent between fast-twitch and slow-twitch muscle fibers. Slow-twitch fibers are better able to metabolize lactic acid. Consequently, some of the lactic acid produced in fast-twitch muscle fibers can be transported directly across their cell membranes into adjacent slow-twitch muscle fibers where it will enter their mitochondria and be oxidized. Finally, lactic acid can also leave fast-twitch muscle fibers where it is being produced and enter the bloodstream, which carries it to resting slow-twitch fibers, the liver, and the heart, where it will eventually be oxidized to carbon dioxide and water or converted to glycogen and stored. Some of the lactic acid transported to the heart can also be used directly as a source of energy for cardiac muscle fibers.

Slow-twitch muscle fibers also produce lactic acid during intense exercise, but the rate of production will be lower than it is in fast-twitch fibers. Nevertheless, some of the lactate in slow-twitch muscle fibers can also be transported out to the bloodstream, which delays the onset of acidosis. Mounting evidence indicates that training can increase these lactate transporters so that less lactic acid will accumulate in the working muscle fibers at any exercise intensity (Bonen, Baker, and Hatta 1997).

Despite the fact that the mechanisms for oxygen consumption and lactate removal reduce the rate of lactate accumulation, the rate of lactic acid production will still exceed its rate of elimination during intense exercise. A considerable amount of lactic acid will remain in the protoplasm of the muscle fibers where it was produced when the exercise has ended. That lactic acid will be converted back to pyruvate and hydrogen ions during the recovery period following exercise. From there it can be metabolized aerobically to carbon dioxide and water or converted to glycogen and stored within the muscle fiber.

Exercise Intensity and Lactic Acid Accumulation The graph in figure 10.10 illustrates the effect of different intensities of exercise on the accumulation of lactic acid in muscles. Some lactic acid is always being produced in the muscles. As indicated, the concentration of lactic acid in muscles will be approximately 1.0 to 2.0 mmol per kg of wet muscle tissue (1.0 to 2.0 mmols/kg). Athletes will begin producing additional amounts of lactic acid at the instant exercise begins, even when aerobic metabolism can supply the necessary energy. During even the easiest exercise, athletes need 1 to 2 min to increase their rates of oxygen consumption enough to metabolize the excess pyruvate and hydrogen ions being produced. Once oxygen consumption has increased, however, the rate of lactic acid production will decline and most of the additional lactate will be removed so that the amount in muscles will be near the normal range. The plot for exercise of easy intensity in figure 10.10 indicates this response.

Exercise of moderate intensity will cause muscle lactic acid to accumulate two to four times above resting levels in the first few minutes. But after the athlete is consuming a reasonable amount of oxygen, the rate of lactic acid production will decrease so that a relatively constant, although somewhat elevated, level of lactate will be maintained until

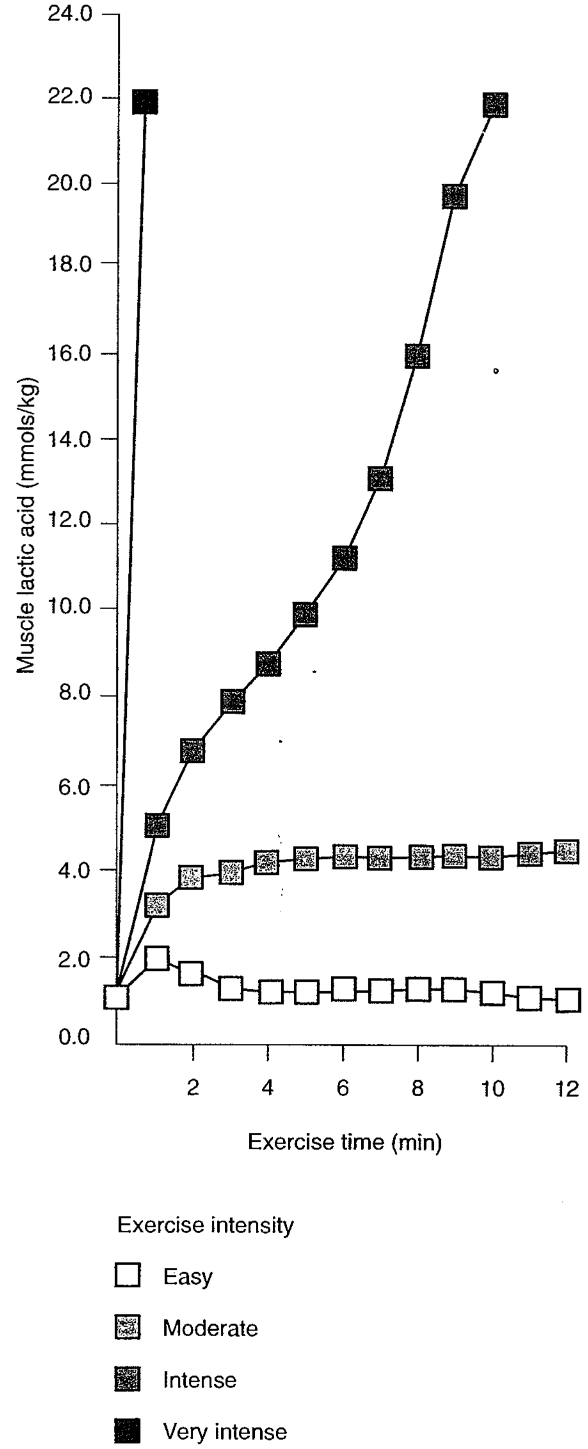


Figure 10.10 The pattern of lactic acid accumulation in working muscle fibers during exercise at intensities varying from easy to very intense.

the exercise ends. That level of lactic acid accumulation is usually between 2 and 4 mmols/kg. The plot for exercise of moderate intensity in figure 10.10 indicates this response. Acidosis will not cause fatigue at this pace because the rate of lactic acid accumulation is not great enough to drop muscle pH significantly. Athletes can maintain this pace as long as sufficient glucose is in their muscles to provide energy.

When exercise is intense, the rate of lactic acid production will be so great that lactic acid will accumulate in the muscles until, at some point, the pH of those muscles declines so much that the athlete becomes fatigued. Athletes usually pace their races so this does not happen until they have covered the complete race distance. The plot for intense exercise in figure 10.10 indicates this response. In this case, the exercise time is 10 min, and the peak muscle lactic acid level that the athlete can attain is 22 mmols/kg, when severe acidosis occurs. In shorter races he or she would pace the race faster and reach that peak lactic acid level and resulting acidosis earlier. Readers familiar with blood lactate levels should remember that the plots in figure 10.10 are for muscle lactic acid, which will be much higher than blood lactate during intense exercise.

Another plot in figure 10.10 indicates the muscle lactic acid response for a 100 m sprint. In this case, the pace is nearly maximum, and the rate of lactic acid production is so rapid that it accumulates to the maximum level of 22 mmols/kg in less than 1 min. The rate of accumulation is so fast that severe acidosis occurs in a short time, so quickly that the athlete could not delay it much by consuming oxygen.

Maximum blood lactate, and probably muscle lactic acid concentrations, will be approximately the same for events that are between 40 sec and 8 min in length. Concentrations will be somewhat lower for longer events, probably because athletes have more time to eliminate lactic acid at longer distances. In one study, peak blood lactate concentrations were approximately the same for one male athlete after 12 maximal efforts that required between 30 sec and 8 min to complete (Hermansen 1971). The peak blood lactates for this subject were between 18 and 22 mmols/L regardless of whether the event lasted 30 sec or 8 min. For an event that was 10 min in length, his maximum blood lactate concentration was slightly lower, approximately 15 mmols/L.

In all races, with the exception of 50 sprints, athletes must swim the first portion of the race at a speed somewhat slower than maximum. This pacing allows for a slower rate of anaerobic metabolism so that the accumulation of lactic acid in muscles does not lower pH too quickly. Athletes can afford to swim closer to maximum speed in the first portion of shorter races such as 100 and 200 events because the race will be nearly over before muscle pH drops to low levels. Nevertheless, they must still swim the early portion of these races at a pace that permits them to reach the end of the race before the accumulation of lactic acid becomes so severe that they cannot maintain a competitive speed. They must swim the first portion of longer races even slower for the same reason. I will offer suggestions for pacing races later in this book.

Acidosis and Fatigue

By now you should understand that it is not lactic acid per se that causes fatigue during work. Instead, what causes fatigue is the effect that the hydrogen ions in lactic acid have on the pH of muscle fibers, where they accumulate during exercise. The hydrogen ions lower the pH, causing acidosis. Despite opinions to the contrary (Brooks and Fahey 1984; Sapega et al. 1988) most experts believe that acidosis is the major cause of fatigue in all swimming events longer than 50 yd or m.

A reduction in muscle pH will cause swimmers to lose speed for several reasons. The most noticeable of these is that the acidity of the intracellular fluids stimulates pain receptors, causing athletes to experience a sharp, powerful burning sensation. Some athletes tolerate this pain better than others. Some athletes will slow their rate of speed when the pain reaches a certain threshold. Others may slow their speed before they reach that threshold because they fear that they will not be able to finish their race with a strong sprint if they do not slow down temporarily. Others will push on despite the pain. The ability of athletes to fight through this pain is often referred to as *pain tolerance*.

Coaches should understand that swimmers, no matter how great their tolerance to the pain of reduced pH, will of necessity slow down when the fluids within their muscles become acidic. The effect will become progressively more severe as the degree of acidosis increases. This circumstance will occur because the rate of ATP recycling decreases when muscle pH falls below 7.0, and it will continue to slow with each 0.1 unit of decline until swimmers find it impossible to contract their muscles rapidly and forcefully enough to maintain competitive speed. The rate of anaerobic metabolism can fall so much at pH values of 6.5 to 6.8 that little additional lactic acid will form. When that happens, the athlete will not be able to swim any faster than his or her ability to generate energy aerobically will permit. That pace will be too slow to be competitive in any race.

At fast speeds the accumulation of lactic acid can lower muscle pH to values between 6.6 and 6.4 in less than 60 sec. A distance of 100 yd or m is thus the upper limit for all-out sprint events. When athletes swim longer races at slower speeds, muscle pH will decline more slowly. Nevertheless, acidosis will ultimately cause fatigue when the accumulation of lactic acid exceeds its rate of removal from muscles and causes muscle pH to fall below 6.8.

Progressive acidosis reduces the rate of anaerobic metabolism for several reasons. For one, the muscles need more calcium for muscular contraction to occur when their pH is low. Calcium activates the coupling of myosin and actin filaments within muscle fibers, causing contraction. The rate of contraction will decrease if more calcium is required and not available immediately. The rate of activity of ATPase will also fall during acidosis, causing energy from ATP to be released at a slower rate. ATPase activity has been reported to decrease by 25% when muscle pH decreases from 7.1 to 6.5 during exercise (Portzehl, Zaoralek, and Gaudin 1969).

The rate of activity of the enzymes phosphorylase and phosphofructokinase (PFK) will also be inhibited when muscle pH falls below 7.0 (Hultman et al. 1990). These enzymes are the chief regulators of anaerobic metabolism; and a reduction in their activity will slow that rate. In fact, anaerobic metabolism will be completely inactive when muscle pH falls to 6.4 (Danforth 1965).

Lactic acid will be removed at a slower rate when muscle pH falls below 7.0 (Hirche et al. 1975), causing more to remain in the muscle fibers, where it will reduce pH even more.

Some athletes and coaches mistakenly believe that competitors can overcome the fatigue of acidosis by sheer force of will, that a strong desire to win will permit some people to continue despite the burning pain of acidosis. But pain tolerance by itself is not sufficient to ensure success. We have all seen athletes with great courage and desire who simply could not maintain the pace needed to win when acidosis became severe. Swimmers must train to produce adaptations that will allow them to delay severe acidosis so that they can maintain an average faster pace through the middle of their races. Then, as they swim the final portion of their races, they can use their desire and motivation to maintain the fastest possible pace in spite of severe acidosis.

Effects of Acidosis

- An increase in the calcium needed for muscular contraction
- Reduced rate of ATPase activity
- Reduced rate of phosphofructokinase activity
- Reduced rate of lactic acid removal from muscles
- Increased pain

The rate and the extent of acidosis depends, to a great extent, on three factors:

1. the rate of lactic acid production within the muscle fibers,
2. the amount that remains in them after it is produced, and
3. the extent to which the remaining lactic acid can be buffered within those muscles.

The first two factors affect pH in the same way that they affect lactic acid accumulation. The previous section discussed those factors but did not mention buffers. *Buffers* are substances in muscles that can combine with hydrogen ions and weaken them so that their effect on pH is not so potent. When buffers are operating, a given amount of lactic acid will not reduce muscle pH as much as it would have otherwise. Buffers allow athletes to swim at a particular pace for a longer time before they become fatigued or to swim faster with no increase in fatigue. Athletes can increase buffers with proper training.

Energy Metabolism Summarized

Figure 10.11 may make the three systems of energy metabolism easier to understand. Remember that all these metabolic reactions are taking place in each individual working muscle fiber. The anaerobic processes occur in the protoplasm of the muscle cells, and aerobic metabolism takes place in their mitochondria.

The ATP-CP system is shown at the top of figure 10.11, with ATP supplying the energy for muscular contraction. ATP is then recycled by the splitting of creatine phosphate and by the metabolism of muscle glycogen. The mechanism for recycling ATP with creatine phosphate is also shown at the top of the illustration. The anaerobic system is illustrated in the middle, showing the breakdown of glycogen to pyruvate in the protoplasm of the muscle fiber, together with the release of hydrogen atoms, some of which combine with NAD^+ to forming NADH and hydrogen ions (H^+).

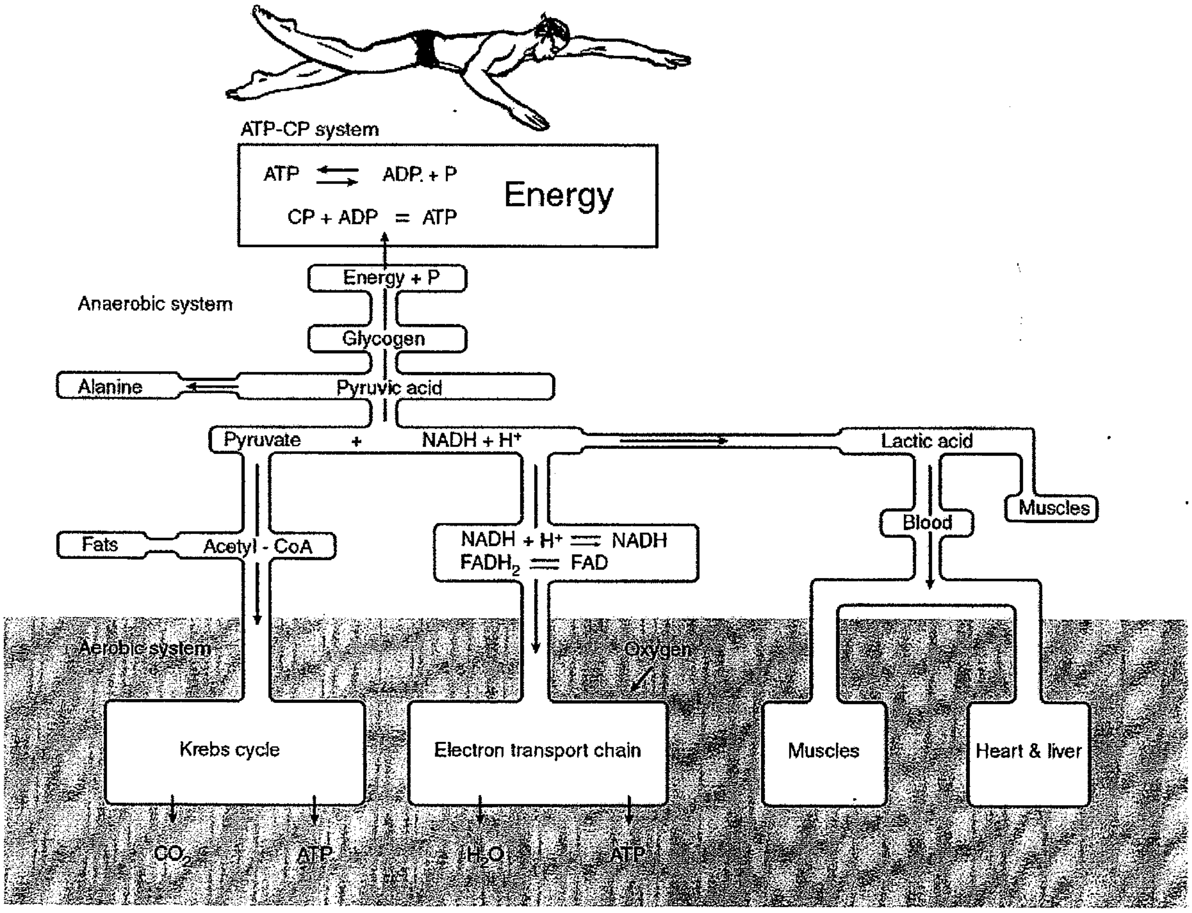


Figure 10.11 A schematic of energy metabolism showing the ATP-CP, anaerobic, and aerobic phases.

The aerobic system is illustrated at the bottom of the drawing. The pyruvate will enter the mitochondria of the muscle fibers and from there enter Krebs cycle, where it will be metabolized to carbon dioxide. Also inside the mitochondria, the NADH and hydrogen ions (and $FADH_2$) will be transported into the electron transport chain where their hydrogen atoms will be used to form water. In the process, the energy in the electrons of those hydrogen atoms will be used to recycle ATP from ADP.

If the pace is rapid enough, approximately 70% to 80% of maximum or greater, not enough oxygen will be available to permit all the hydrogen atoms produced during anaerobic metabolism to enter the aerobic system. The hydrogen atoms that remain will combine with pyruvate to form lactic acid. That reaction is shown in the middle right-hand portion of the drawing in figure 10.11.

Although some of that lactic acid will remain in the muscle fibers, a sizable portion will also be transported out of them to inactive or lightly used fibers, where it can be oxidized back to pyruvate and thence to glycogen. Additional amounts of lactic acid will enter the bloodstream, which will carry it to the heart, the liver, and nonworking skeletal muscle fibers, where it can be oxidized and used as fuel. A small portion of the remaining pyruvate can enter the glucose-alanine cycle, where it will be metabolized aerobically and converted back to glucose in the liver. The bottom right-hand portion of the drawing illustrates those reactions.

Energy Metabolism During Races and Training

Swimming events are commonly referred to as either aerobic or anaerobic, giving the false impression that these phases of metabolism act separately and in sequence, with one phase beginning at the instant that the preceding phase ends. Actually, all three phases of the metabolic process operate from the first moment of exercise. The difference is in the contribution from each phase. In sprints the major contributors of energy for ATP recycling are the ATP-CP system and anaerobic metabolism simply because they are the only processes that can keep up with the rapid demand for energy during fast swimming. Although aerobic metabolism is also functioning, it proceeds too slowly to meet much of the demand for energy in those events. Nevertheless, it supplies a small amount of the energy for sprinting. The aerobic contribution becomes greater as the race distance increases or as the athlete swims at slower speeds.

Muscle glycogen is the principal foodstuff metabolized during moderate to fast swimming because it is readily available in the muscles and can be metabolized both anaerobically and aerobically. Blood glucose, fat, and protein can also provide energy for ATP replacement. The energy they contribute is greatest when the pace is slow or when the glycogen supply in the muscle is low. Blood glucose is the best source for energy after muscle glycogen because it can also be metabolized both anaerobically and aerobically. The process of releasing energy from glucose is somewhat slower, however, because it must first diffuse into the muscles from the blood before it can be used. Fat can contribute energy only at slow speeds because it can only be metabolized aerobically and because only small amounts are stored in muscles. Protein is readily available in muscles, but the process of releasing energy is a slow one, and some glucose must be available in the muscles for it to proceed.

Contributions of the Three Metabolic Phases to Racing and Training

We commonly refer to sprints as anaerobic events and to distance events as aerobic events, but these characterizations are not completely accurate. As explained earlier, all the phases of the metabolic process go into operation simultaneously when athletes begin a race or a practice repeat. The values in table 10.1 are estimates of the contributions that each of the three phases of metabolism makes during races and repeat sets of different distances and speeds. The aerobic phase of metabolism is subdivided into two parts, glucose metabolism and fat metabolism, to differentiate the roles played by these two substances in supplying energy during work.

The percentages for different race and repeat distances in table 10.1 apply to experienced senior-level swimmers. Note that these percentages are listed according to work time so that the information can be adapted for swimmers of other ages and levels of ability. The time swimmers spend swimming provides a more accurate estimate of the way energy is made available than do race or repeat distances. The way the body metabolizes energy depends on work time, not distance. For example, a 10 yr old athlete who swims 100 m in 1:50.00 probably derives energy from the three metabolic phases in approximately the same proportions as a 22 yr old athlete who swims 200 m in the same time. At the same time, these systems would be supplying energy in different proportions for a senior athlete who swims 100 m in 50.0 sec.

The ATP-CP system and anaerobic metabolism supply most of the energy for events of 25 to 50 yd or m (events requiring 10 to 30 sec). Anaerobic metabolism is the major contributor for race distances of 100 and 200 yd or m (events lasting 1 to 3 min), although the role of aerobic metabolism becomes increasingly more important at the 200 distance. Both anaerobic and aerobic metabolism contribute substantially to the energy supply in races of 400 m and 400 yd (4 to 6 min of swimming). Aerobic metabolism is the chief source of energy for races of 800 m to 1,650 yd, although anaerobic metabolism contributes one-third to one-fourth of the energy for these distances. The amount of energy supplied through ATP-CP metabolism becomes increasingly less important in events of 200 yd or m and longer until it is negligible in the longest races.

Muscle glycogen and creatine phosphate are both important sources for energy for ATP recycling for events of 25 to 50 yd or m. After that, muscle glycogen becomes the primary energy source. Fat and protein metabolism are not significant contributors of energy for ATP recycling at any of the race distances listed.

For repeat sets, the ATP-CP system and anaerobic metabolism supply most of the energy for sprints of 25 yd or m and less. Anaerobic metabolism is the major source during fast swims of 50 and 100 yd or m. The energy for fast repeats of 200 yd or m is obtained almost equally from aerobic and anaerobic sources, with muscle glycogen as the primary source of fuel.

Factors That Limit Performance

The factors that limit performance in races and training will vary according to the distance of the event, the time athletes spend working continuously or nearly continuously, and their swimming speed. At distances of 25 and 50 yd or m, the answers involve the operation of the ATP-CP system and anaerobic metabolism. For longer race distances acidosis is the limiting factor. The amount of glycogen stored in muscles will not limit performance in races unless it is quite low before the race begins. Low muscle glycogen supplies, however, can limit performance in training.

Obviously, good swimming techniques play a significant role in performance at any race distance. Swimmers who apply propulsive force and reduce resistive drag more effectively will need less energy to swim at any speed less than maximum, and they will achieve greater speeds when they maximize their rate of energy expenditure. Having said this, let me describe the metabolic limitations on performance for various race distances.

25 and 50 Events

Performance in these events is limited by an inability to achieve and maintain a high rate of speed. Performance involves the rate of ATP recycling by both the ATP-CP system and anaerobic metabolism and perhaps the maximum amount of creatine phosphate stored in muscle fibers. Acidosis will limit performance somewhat, particularly in events of 50 yd or m, but not because muscle pH becomes severely depressed. The

Table 10.1 Relative Contributions of Each Phase of Energy Metabolism to Various Swimming Races and Practice Repeats

				Aerobic metabolism	
COMPETITION TIMES	**RACE DISTANCES**	**% ATP-CP**	**% ANAEROBIC METABOLISM**	**% GLUCOSE METABOLISM**	**% FAT METABOLISM**
10–15 sec	25 yd/m	50	50	Neg	Neg
19–30 sec	50 yd/m	20	60	20	Neg
40–60 sec	100 yd/m	10	55	35	Neg
1:30–2 min	200 yd/m	7	40	53	Neg
2–3 min	200 yd/m	5	40	55	Neg
4–6 min	500 yd (400 m)	Neg	35	65	Neg
7–10 min	900 yd (800 m)	Neg	25	73	2
10–12 min	1,000 yd (900 m)	Neg	20	75	5
14–22 min	1,650 yd (1,500 m)	Neg	15	78	7

REPEAT SETS

				Aerobic metabolism	
TYPE AND DISTANCE	**SEND-OFF TIMES**	**% ATP-CP**	**% ANAEROBIC METABOLISM**	**% GLUCOSE METABOLISM**	**% FAT METABOLISM**
Sprints					
10–15 yd/m	1–2 min	50	50	Neg	Neg
25 yd/m	1–2 min	20	80	Neg	Neg
Anaerobic					
50 yd/m	3–5 min	15	60	25	Neg
100 yd/m	5–10 min	10	50	40	Neg
200 yd/m	8–12 min	2	35	63	Neg
Aerobic					
Set length	15–20 min	Neg	15	80	5
	30–40 min	Neg	5	75	20
	50–60 min	Neg	2	70	28
	90–100 min	Neg	1	30	70

Neg = Negligible

These figures are for middle distance swimmers. The aerobic and anaerobic contributions can differ widely from those presented in this table for sprint and distance swimmers. Anaerobic contributions can be 10% to 20% greater at all distances for sprinters, whereas they may be smaller by a similar amount for distance swimmers.

Sources: Nomura, Wakayoshi, Miyashita, and Mutoh 1996; Ring, Mader, Wirtz, and Wilkie 1996; Serresse et al. 1988; Trappe 1996.

race is too short for that to happen. Nevertheless, mild acidosis will limit speed later in the race because it slows the rates of muscle contraction (because of an increased calcium requirement), ATP-CP metabolism, and anaerobic metabolism. This slowing usually does not occur until after the first 10 to 12 sec of the race. Training should focus on improving stroking power and the rate of anaerobic metabolism. Improving buffering capacity or the rate of aerobic metabolism is not important.

100 and 200 Events

The ATP-CP system will provide most of the energy during the first few seconds of these races, after which lactic acid will be produced rapidly as anaerobic metabolism becomes the primary source of energy for ATP recycling. Acidosis will be the cause of fatigue in these events.

Most athletes cannot swim at maximum effort for much longer than 40 sec before acidosis becomes so severe that they have to slow considerably. The progressive increase of acidosis, however, will reduce their metabolic rate and thus their swimming speed long before they reach this point. Swimmers generally pace the first part of a 100 race slightly slower than top speed to reduce the rate of lactate production so that acidosis does not reduce their speed noticeably until very near the end of the race. They will pace the first portion of a 200 race even more slowly for the same reason.

The pace will be very fast right from the beginning of 100 races, and the time to complete them is so short that the rate of oxygen consumption will not reach maximum. It may reach maximum in 200 events but only near the very end. Consequently, aerobic metabolism plays a minor role in delaying acidosis during the shorter event, but its contribution becomes more important, although still minor, at the 200 distance. The removal of lactic acid from the muscles and the buffering of that substance within the muscles play much greater roles.

The maximum rate of anaerobic metabolism is also a limiting factor in these events, although it is not as important as it is in shorter events. Athletes require a reservoir of speed that will permit them to swim the early portions of these races faster with a lower energy requirement. In other words, they need what is known as *easy speed.*

The rate of ATP-CP metabolism and the quantity of creatine phosphate stored in muscle fibers will limit performance little, if at all, in these events. Athletes pace the first portions of these races so a normal quantity of creatine phosphate and a normal rate of ATP-CP metabolism are probably sufficient to support that speed.

Training should focus on improving sprint speed, the rate of anaerobic metabolism, and buffering capacity. The rate of aerobic metabolism is also important for 100 swimmers, but it plays a minor role compared with the other three factors. It becomes more important for 200 swimmers, but training to improve it should not overshadow or interfere with adequate amounts of sprint training.

Middle Distance and Distance Races

Acidosis is the cause of fatigue in middle distance and distance races. The demand for energy from ATP is high at middle distance speeds, as is the speed at which this compound must be recycled. The ATP-CP and anaerobic systems will carry the load of supplying that energy for the first several seconds. Within a few seconds the muscle's creatine phosphate supply will decline, and anaerobic metabolism will be the primary vehicle for ATP recycling.

The pace for these swims requires more oxygen than swimmers can possibly consume, so although they generally reach maximum levels of oxygen consumption and lactate removal after the first minute, a substantial amount of lactic acid will still be accumulating in their muscles. Consequently, they cannot maintain these speeds for much longer than 4 to 12 min before severe acidosis sets in. In these races and in the 1,500 m and 1,650 yd events, a swimmer's ability to maintain a particular race speed will depend on

- how much of the pyruvate and hydrogen ions he or she can metabolize aerobically during the race,
- how much lactic acid can be removed from the working muscle fibers during the race, and
- how much lactic acid can be buffered during the race.

Training should therefore focus on improving the rates of both aerobic and anaerobic metabolism. The rate of ATP-CP metabolism and the quantity of stored creatine phosphate will not limit performance for the reasons cited in the previous section.

Day-to-Day Training

Daily training sessions include a combination of swimming speeds. Some are very easy, including activities such as warming up and swimming down. Others are easy and include stroke drills, recovery swims, kicking, pulling, and long swims or long sets of repeats at moderate speeds. The core of most training sessions includes some intense endurance training or some very fast sprint training that produces severe acidosis. Most sessions also include short, fast sprints.

At slow speeds most of the energy will come from fat metabolism because fat is the most plentiful source and because the rate of energy release from ATP is slow enough that even this slow process can recycle it at an adequate rate. Creatine phosphate, muscle glycogen, glucose, and protein will supply some energy, but the amounts will be small indeed. Only a small amount of lactic acid will be produced early in the swim, and it will be converted back to pyruvate and oxidized later in the swim when the athlete's consumption of oxygen increases sufficiently to permit aerobic metabolism to provide all the energy for ATP recycling. Acidosis does not cause fatigue at these speeds. Athletes can continue to swim as long as they have enough fat on their bodies to provide energy.

When swimmers increase their speed to a moderate pace between 70% and 85% of maximum effort, depending on the athlete, muscle glycogen will provide more of the energy. The process will still be almost entirely aerobic. Some excess amounts of lactic acid will accumulate in the early minutes of the swim, but it will be metabolized after the first few minutes when the oxygen supply increases. Acidosis is not a cause of fatigue at these speeds. Athletes will be limited only by their muscle glycogen and glucose supplies, which should not diminish greatly until approximately 2 to 3 hr after the swims began.

At faster speeds, in excess of 70% to 85% of maximum effort, the demand for energy for most swimmers will be greater than aerobic metabolism alone can supply. Therefore, excess pyruvate and hydrogen ions will combine to form lactic acid. Muscle glycogen will be the principal source of fuel, with glucose, fat, and protein contributing minor amounts of energy. Acidosis will generally cause fatigue at these training speeds. The rate of muscle glycogen use will be high, particularly during repeat sets in which athletes can delay acidosis by taking short periods of rest after each repeat.

Muscle glycogen and creatine phosphate are the principal sources of fuel for short sprints. Little muscle glycogen, however, will be used. Each swim and the repeat sets are so short that although the rate of glycogen metabolism is rapid, the total amount metabolized will be small. The creatine phosphate supply of muscles will diminish considerably, but it will be replaced within a few minutes after the set of repeats has been completed.

As you can see, serious daily training that includes 2 or more hr of reasonably fast swimming (efforts in excess of 70% of race speed) uses a considerable amount of muscle glycogen. When the supply of that substance is low within muscle fibers, athletes will find that they cannot train as intensely as they would like. As a result, the most common cause of fatigue that results from day-to-day training is a reduction in the muscle glycogen supply. Athletes can become nearly depleted of this substance after one or two training sessions or by long, intense training sessions of 1 hr or more (Houston 1978; Beltz et al. 1988). Conclusive proof exists that successive days of intense training can almost completely deplete it (Costill et al. 1988), even when adequate supplies of fat, protein, and blood glucose are available.

The problem for athletes is that after they have used a large amount of muscle glycogen for energy, they require 24 to 48 hr of complete rest or low-intensity training to replace it. Consequently, the ability of swimmers to do intense, long endurance sets of repeats will be severely limited when their muscle glycogen supplies are low. Their ability to swim long sprint sets such as 50 and 100 repeats in sets of six or more may also be compromised.

The symptoms of fatigue that swimmers experience from muscle glycogen depletion differ from those involving acidosis. The pain is not sharp and intense. Instead, swimmers complain of a dull, heavy, lethargic feeling in their muscles. These swimmers often do not believe they are fatigued; they think they are lazy or depressed. They will be able to swim long sets at slow to moderate speeds in training with no noticeable symptoms because stored fat, blood glucose, and protein can supply much of the energy for ATP recycling at those speeds. Only when they try to swim fast do they become exhausted. Insufficient glycogen is available in the muscles to recycle ATP rapidly enough to sustain those speeds..

Factors That Limit Performance in Sprint, Middle Distance, and Distance Swimming Events

25 and 50 races

1. Stroke technique
2. Rate of anaerobic metabolism
3. Amount of CP stored in working muscle fibers

100 and 200 races

1. Stroke technique
2. Ability to delay acidosis
3. Rate of anaerobic metabolism
4. Possibly the amount of CP stored in working muscle fibers

Middle Distance and Distance Races

1. Stroke technique
2. Ability to delay acidosis
3. Rate of anaerobic metabolism

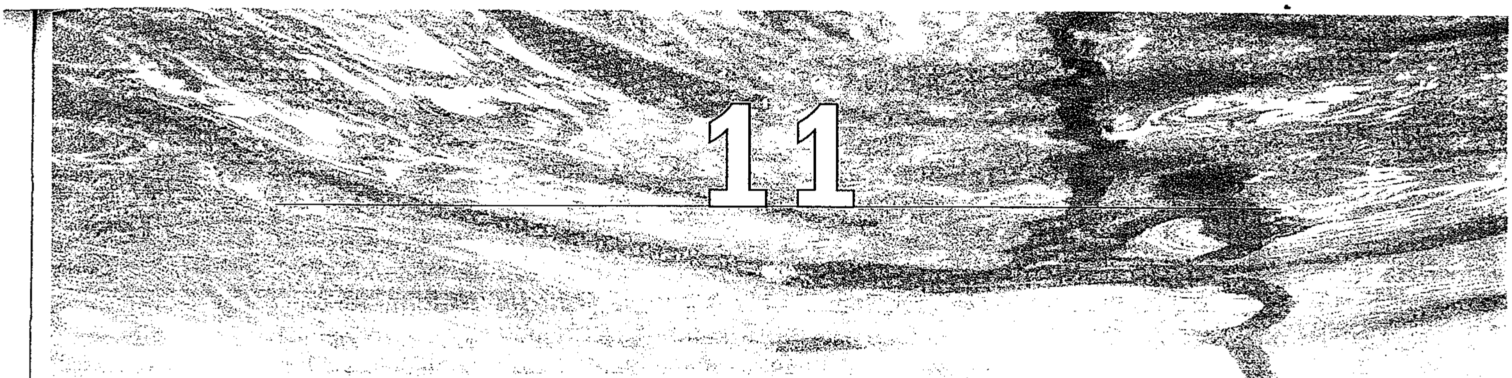
Day-to-Day Training

1. Muscle glycogen depletion
2. Muscle tissue injury

Weekly training plans should include provisions for replacing muscle glycogen. This can be done by scheduling training sessions made up largely of long, slow swimming and short sprints after every one or two sessions of long, intense endurance and sprint training.

Low muscle glycogen is usually not a limiting factor in swimming competitions, particularly if athletes are well fed and have had 1 or 2 days of light training before the competition. Enough muscle glycogen is usually available for all racing distances, even when the supply is not stored to capacity. The only time glycogen depletion should affect competition is when the amount in muscles is low to begin with because of several days of intense training immediately before the competition.

Another potential limiting factor is the tissue damage that results from acidosis. Although little scientific evidence supports this notion, it seems reasonable that subjecting muscles to repeated bouts of acidosis will cause damage to their structures that will require some time for repair and adaptation. One such example was provided by Gullstrand (1985), who reported that daily bouts of hard training caused muscle mitochondria to lose their structure and function. His data suggest that muscles of athletes may require 24 to 48 hr of less intense training to recover and adapt once they have been subjected to several lengthy periods of extreme acidosis.



11

Performance Benefits of Training

New in this edition:

- An updated and expanded section on lactate removal

Exercise taxes the various physiological systems of the body beyond their normal resting level of performance. Changes that occur because of training allow those systems to function more effectively and efficiently during competition. Two of the primary purposes of training are to (1) increase the rate of energy release during races and (2) delay fatigue. As you learned in the previous chapter, the rate of energy release and the occurrence of fatigue involve complex anaerobic and aerobic metabolic processes that take place inside individual muscle fibers. Energy release and fatigue also involve many other physiological systems in the body, including the respiratory, circulatory, nervous, and endocrine systems.

The training process is complex and only partially understood. Simply working to exhaustion each day will not improve each physiological system and each phase of metabolism equally. Training that benefits one system or one phase of metabolism may be detrimental to others. Therefore, training must be carefully planned and executed. Coaches should have a specific goal in mind for each set of repeats, and they should understand the effects of those repeats on each physiological system. The purpose of this chapter is to describe the effects of different forms of training on the various physiological systems. The remaining chapters of this section will describe methods of training.

Training the ATP-CP System

The energy for muscular contraction comes from ATP, which is the only chemical stored in muscles that can provide that energy. The primary purpose for all other phases of metabolism is to replace the energy in ATP so that contraction can continue. The ATP-CP system can provide energy for muscular contraction more rapidly than any other phase of metabolism, but it can do so for only 4 to 6 sec. The activity of the enzymes that catalyze the various reactions and the amounts of ATP and creatine phosphate stored in each muscle fiber regulate the release of energy by this metabolic phase. The principal enzymes in question are ATPase and creatine kinase (CK). It seems reasonable to assume that an increase in the activity of these enzymes and increases in stored ATP and CP would help athletes extend their ability to maintain maximum speed for a longer time and thus improve their performances. Many experts have probably overstated the benefits of training this system. The increase in energy release that can be achieved is minor and would probably only benefit athletes competing in 25 and 50 races.

Training probably does not increase the activity of these enzymes much because their normal rate of activity is sufficient for most athletic events that last more than a few seconds. Except for leg extensions during the starts and turns of races, it is difficult to conceive of situations in competitive swimming where a normal rate of ATP-CP metabolism would not be adequate to produce a swimmer's maximum speed. Swimmers stroke at optimum, not maximum, rates even in their shortest events, and a normal rate of energy release from ATP and a normal rate of recycling of that compound should be more than adequate to provide the energy they need as rapidly as they need it. After ensuring that technique is good, a swimmer can improve maximum swimming speed most significantly by (1) increasing the size and strength of the fibers in particular muscle groups so that the fibers can generate more power and (2) improving the rate and pattern of fiber recruitment by the central nervous system so that they can be brought into play quickly and in the proper sequence for a particular skill without involving unneeded fibers. In other words, improving muscle strength and recruitment patterns probably benefits sprint speed more than does increasing the activity of the enzymes that regulate the ATP-CP system.

Increasing the quantities of ATP and CP stored in muscle fibers represents another possible training effect that might increase swimming speed. Increases could extend the maximum rate of ATP recycling for an additional few seconds, which in turn may allow athletes to maintain their sprint speed slightly longer. Training has been reported to increase the storage of both ATP and CP by 18% and 35%, respectively (MacDougall et al. 1977). The results of the study by MacDougall and his colleagues are shown in figure 11.1.

Besides training, athletes have tried to improve the creatine phosphate supply in their muscles by supplementing their diets with creatine, a procedure known as *creatine loading.* This procedure has been reported to increase the free creatine in muscle fibers by about the same amount as training does, 20% (Hultman et al. 1996). The results of several studies have been equivocal about whether creatine loading can improve the performances of sprint swimmers. Some have reported

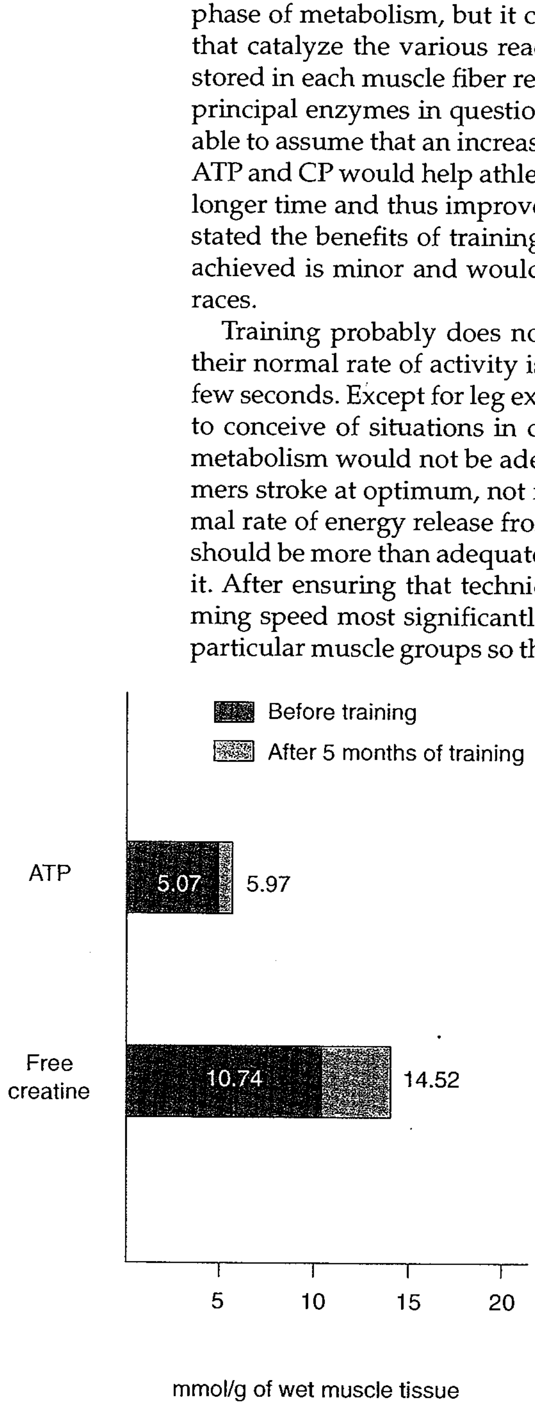


Figure 11.1 The effects of training on the ATP and CP concentrations of human muscle fibers.

Adapted from MacDougall, Ward, Sale, and Sutton 1977.

improved performances, but others have not (Balsom, Soderlund, and Ekblom 1994; Greenhaff 1995; Maughan 1995; Mujika et al. 1996).

Among the reasons why increases in muscle ATP and CP have not been shown to improve performances in swimming races are (1) the length of those races and (2) the small amount of increase those percentages actually represent. Although increases of 18% in ATP and 20% to 35% in CP are quite substantial in percentage terms, their effect on performance will be minor in most events because of the small increase in the actual quantity of each compound. After all, we are talking about increasing the ATP supply of muscle fibers by about only 1 mmol/kg and the CP supply by 3 mmols/kg. These increases may allow athletes to maintain maximum speed for 1 to 2 additional sec, which might translate into an improvement of 0.10 to 0.20 sec in a 25 or 50 event. Improvements like these pale in comparison to those that a swimmer can achieve in sprint swims by increasing muscular power, increasing the rate of anaerobic metabolism, and improving stroke technique. Increases in muscle ATP and CP are unlikely to result in any improvement in longer events in which swimmers pace the first portion at somewhat less than maximum speed.

I do not think that coaches and athletes need to consider special repeats that train the ATP-CP system, for two reasons. First, the time would be better spent working on drills that can improve muscle strength and stroking power. Second, the ATP and creatine phosphate supplies of muscles will increase as a by-product of such training anyway. Coaches and swimmers should also understand that swimmers must not perform strength and power training only on land. In-water sprint training must play a major role because stroking power will improve only through muscle-fiber recruitment patterns that employ the proper fibers in the correct sequences of motion (Sale 1986).

Training Anaerobic Metabolism

The anaerobic breakdown of muscle glycogen supplies approximately half the energy for ATP-CP recycling during the first 5 to 6 sec of a race. Thereafter, the proportion will increase considerably until anaerobic metabolism will be supplying by far the greatest amount of energy for sprinting within 10 to 15 sec after the race begins (Serresse et al. 1988). The bar graphs in figure 11.2 illustrate the contributions of creatine phosphate and anaerobic glycolysis to ATP recycling during 30 sec of intense work.

You will notice that most of the energy for muscular contraction comes from creatine phosphate during the first 2.6 sec. Notice also that anaerobic glycolysis provides energy from the first second of work. Consequently, lactic acid will be produced even during this early stage. From 2.6 to 10.0 sec into the effort, the energy for ATP recycling contributed by creatine phosphate and anaerobic glycolysis is approximately equal, after which anaerobic glycolysis becomes the major contributor of energy for ATP recycling during the last 20 sec of effort. The contribution of creatine

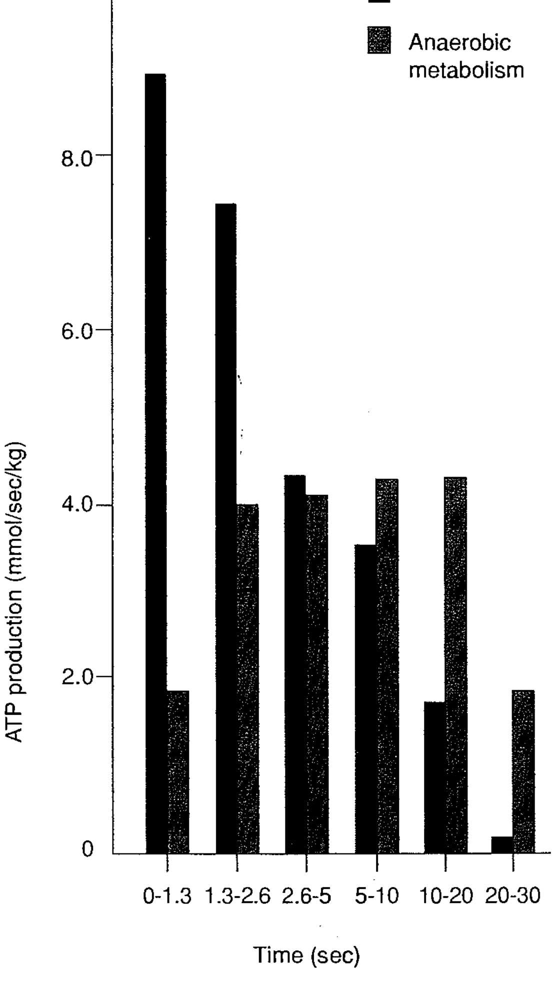


Figure 11.2 The contributions of creatine phosphate and anaerobic metabolism to ATP recycling during 30 sec of exercise.

Adapted from Greenhaff and Timmons 1998.

phosphate decreases considerably during the period from 10 to 20 sec after work begins, although muscles still contain some of their creatine phosphate.

As mentioned earlier, the process of recycling ATP from anaerobic glycolysis is slower than the process involving creatine phosphate because the former process involves 11 steps rather than 1. Consequently, the power available for fast swimming will decline somewhat after the first few seconds of a race. An athlete's ability to generate muscular power will decrease by approximately 10% after the first 4 to 6 sec of effort when the muscle's creatine phosphate supply is partially depleted and anaerobic glycolysis becomes the primary source of energy for ATP recycling (Newsholme et al. 1992). For this reason the rate of anaerobic glycolysis has a greater influence than the ATP-CP system does on how fast athletes can swim in sprint events.

Training appears to increase both the quantity and activity of many of the enzymes of anaerobic glycolysis (Costill, Fink, and Pollock 1976; Costill 1978; Jacobs et al. 1987). Sprints are particularly good for bringing about these increases, whereas endurance training tends to suppress their quantity and rate of activity. In general, training-induced increases of anaerobic enzymes have not been as great as those reported for the enzymes of aerobic metabolism. Most of the increases in anaerobic enzymes have ranged between 2% and 22%.

The major obstacle to increasing the quantities of anaerobic enzymes is the endurance training that swimmers must engage in. Endurance training suppresses the activity of most anaerobic enzymes. A considerable body of research points to the possibility of an antagonistic relationship between endurance training and sprint speed because endurance training reduces the rate of anaerobic metabolism (Baldwin et al. 1973; Holloszy 1973; Sjodin and Jacobs 1981). Some experts have even suggested that the rate of anaerobic metabolism is most rapid when athletes are untrained. They cite as evidence the fact that many swimmers are able to produce their best sprint performances after long layoffs.

The dilemma most swimmers face is that they must improve both endurance and speed to improve their performance in most swimming events. But swimmers typically do so much endurance training that the best they can do is maintain their innate ability to recycle ATP rapidly through anaerobic metabolism. More often, their rates of muscle contraction and anaerobic metabolism decline during most of the season because of the large volume of endurance training they perform. Lucky swimmers manage to regain their speed during the taper. When the loss of speed has been extreme, however, the taper may not be long enough and speed will not return to inherited levels until several weeks after endurance training has been terminated or considerably curtailed. Middle distance swimmers and distance swimmers may be able to post good performances in spite of loss of sprint speed if they have made substantial improvement in endurance. Most sprinters, however, will not produce good performances if they cannot regain their sprint speed.

An important question concerning sprinters is whether their training would be more effective if it focused more on improving rates of muscle contraction and anaerobic metabolism and less on improving aerobic endurance. Some experts question whether sprint training increases the rate of anaerobic metabolism or only returns it to inherited maximums. Others believe it is possible to improve the rate of anaerobic metabolism (Cunningham and Faulkner 1969; Karlsson et al. 1972; Saltin et al. 1976). Olbrecht (2000) reported increases in innate anaerobic capacity in mature athletes, although between 1 and 2 yr of specialized training were required for those increases to take place. I will say more in a later chapter about the possible limiting effect of endurance training on anaerobic metabolism and the potential for improving anaerobic metabolism with proper sprint training.

Training to Delay Acidosis

Swimmers' bodies can be trained to delay acidosis during races and training in three principal ways:

1. by reducing the rate of lactic acid production,
2. by removing lactic acid from working muscle fiber, or
3. by buffering lactic acid.

A fourth training effect that can improve performance is to increase the tolerance of athletes to the pain of acidosis.

The first of these training effects can be brought about by improving the rate of aerobic metabolism so that more of the pyruvate and hydrogen ions produced during anaerobic metabolism can be metabolized aerobically, thus reducing the amount of lactic acid produced in muscles at any given swimming speed. The second procedure allows some of the lactic acid produced during races and training to be removed from the working muscles' fibers, where impending acidosis is a threat to performance, and transported to other areas of the body that can handle it without producing acidosis. In the third procedure, buffering, the lactic acid that remains in muscles during hard effort can have some of its hydrogen ions removed by the addition of certain alkaline substances so that those hydrogen ions do not rapidly reduce muscle pH. These first three training effects can only delay the rate of acidosis, not eliminate it. Acidosis will occur in races, and it will cause pain. Improving the tolerance of athletes to the pain may enable them to maintain a slightly faster pace for a longer time despite the detrimental effects that acidosis produces on the release of energy in their bodies.

Reducing the Rate of Lactic Acid Production

The end product of anaerobic metabolism, pyruvate, combines with hydrogen ions to form lactic acid unless both the pyruvate and hydrogen ions are reduced to other compounds through the process of aerobic metabolism. The rate of appearance of these two substances depends on the swimmer's speed. Faster speeds require faster rates of anaerobic metabolism to maintain a constant supply of ATP, so the rates of pyruvate and hydrogen ion production will be directly related to the athlete's swimming speed. At the same time, reducing the amounts of these two substances that combine to form lactic acid depends on the speed with which they can be metabolized aerobically. In turn, that speed depends on the oxygen supply of muscles. Consequently, most of the training adaptations that reduce the rate of lactic acid production in muscle fibers provide an increase of oxygen to the working muscle fibers. Therefore, an increase in maximum oxygen consumption ($\dot{V}O_2$max) is a desired outcome of training.

Other physiological mechanisms can remove some of the pyruvate and hydrogen ions formed during anaerobic metabolism. One of these is through the formation of alanine by means of the glucose-alanine shuttle. Another is through the production of aspartic acid by means of the malate-aspartate shuttle. I will discuss the effects of alanine and aspartate production on lactic acid production later in this section. Because oxygen consumption plays by far a greater role in reducing the rate of lactic acid production, I will discuss its significance to performance next.

Improving Oxygen Consumption

The previous chapter discussed the importance of oxygen consumption to performance. The literature has reported significant relationships between $\dot{V}O_2$max and performance in events ranging from 100 to 1,500 m. Training will increase $\dot{V}O_2$max by 20% to 30% within 8 to 10 weeks and by 40% to 50% within 1 to 4 yr. Training also reduces the response time of oxygen consumption (Green 1996). In other words, athletes can increase oxygen consumption from resting to maximum (or whatever level is required by the exercise) in a shorter time.

The training effects that increase the oxygen supply during exercise can be divided into two categories: (1) those that increase oxygen delivery to the muscles and (2) those that increase oxygen use by the muscles. Several prominent training-induced adaptations will increase the rate and magnitude of the oxygen delivery to the muscles:

- *An increase in the pulmonary diffusion rate of oxygen into the bloodstream.* Training will increase the amount of air and thus the amount of oxygen that athletes take into their bodies during each minute of exercise. Some of that oxygen will then diffuse from the lungs into the bloodstream, where it will be carried to the heart and then pumped out to the muscles.
- *An increase in the total amount of blood in the body (blood volume).* An increase in volume reduces the thickness of blood so that it can flow faster from the heart to the muscles.
- *An increase in the number of red blood cells.* Oxygen is transported in the blood in combination with an iron-containing protein compound called *hemoglobin,* which is the cellular component of that liquid. More hemoglobin will permit the blood to transport more oxygen.
- *An increase in cardiac output.* The cardiac output refers to the amount of blood ejected from the heart during each minute. When it increases, each red blood cell can more quickly make its trip from the lungs, where it picks up oxygen, to the muscles, where it deposits some of its supply. This will increase the amount of oxygen that reaches the muscle fibers during each minute of exercise. An increase in cardiac output accounts for approximately 50% of the increase in $\dot{V}O_2$max that occurs with training (Holloszy and Booth 1976). The other 50% is the result of improved consumption by working muscle fibers.
- *An increase in capillaries around individual muscle fibers.* The bloodstream transports oxygen from the lungs through the left side of the heart and out to the muscle fibers through the veins, arteries, arterioles, and finally to the capillaries, where it diffuses into the muscle fibers they surround. An increase in the number of those capillaries will bring more oxygen into proximity with the muscle fibers so that a greater quantity may diffuse into them.
- *Improvements of blood shunting to working muscles.* The human body contains approximately 5 L of blood, which is usually equally distributed to all areas of the body during rest. During exercise, however, the blood vessels that serve working muscles dilate and those that serve nonworking muscles and organs constrict, causing a greater quantity of the total blood supply to be directed to the working muscle fibers. This effect will increase the quantity of oxygen that reaches those fibers.

Several training effects will increase oxygen utilization by the muscles:

- *An increase in the quantity of myoglobin stored in muscle fibers.* Once oxygen diffuses into the muscle fibers, myoglobin transports it to their mitochondria where it can participate in aerobic metabolism. Therefore, an increase in muscle myoglobin should increase the supply of oxygen available for aerobic metabolism.
- *An increase in the size and number of mitochondria.* All aerobic metabolism takes place in the mitochondria, so when more of them are available and they are larger, they will be able to absorb more oxygen and make it available for aerobic metabolism.
- *Increases in the activity of the enzymes that regulate aerobic metabolism.* Besides the amount of oxygen available, the other factor that controls the rate of aerobic metabolism is the activity of hundreds of enzymes. Endurance training can improve

their concentration and rates of activity. In the presence of sufficient oxygen and a near-normal muscle pH, enzymes will increase the rate at which aerobic metabolism can reduce pyruvate and hydrogen atoms and their electrons.

I want to present some information on the effects of training on each of these adaptations and the types of training that produce them in the following sections, beginning with pulmonary diffusing capacity.

Increasing Pulmonary Diffusing Capacity Pulmonary diffusion refers to the amount of oxygen that diffuses from the lungs into the bloodstream. Pulmonary diffusion serves two important purposes. First, it replenishes the oxygen supply that has been depleted from red blood cells during their trip around the body, and second, it removes carbon dioxide from the same blood. Pulmonary diffusion increases in direct proportion to the intensity of exercise, primarily through an increase in tidal volume (the amount of air inspired with each breath) at low-intensity effort and by an increase in the rate of respiration as exercise becomes more intense. Training can increase the maximum amount of oxygen that diffuses from the lungs into the blood by increasing both the total amount of air taken into the lungs each minute (the minute volume) and the amount of oxygen that leaves the lungs each minute.

Untrained persons typically exchange 80 to 140 L of air per min depending on their size. Larger persons can naturally exchange more air per minute than those who are smaller simply because their lungs are larger. Training can increase by more than 50% the maximum amount of air that a person can exchange during each minute of exercise. Many well-trained athletes can ventilate more than 180 L of air per min, and minute volumes in excess of 240 L/min have been measured in large, well-trained athletes (Wilmore and Costill 1999). This increase in maximum minute volume is accomplished by an increase in both the amount of air they take in with each breath and the number of breaths they take per minute. This increase results from improvements in the strength and endurance of the respiratory muscles, the external and internal intercostal muscles.

The amount of oxygen that diffuses from the lungs to the bloodstream depends largely on the number of alveoli in the lungs and the number of capillaries around them. The alveoli are the tiny sacs at the end of bronchial tubes that fill with air during inhalation. The oxygen in air diffuses out of these sacs and into the capillaries that surround them, after which the bloodstream transports it to the heart. Some of the carbon dioxide produced during aerobic metabolism also diffuses from the capillaries into the alveoli so that it can be exhaled into the atmosphere.

The number of alveoli in the lungs of normal untrained persons is more than adequate to accommodate all the air they take in. The surface area covered by alveoli is so huge it would cover half of a singles tennis court (Brooks and Fahey 1987). Not surprisingly, training does not cause any substantial increase in those structures, although it can improve the elasticity of the alveolar walls so that they fill and empty more easily.

On the other hand, training can increase the number of capillaries that surround each alveolus, which will allow more oxygen to diffuse out of the alveoli and into the blood (Jensen and Fisher 1975). Despite this increase, reports have been contradictory about the effects of training on the amount of oxygen that diffuses out of the alveoli and into the blood during exercise. Some researchers report increases (Magel and Andersen 1969), and other sources report no change (Gibbins et al. 1972; Hagberg, Yerg, and Seals 1988; Mahler, Moritz, and Loke 1982). Gibbins and colleagues reported a trend toward improved pulmonary diffusion for a group of swimmers.

Contradictory findings about the effect of training on maximum pulmonary diffusing capacity may have occurred because diffusion of oxygen from the alveoli into the blood does not appear to limit the ability of athletes to supply oxygen to their muscles. The amount of hemoglobin in the blood limits its capacity to carry oxygen to between 16 and 24 ml of oxygen per 100 ml of blood. Consequently, more oxygen is present in the alveoli of even untrained persons than can be absorbed into the blood during exercise.

Studies have shown that the blood leaving the lungs is completely saturated with oxygen during even the most strenuous exercise and that almost half the oxygen in inspired air is exhaled instead of entering the circulatory system. Therefore, an increase in the amount of oxygen available for diffusion from the alveoli would not necessarily result in an increase in the amount that diffuses from them. Thus, pulmonary diffusion does not appear to limit an athlete's ability to consume oxygen. Improving this capacity with training is not considered important for improving endurance.

Early in the 20th century, athletes often used deep-breathing and breath-holding exercises to improve maximal air exchange and pulmonary diffusion of oxygen. Some athletes still do them in the mistaken belief that the exercise will improve their rates of maximum oxygen consumption. Such exercises are unnecessary. Any training, on land or in the water, that stresses the rate and depth of breathing over a reasonable time will increase maximum pulmonary diffusion rates as much as they can possibly be improved. Swimmers engaged in a normal mixed program of training will improve both the rate and depth of breathing.

Training does not significantly affect the amount of oxygen diffusing from the lungs to the blood during submaximal efforts, but it does cause that oxygen to be provided in a more efficient manner. The respiratory rate will actually decrease during submaximal exercise after training. In other words, trained athletes will consume the same amount of oxygen by taking larger but fewer breaths. This change is perhaps the most important effect of training on pulmonary diffusion capacity, more important than an increase in maximum pulmonary diffusing capacity.

Increasing Red Blood Cells An increase in red blood cells is important because they contain hemoglobin, the iron-containing protein substance that allows the blood to carry oxygen. Therefore, any increase in hemoglobin should increase the quantity of oxygen that the blood can carry. One reason that athletes train at altitudes well above sea level is to increase hemoglobin. For the same reason, some athletes engage in blood doping (being reinfused with his or her own blood before competition) or use the banned substance erythropoietin (EPO), which also increases the number of red blood cells.

At best, athletes can expect only slight improvements in the oxygen-carrying capacity of the blood from training at sea level. Some studies have reported no increase, whereas others have reported only a small improvement (approximately 8%) by training at sea level (Green et al. 1991). On the other hand, several studies have reported gains of 7% to 18% in the hemoglobin content of blood after altitude training (Karvonen, Peltola, and Saarela 1986; Hannon et al. 1969).

Increasing Blood Volume The total volume of blood in the human body is approximately 5 L. Endurance training can increase that amount by approximately 30% (Green et al. 1991). Training that increases the hemoglobin can also cause the blood to become thicker (more viscous) because hemoglobin is the solid component of red blood cells. If the fluid portion of blood did not increase along with the hemoglobin, the blood would not flow through the arteries and veins so easily. Consequently, the amount of oxygen that would reach the muscles each minute would decrease.

Luckily, the fluid in blood increases relatively more than its hemoglobin with training so that blood viscosity actually decreases. The reduction in blood viscosity after training can therefore increase the rate of blood flow through the vessels during exercise and thus increase the amount of oxygen that reaches the muscle fibers. The training-induced reduction in blood viscosity seen in highly trained athletes has caused some of them to be diagnosed as anemic because the hemoglobin was lower for any standard quantity of blood. Endurance training performed at a relatively intense pace appears to be most effective in increasing blood volume (Wilmore and Costill 1999).

Increasing Cardiac Output Cardiac output refers to the amount of blood that is pushed out of the heart each minute. It is the product of stroke volume (the amount of blood pushed out of the heart with each beat) multiplied by the heart rate (the number of heart beats per minute). Cardiac output is approximately 5 L at rest, and during maximum effort it may increase to between 14 and 16 L per min in untrained persons. Training can increase it further to between 30 and 40 L/min. This important training effect is primarily responsible for increasing the oxygen supply to muscle fibers (Brooks and Fahey 1987)

An increase in maximum cardiac output is the result of an improvement in the athlete's stroke volume (the amount of blood pushed out of the heart with each beat). Maximum heart rates do not increase with training, and heart rates during submaximal effort decrease after training. Proper training can increase stroke volume during maximum and submaximal efforts by as much as 50%.

Long, slow endurance training at low heart rates (110 to 130 bpm) appears to work best for improving stroke volume. Astrand and Rodahl (1977) suggested that training speeds between 50% and 60% of maximum were ideal for this purpose. Low heart rates will increase stroke volume more because at high rates the ventricles of the heart do not have time to fill completely with blood between beats. Thus, although cardiac output is greater at fast speeds, stroke volume will be lower and the training effect will diminish.

After low-intensity endurance training has increased an athlete's stroke volume, swimming endurance sets at higher intensity will train the heart to fill at a faster rate so that the athlete can maintain more of the percentage increase in the maximum stroke volume at near-maximum heart rates (Gledhill, Cox, and Jamnik 1994; Spina et al. 1992). This second step is a necessary one because athletes must be able to maintain a large stroke volume at a high heart rate if they want to increase their maximum cardiac output and make more oxygen available to the muscles in races.

The effects of training on stroke volume can be monitored by charting swimmers' heart rates during standardized training sets that produce heart rates between 120 and 170 bpm for most swimmers. Any decrease in heart rates at these submaximal speeds indicates that stroke volumes have increased.

Increasing Muscle Capillaries Research has shown that endurance training will increase the number of capillaries around alveoli and muscle fibers (Brodal, Ingjer, and Hermansen 1976; Carrow, Brown, and Van Huss 1967; Hermansen and Wachtlova 1971). Of the two, the increase of capillaries around individual muscle fibers has the greater effect on improving endurance. Several studies have shown an increase of 15% to 50% after long-term endurance training (Andersen 1975; Brodal, Ingjer, and Hermansen 1976).

An increase in the number of capillaries around muscle fibers can significantly increase the amount of oxygen that diffuses from the blood into the muscles. Untrained persons usually have three or four capillaries around each muscle fiber, whereas trained endurance athletes have four to six around each muscle fiber (Saltin et al. 1977).

You should be aware that capillary increases take place only around muscle fibers used in training. Many of the other circulatory adaptations I mentioned earlier are general in nature, that is, they involve the heart and large arteries that serve all areas of the body. Any type of endurance exercise could produce those adaptations, which would benefit any other type of work. For example, an increase in stroke volume produced from running would benefit athletes when they swim. But capillaries are different. The increase is specific to the muscle fibers that are trained. Capillaries do not move from muscle fibers where they were increased through training to other muscle fibers. The number of capillaries will increase around a muscle fiber only when the demand for oxygen in that particular fiber is greater than its supply. In other words, running may improve the capillaries around many of the leg muscles, but it will not increase the number of capillaries around arm and trunk muscles. For that reason swimmers should do most of their aerobic training in the pool to ensure that they increase the number of capillaries around the muscle fibers they will use in races. They should use other forms of endurance training only as supplements to swim training, not as substitutes for it.

Improved Blood Shunting Because it causes the most substantial increase in blood flow to the working muscles during exercise, improved blood shunting may be the most important training effect for improving performance. The human body contains about 5 L of blood. At rest, the total volume is equally distributed to all tissues. During exercise, however, shunting sends more blood to the working muscles while reducing the supply to nonworking muscles and other tissues. For example, at rest only 15% to 20% of the total blood volume goes to the skeletal muscles, whereas during exercise that amount increases to 85% or 90% of the total (Mathews and Fox 1976). More oxygen and other nutrients thus go where they are needed. Shunting also increases the amounts of carbon dioxide and lactic acid that can be removed from working muscle fibers during exercise.

Training will increase the proportion of blood that flows to working muscles during maximum efforts (Clausen et al. 1973; Keul, Doll, and Keppler 1972; Saltin 1973; Simmons and Shephard 1972), which will have a significant positive effect on performance. Henriksson (1977) reported an 8% increase in the amount of blood flowing to trained muscles during exercise.

Endurance training is probably the most effective way to increase blood flow to working muscles during exercise. The question of whether the effect is greatest at low, moderate, or fast endurance training speed remains unresolved. I would speculate that fast endurance training might increase the dilation of vessels and, therefore, be more effective than slow- or moderate-speed endurance training for improving the shunting response. I am sure, however, that the training must use the same muscle fibers the swimmers use in competition so that the vessels trained to dilate more rapidly will be those supplying the muscles that swimmers use in races. In other words, swimmers will achieve the best training effect by swimming.

Increasing Mitochondria Mitochondria are the small "chemical plants" in muscle cells where aerobic metabolism takes place. They are constructed of proteins. Both slow-twitch and fast-twitch muscle fibers contain many mitochondria, but they are more numerous in slow-twitch fibers. Training causes an increase in both the size and the number of mitochondria in both types of muscle fibers (Morgan et al. 1971). An increase of 120% in the size of mitochondria was reported in human subjects after 28 wk of endurance training, and the increase in number varied between 14% and 40% (Kiessling, Piehl, and Lundquist 1971). Another study (Rosler et al. 1985) reported an increase in total volume of 40%, encompassing increases in both mitochondrial number and size.

Mitochondrial increases help in one important way: to reduce the rate of lactic acid production. With more mitochondria available, aerobic metabolism can take place in a greater number of locations within each muscle fiber. More energy will therefore become available from aerobic metabolism during each minute of exercise, provided the oxygen supply is adequate. This effect (and, perhaps, an increase in myoglobin) probably permits trained athletes to use a larger percentage of their $\dot{V}O_2$max without increasing lactic acid production.

Swimming is the best method for increasing the mitochondrial size and number in swimmers' muscle fibers. These training effects also take place only in muscle fibers that are exercised. Therefore, nonswimming training that does not use the same muscle fibers that swimmers use in competition will not increase the size and number of mitochondria in the relevant muscle fibers. For that matter, pulling will not increase the number and size of mitochondria in swimmers' leg muscles, nor will kicking increase the size and number of mitochondria in the arms, shoulders, and trunks. To carry this example even further, long, slow endurance training can increase the size and number of mitochondria in slow-twitch muscle fibers. But to increase the mitochondrial size and number of fast-twitch muscle fibers, swimmers must perform endurance training at moderate to fast speeds. Consequently, they must do their endurance swimming at a variety of speeds, ranging from slow to fast, to increase the size and number of mitochondria in all the muscle fibers they will use in races.

Let me add a word of caution here. Too much high-speed endurance training may be counterproductive to achieving this training effect. Endurance training should generally not be conducted at speeds that produce severe acidosis nor should it be performed when muscle glycogen is nearly depleted. Such efforts may damage mitochondria beyond repair, and overtraining will occur if they are subjected to severe acidosis too often (Gullstrand 1985). Damage can also occur if the protein in these structures is metabolized for energy, as would occur when swimmers train with an inadequate supply of muscle glycogen. High-speed endurance training to increase the size and number of the mitochondria in fast-twitch muscle fibers should occur sparingly during each week, and only for short periods, so that the mitochondria in these and other muscle fibers will not be damaged too much. Endurance athletes should know that they can also increase the size and number of mitochondria in fast-twitch muscle fibers by swimming at moderate speeds for long periods because fast-twitch fibers tend to rotate in to perform the work of fatigued slow-twitch muscle fibers during such swims.

Altitude training also appears to increase the mitochondria in muscles (MacDougall et al. 1991) and may be more effective for this purpose than training at sea level.

Increasing Aerobic Enzymes When mitochondria increase in size and number, the quantities of aerobic enzymes they contain will also increase (Morgan et al. 1971). The significance of this change is that aerobic metabolism will proceed at a faster rate when larger quantities of enzymes are available to operate the process.

Increases in the size and number of mitochondria and concomitant increases in the activity of the aerobic enzymes they contain may improve an athlete's anaerobic threshold more than it improves the maximum rate of oxygen consumption ($\dot{V}O_2$max). Training appears to increase the activity of aerobic enzymes out of proportion to the improvements in $\dot{V}O_2$max that result from that training (Gollnick and Hodgson 1986; Gollnick et al. 1972), and enzyme activity continues to increase even after improvements in $\dot{V}O_2$max no longer occur (Wilmore and Costill 1999). Therefore, the increased activity of aerobic enzymes may have more to do with continuing exercise at some percentage of $\dot{V}O_2$max than it has to do with increasing $\dot{V}O_2$max itself (Davies, Packer, and Brooks 1981). At the same time, improvements in $\dot{V}O_2$max may be more closely tied with the capacity of the circulatory system to deliver oxygen to working muscle fibers than with the ability of the muscle fibers to use that oxygen in aerobic metabolism (Rowell 1974).

The same range of slow- to fast-speed endurance training that produces increases in the mitochondria of fast-twitch and slow-twitch muscle fibers should also increase the activity of the aerobic enzymes in those fibers. Large volumes of slow endurance training can increase the activity of aerobic enzymes in slow-twitch muscle fibers. The greatest increases have been found when training levels require athletes to use a high percentage (70% to 80%) of their maximal oxygen consumption, probably because training at that level also causes the fast-twitch muscle fibers to rotate in and carry some of the workload (Henriksson 1992). Although intense, that training must remain within the athlete's ability to maintain a balance between the rates of production and elimination of lactic acid so that muscle pH remains near normal levels. A low muscle pH will reduce the activity of certain aerobic enzymes and cause a shift toward a greater rate of lactic acid production. That effect is opposite the one desired. The athlete wants to increase the activity of these enzymes while also encouraging more rapid metabolism of pyruvate and hydrogen ions through oxidation. Therefore, the bulk of the training for improving the aerobic enzymes should occur at or below the athlete's anaerobic threshold, with only a small volume of training conducted at faster speeds.

Altitude training may be more effective than sea-level training in producing an increase in the activity of the enzymes of aerobic metabolism. Given the close relationship between the size and number of mitochondria and the activity of aerobic enzymes, and the finding that altitude training is effective in improving the former, it stands to reason that altitude training should improve the latter.

Increasing Myoglobin Myoglobin is the iron-containing protein in muscle fibers that gives them their reddish color. Myoglobin serves two functions in the muscle cells. Most important, it absorbs the oxygen that diffuses into them and transports it to mitochondria where it can be used in aerobic metabolism. The second purpose is to store small amounts, approximately 240 ml, of oxygen in the muscle cells. That reserve is used during the first several seconds of exercise, providing oxygen to the mitochondria until an additional supply arrives through the circulatory system. Slow-twitch muscle fibers contain approximately one-third more myoglobin than their fast-twitch counterparts, which accounts for the darker red appearance of the former and the white (actually pink) hue of the latter (Nemeth et al. 1983).

Research has reported that training increases the myoglobin content by 80% in the muscles of rats (Pattengale and Holloszy 1967), but research with human subjects has failed to produce this effect. For example, Svedenhag, Henriksson, and Sylvan (1983) could not produce an increase of myoglobin in a group of human subjects after 8 weeks of training, and Jansson, Sylven, and Sjodin (1983) reported that the amount of myoglobin was similar in the muscles of untrained persons and endurance-trained athletes. Training at altitude, however, may increase the quantity of this substance. Persons who live at high altitudes have as much as 16% more myoglobin in their muscles (Reynafarje 1962). Evidence is not conclusive about whether training at altitude for short periods can produce increases of this magnitude or if one must live at altitude for long periods to attain it.

Regardless of the lack of scientific proof, the possibility remains that training, at altitude or at sea level, can increase myoglobin. A reasonable assumption is that a substance that serves such an important function during exercise would be amenable to increases with proper training. Indeed, most studies show that the muscles of endurance-trained animals have more myoglobin than those of their less trained counterparts (Hickson 1981; Lawrie 1953). Coaches and athletes should therefore consider myoglobin increases as one of the important outcomes of endurance training, and they should plan programs to encourage this effect until evidence to the contrary is overwhelming.

The literature has given little attention to the type of training that might be most effective for improving the myoglobin content of muscles. One can reason, however, that athletes should train at speeds that produce near-maximum to maximum levels of oxygen consumption. The slow-twitch fibers already contain significant amounts of this substance and would be likely to increase that amount minimally unless stimulated almost to the point of failure in their ability to deliver oxygen to the mitochondria. At the same time, the fast-twitch muscle fibers, which have the greatest potential to improve their myoglobin content, will become active only after the intensity of training is great enough to require athletes to use a large fractional component of their $\dot{V}O_2$max, perhaps 70% to 80% of maximum capacity (Andersen and Sjogaard 1975).

Improving the Glucose-Alanine Cycle

Protein can also play a small role in reducing the production of lactic acid during exercise through a process known as the *glucose-alanine cycle* (Felig and Wahren 1971). Some of the pyruvate formed as a product of anaerobic metabolism binds with ammonia to form alanine in this process. As a result, that pyruvate will not be available to combine with hydrogen ions, so less lactic acid will be produced. The alanine produced in this process will be transported to the liver, where it can be converted back to glucose as part of another process, the *Cori cycle*. That glucose then reenters the bloodstream, which carries it to the muscles where it can be used to recycle ATP.

The glucose-alanine cycle functions during short sprints as well as during endurance events, although it is doubtful that it would have any positive effect on performance in events shorter than 100 yd or m in length (Weicker et al. 1983). The rate of pyruvate formation, and thus ATP recycling, by anaerobic metabolism is the major factor in maintaining speed in these events, not the removal of pyruvate. But removing some of the pyruvate by converting it to alanine may have a significant effect on reducing acidosis in long sprints and endurance events because the process has the effect of reducing the amount of lactic acid produced at any particular swimming speed. The bar graphs in figure 11.3 illustrate the results of a study by Felig and Wahren (1971) on alanine production during exercise. The graphs show that the content of alanine in muscles more than triples when the intensity of endurance exercise increases to a high level. Weicker and coworkers (1983) also reported high concentrations of alanine in the muscles of runners after races ranging from 100 m to 1,500 m in length. Therefore, this process may contribute significantly to reducing lactic acid production in muscles at any swimming speed, including high speeds.

Studies suggest that the conversion of glucose to alanine is a trainable response (Brooks and Fahey 1984; Weicker et al. 1983), perhaps in part because the activity of the major enzyme that regulates this reaction, *alanine transaminase*, increases with training (Mole et al. 1973). Little is known, however, about the relative effectiveness of low-, moderate-, and high-intensity swimming for producing this training effect.

Improving the Malate-Aspartate Shuttle

A mechanism known as the malate-aspartate shuttle can reduce the rate of lactic acid production by removing some hydrogen ions before they combine with pyruvic acid to form lactic acid. The process begins in Krebs cycle where aspartic acid is formed in the process of converting malic acid to oxaloacetic acid. As part of this conversion, hydrogen ions are released from NADH so that they can enter the electron transport chain. Once the hydrogen ions have been released, the NAD$^+$ that remains is free to pick up other hydrogen ions before they can combine with pyruvic acid and lower muscle pH.

The major enzymes of the malate-aspartate shuttle, *aspartate transaminase* and *malate dehydrogenase*, have been reported to increase as much as 60% in humans after endurance training (Holloszy 1975). Therefore, the malate-aspartate shuttle may play a small but important role in reducing lactic acid production during exercise.

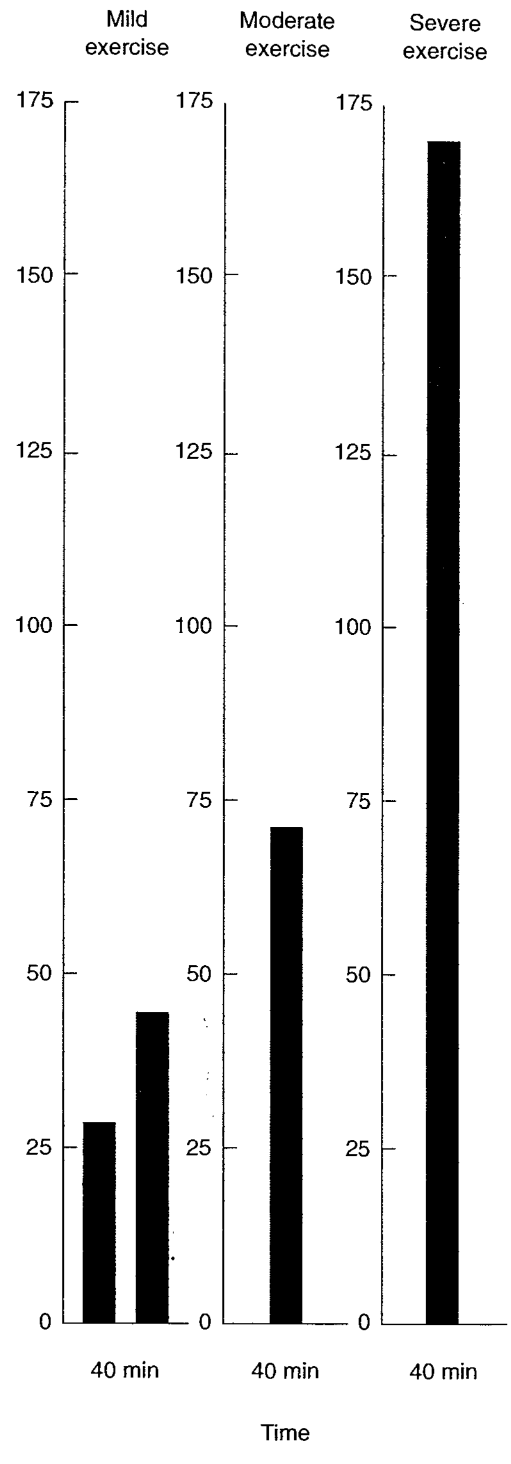


Figure 11.3 The effects of three bouts of exercise at different intensities on alanine production.

Adapted from Felig and Wahren 1971.

Increasing the Rate of Lactate Removal From Muscles and Blood

In the past, lactic acid was thought to be a waste product of anaerobic metabolism that was produced during exercise and remained in the muscles and blood until it was removed during the subsequent recovery period. The results of many studies have now made it clear that this substance is simply an intermediate product of the metabolic process and that it is removed continuously during exercise as well as during recovery. The amount of lactic acid that accumulates in muscle fibers during exercise is therefore the difference between the amount produced in the muscle fibers and the amount removed from them during that exercise.

When exercise intensity is well below the ability of working muscle fibers to oxidize pyruvate and hydrogen aerobically, the lactic acid formed early in the work, when the oxygen supply was temporarily inadequate, will be transformed back to pyruvate and hydrogen and oxidized within those muscle fibers. The mechanism of lactate removal is not important at those levels because not much lactic acid will be accumulating. But lactate removal becomes increasingly important to good performance at race speeds. As we know, the energy demand of all swimming races greatly exceeds the ability of aerobic metabolism to supply that energy, so anaerobic metabolism and the production of lactic acid supplies the remaining amount. Any mechanism that can remove some of that lactic acid from its production site, the working muscle fibers, will delay the rate of pH decline in those muscles during races, which will allow athletes to maintain faster speeds for longer periods. Obviously, a faster rate of lactate removal will result in a slower decrease in muscle pH, so any improvement in that rate that training can bring about should benefit performance considerably. Indeed, several experts have suggested that increasing the rate of lactate removal from working muscle fibers can significantly reduce the rate of acidosis in muscles during exercise. Several studies have reported significant relationships between the rate of lactate removal from muscles and blood and performance (Messonnier et al. 1997; MacRae et al. 1992).

Lactate Removal Process

The removal of lactate out of working muscles appears to be the result of both passive diffusion and active transport (Juel 1997). The rate of diffusion depends on the difference between the lactate concentration within the muscle fiber and the concentration in the blood or other body compartments. When exercise causes high rates of lactic acid production within the muscle fibers, more will tend to move out of them. In time, however, the amount in the blood could increase to the point where the difference in concentration, and thus the rate of diffusion out of muscle fibers and into the blood, would decrease. Therefore, this process also depends on the rate at which lactate can leave the blood and be picked up by other tissues because the rapid loss of lactate from the blood permits the maintenance of a high concentration gradient between the muscle fibers and the bloodstream.

Scientists have only recently identified the existence of a transport system that *pushes* lactate out of the muscles (Roth and Brooks 1990; Juel 1997). The nature of the carrier is believed to involve a system of proteins in muscles and blood, some of which have been identified as moncarboxylate transporters 1 through 7 (MCT1, MCT2, MCT3, and so on) (Wilson et al. 1998). The significance of a system for lactate transport out of the muscles and out of the blood is that lactate can be removed even when the concentration gradient does not favor maximum rates of diffusion. Researchers have estimated that lactate transport accounts for 50% to 75% of the lactate removed from muscles during exercise (Juel 1997).

As mentioned in chapter 10, some of the lactic acid can be transported from the protoplasm of the muscle fibers where it was produced directly into the mitochondria of the same muscle fibers, where it can be converted back to pyruvate and oxidized (Brooks et al. 1996). This can occur while exercise is ongoing. Most of the lactic acid removed in this way is produced in slow-twitch muscle fibers. A portion of the remaining amount can be transported out of the muscles and into adjacent muscle fibers, where it can be oxidized (Juel 1997). This method of removal occurs principally in fast-twitch muscle fibers, where most of the lactic acid is produced, into slow-twitch muscle fibers, where the increased size and number of mitochondria allow for greater oxidation of this substance (Mazzeo et al. 1986).

Another portion of the remaining lactic acid can be transported into the blood and carried to other parts of the body, principally the liver and other nonworking muscle fibers, where it can be oxidized and used for energy, or to the heart, where it can used for energy in its present form (Ahlborg, Hagenfeld, and Wahren 1975; Poortmans, Delescaille-Vanden Bossche, and Leclercq 1978; Rosler et al. 1985). The amount not removed will remain in the muscle fibers where it will cause a reduction in their pH. Another physiological mechanism that will be discussed later, buffering, can delay the extent of that reduction.

All the processes that remove lactic acid from working muscle fibers contribute to delaying the rate and extent of a decline in muscle pH, which in turn allows athletes to maintain a faster rate of anaerobic metabolism despite the fact that they are producing large amounts of lactic acid. Therefore, the significance of removing lactate from working muscle fibers is that athletes will be able to maintain a higher rate of muscular contraction, greater stroking power, and thus faster swimming speeds for a longer time before severe acidosis causes them to slow down. Consequently, the removal of lactic acid provides a means for athletes to swim at faster speeds than they could maintain through aerobic metabolism alone, without increasing the rate of acidosis occurring within their working muscle fibers.

Estimates are that between 60% and 70% of the lactate removed is metabolized to CO_2 and water in the working muscle fibers and other muscle fibers throughout the body. The remaining amount goes to the liver and heart, where it is converted back to glycogen and stored. Most of that conversion and storage takes place in the liver.

Obviously, training effects that increase the rate of lactic acid removal should play a major role in improving performance. That role should be most significant in middle distance and distance races because of the total amount of lactic acid that can be removed over time. The effect should also be significant in shorter races. Races that last less than 2 min require a high rate of energy release, yet they are so short that athletes cannot consume a large amount of oxygen. As a result, the rate of anaerobic metabolism will greatly exceed the ability of the aerobic system to oxidize most of the pyruvate and hydrogen ions being generated, so large amounts of lactic acid will be produced in the athlete's muscles. Severe acidosis should be delayed somewhat if a significant amount of that lactic acid can be removed from the muscles during the race. Findings of blood lactate levels of 8 to 18 mmols/L after 50 and 100 races (Maglischo, unpublished, 1984) substantiate the belief that a significant amount of lactate can be removed from muscles within the first minute of exercise.

I should make it clear that most of the lactic acid produced during fast, intense swimming will remain in the muscle fibers. Lactate production rates will be very rapid, and lactate removal rates are simply not fast enough to prevent this substance from accumulating in the muscles. Experts have stated that the maximum rate of lactic acid production within muscle fibers is two to three times greater than its rate of removal from them (Bangsbo et al. 1990; Juel et al. 1990; Hultman and Sjoholm 1986; Hultman and Sahlin 1981). Thus, although the process of removing lactate from muscles during exercise can delay the onset of acidosis, most of the lactic acid produced will not be removed. For example, muscle lactic acid contents of 28 to 35 mmols/L have been reported after only 30 sec of high-speed cycling (Hultman and Sjoholm 1986), yet blood lactate reaches only 8 to 12 mmols/L in the same time. At the same time muscle lactic acid concentrations between 45 and 50 mmols/L have been reported in humans at the point of exhaustion from intense efforts (Juel 1997), yet maximum blood lactates of only 15 to 20 mmols/L were found under similar circumstances. The graph in figure 11.4 shows the relationship between muscle and blood lactate concentrations after 3 min of maximum effort.

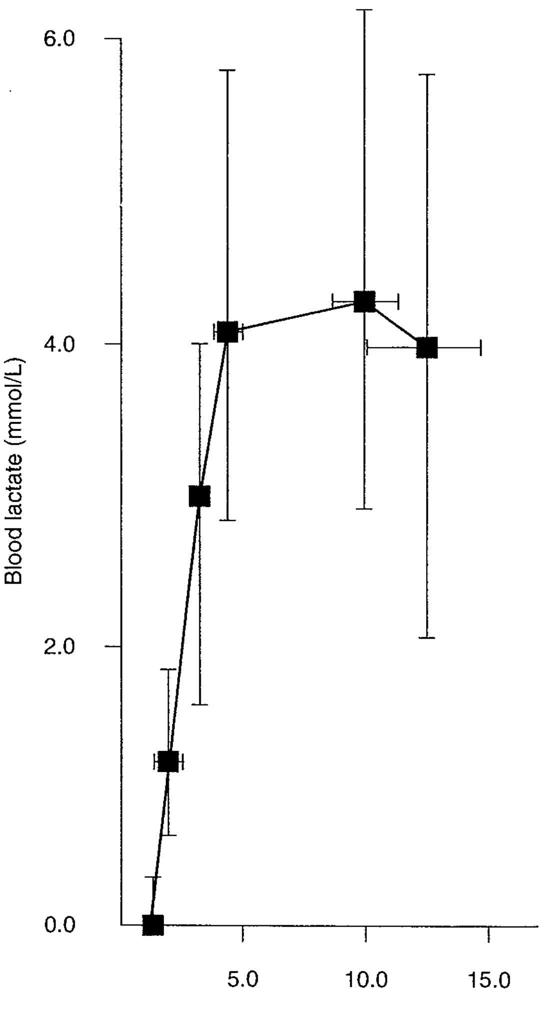


Figure 11.4 Muscle and blood lactate concentrations after 3 min of exhaustive exercise.

Adapted from Juel, Bangsbo, Graham, and Saltin 1990.

Answers to two questions will aid in understanding the significance of lactate removal during exercise to performance:

1. What is the maximum rate of lactate removal from muscles?
2. How much can training increase it?

Maximum Rate of Lactate Removal

Scientists disagree about the first of these questions. The results of several studies have indicated that the maximum rate of lactate transport out of working muscle fibers and into the blood is between 4 and 9 mmols/min during exercise (Juel et al. 1990; Katz et al. 1986; Lindinger, McKelvie, and Heigenhauser 1995; Jorfeldt, Juhlin-Dannfelt, and Karlsson 1978). But Saltin (1990) reported that many human subjects in a study he conducted had peak values of lactate release from the muscles that approached 20 mmols/min. Another study reported peak lactate removal rates between 12 and 16 mmols/min (Bangsbo et al. 1990).

Obviously, rates of lactate removal of 10 to 20 mmols/L would have a significant effect on reducing muscle lactate accumulation during exercise. The pattern of lactate removal seems to mirror that of oxygen consumption during exercise. Approximately 1 to 2 min after exercise begins, lactate removal rates reach a peak (Bangsbo et al. 1990). Thus, this process cannot be mobilized immediately. Therefore, the mechanisms for removing lactate from muscles may not be any more effective than mechanisms involving oxygen consumption in delaying the onset of acidosis during short sprint events.

The process of lactate removal should certainly help delay acidosis during long sprints, middle distance, and distance races and during practice repeat sets. The question that remains is whether training can improve this rate enough to cause a significant improvement in athletes' times for these races. Only a few studies have examined the effects of training on lactate removal during exercise, and the majority have used animals rather than humans for subjects. Most have reported significant improvements in this mechanism (Donovan and Brooks 1983; Donovan and Pagliassotti 1990; Fukuba et al. 1999; MacRae et al. 1992; MacRae, Noakes, and Dennis 1995; Oyono-Enguelle and Freund 1992).

Training to Improve Lactate Removal

To date, only a few studies have involved human subjects. In one, the subjects trained on cycles for only 10 days, 2 hr per day, at light to moderate effort (Phillips et al. 1995). Despite the low intensity of training, the cyclists improved the rates of lactate removal from their blood by an average of 40%. In another study, subjects who trained on bicycle ergometers for at least 45 min per day and 5 days per week at an intensity near their individual anaerobic thresholds improved their rates of lactate removal by an average of 26% (MacRae et al. 1992). This figure is similar to the expected percentage improvement in maximal oxygen consumption after training.

Cross-sectional studies with humans in which the lactate removal ability of athletes and trained persons was compared with that of nonathletes and untrained persons also suggest that this process is highly trainable. One of these studies found no difference between untrained and trained subjects in their rate of lactate removal from muscles to blood. On the other hand, trained athletes had a much higher removal rate. The evidence is inconclusive about whether the reported difference is the result of training or simply because of the fact that trained athletes had a greater inherited ability to transport lactate out of their muscles.

Training to improve lactate removal probably requires a mixture of low-, moderate-, and high-intensity distance swimming. Slow to moderate endurance training should improve this rate in the slow-twitch and FTa fibers, whereas training speeds equivalent to 100% of $\dot{V}O_2$max and higher are necessary to improve that rate in FTb muscle fibers. In this way, training to improve the rate of lactate removal from the various types of muscle fibers is similar to training that improves oxygen consumption in the same fibers. Studies with rats, if the results transfer to humans, suggest that training at speeds exceeding those of $\dot{V}O_2$max produced the highest rates of muscle lactate removal, probably because all three types of muscle fibers were being recruited at those speeds.

The research of Treffene and his coworkers (1980) offers additional support for training at speeds exceeding the anaerobic threshold. Using human subjects, they suggest that the maximum rate of lactate removal from muscles to blood takes place at speeds that are 6% to 14% faster than those at which the anaerobic threshold occurs. In the study by Bangsbo and associates (1990) the highest rates of lactate removal occurred at blood lactate concentrations between 6 and 12 mmols/L (average 8 mmols/L).

Although research suggests that swimming endurance repeats at high intensity provides the greatest improvement in lactate removal rates, there is also evidence that lactate transporters become less effective as muscle pH declines (Roth and Brooks 1990). Consequently, athletes should try to delay acidosis during their repeat sets by descending their times or by doing the repeats in shorter sets. When using the latter method, the sets should end before acidosis sets in, and a brief period of rest should follow each set to restore muscle pH to near normal before the next set begins.

Improving Buffering Capacity

Muscle lactic acid levels can increase four to five times above resting levels before the pH of the muscle drops appreciably. This occurs principally because of the buffers that bind with hydrogen ions and weaken their effect on muscle pH. Substances that can serve as buffers include bicarbonates, collectively known as the alkaline reserve, muscle proteins, and creatine phosphate.

Two statements reveal the significance of buffers to exercise:

1. Buffers can react with lactic acid to delay the rate of impending acidosis almost immediately after exercise begins (Guyton 1964).
2. The accumulation of lactic acid in muscles after a 100 m race would decrease the pH to 1.5, instead of the typical values of 6.6 to 6.8 if buffers were not present (Parkhouse et al. 1983).

Buffers are contained in both the blood and muscle cells in three principal forms, as bicarbonates, phosphates, and proteins. Sodium bicarbonate and the protein hemoglobin are most prevalent in the blood, and the muscles contain potassium and magnesium bicarbonate in larger amounts. Phosphates principally occur within muscle fibers in the form of sodium phosphate. But by far the most abundant source of buffers in the body is various proteins housed within the muscle fibers.

As mentioned, sodium bicarbonate and hemoglobin are the principal buffers of the blood. Hemoglobin is the most effective of the two. The significance of blood buffers is that they can delay a drop in blood pH during exercise so that more lactate will be transferred from the working muscle fibers, where the pH is lower, to the blood, where it is higher.

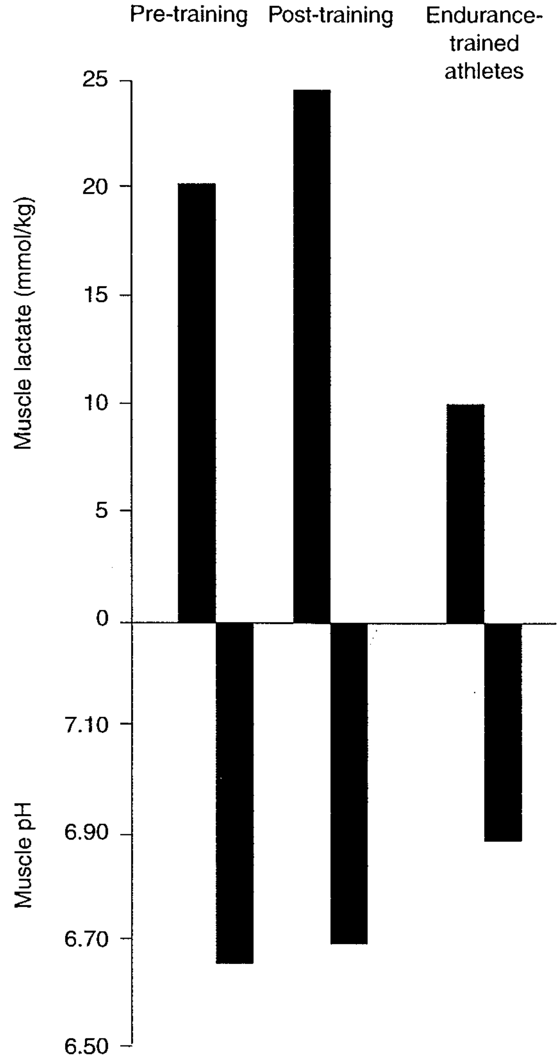


Figure 11.5 The effect of sprint training on buffering capacity in human skeletal muscle fibers.

Adapted from Sharp, Costill, Fink, and King 1986.

Creatine phosphate may also serve a buffering function although the extent to which it can help in stabilizing muscle pH is not known at this time (Henriksson 1992b). This fact points to the possibility that creatine loading might improve the buffering capacity within human muscle fibers.

Buffer systems can react almost immediately when exercise begins to prevent drops in muscle pH. Consequently, this process is probably important to success in 100 and 200 races. It may also play a small role in maintaining a faster speed in the final 10 to 12 yd or m of 50 races. The speed required in these races is so fast and the duration is so brief that most of the energy must come from anaerobic metabolism. Particularly in 50 and 100 events, there is not enough time to consume the oxygen needed to run the aerobic system. Therefore, buffering probably plays at least as great a role in delaying acidosis as lactate removal and oxygen consumption, if not greater.

For a long time, scientist believed that training could not improve buffering capacity. A study by Sharp and his associates (1986) was one of the first to demonstrate that it could. These researchers reported an average improvement of 37% in buffering capacity (ranging from 12% to 50%) for a group of subjects who trained anaerobically. This improvement coincided with an average increase of 22% in their performance on a sprint cycling test to exhaustion. Proof of an increase in buffering capacity after training was provided by the fact that the amount of lactic acid in the subjects' muscles was, on average, 19% greater after an all-out effort when muscle pH had dropped to 6.70 and lower. The subjects in this study trained for 8 weeks, 4 days per week. During each training period they completed eight, 30 sec all-out rides on a bicycle ergometer with a 4 min rest period after each ride. Bar graphs depicting changes in their muscle lactic acid accumulation and its effect on muscle pH both before and after training are shown in figure 11.5.

The effects of training on blood buffering capacity are less certain. Most studies have found no change after training (Robinson and Harmon 1941; Sharp et al. 1983). Traditional forms of endurance training were used in those studies, however, and buffering capacity is unlikely to improve with that form of training. Research has not yet resolved whether sprint training can also increase the buffering capacity of blood.

Some athletes have tried to increase the buffering capacity of their blood by ingesting bicarbonate substances before long sprint events, a procedure known as *soda loading*. Results of these studies have been mixed. Most have reported improvement in performance (Juel 1997; Williams 1998).

Sprint training can improve buffering capacity. On the other hand, endurance training does not improve this process and may even reduce its effectiveness. Training that reduces muscle pH is probably required to increase muscle buffering capacity because acidosis is probably the stimulus for adaptations that will increase the quantities of buffers in muscles. In this respect, McKenzie and coworkers (1983) showed that 800 m runners had significantly greater buffering capacity than a group of marathon runners and untrained subjects. On the other hand, the buffering capacity of marathon runners was no different from that of the untrained subjects. Contrary to this finding, Sharp and his team of researchers (1986) reported that the ability of endurance-trained cyclists to accumulate high levels of lactic acid in muscles was actually lower than that of untrained persons. Figure 11.5 shows the average concentration of muscle lactic acid for trained endurance cyclists after an exhausting cycling sprint.

Results like these suggest that endurance training will not improve buffering capacity and may even diminish it, whereas sprint training can increase it considerably. Care must be exercised with sprint training, however, because producing severe acidosis too frequently each week may destroy protein buffers instead of increasing them.

Improving Pain Tolerance

Besides its effect on reducing the rate of ATP recycling, severe acidosis also causes a burning pain in the muscles. That pain can affect the performance of athletes in a number of ways depending on their tolerance to it. A small number of athletes will slow down when they feel the pain of acidosis simply because they have a low tolerance for pain. Most athletes, however, are sufficiently motivated to push on in spite of that pain. Even so, the pain of acidosis can affect their races detrimentally. When they feel the pain of acidosis beginning in the middle of races, some athletes become concerned that they will not be able to finish strong so they slow down to lessen the pain. If they misjudge the effects of acidosis and slow down more than necessary, their performance suffers.

We do not know why some athletes tolerate the pain of acidosis better than others do. Certainly, it relates to their desire to succeed. As such, it may be a function of motivation and not amenable to training. On the other hand, some evidence indicates that pain tolerance is a trainable phenomenon. In one study, Hays, Davis, and Lamb (1984) believed they were able to improve the pain tolerance of rats with hard swim training because after training the rats were able to stay on a hot plate (55° C) longer before jumping off. Humans who test the limits of their tolerance to the pain of acidosis may be able to train themselves to ignore or at least tolerate that pain better. As a result, they may be able to persevere in races at speeds at which they previously might have slowed down unnecessarily.

Adaptations That Improve the Ability to Train

Training effects that improve the ability to train are important because they allow athletes to train at higher intensity for a greater number of days each season. This capability, in turn, should provide a greater stimulus for the production of training adaptations that will improve the ability to delay acidosis during races. Two major training effects that will improve an athlete's ability to train are an increase in muscle glycogen storage and an enhanced rate of fat metabolism.

Increased Muscle Glycogen Storage

Muscle glycogen provides the major source of fuel for all swimming events longer than 25 m. With a short rest and good diet, enough glycogen is usually stored in the muscles of athletes to provide all the energy they need for any of the events in a typical swimming program, even the 1,500 m freestyle. But training is a different matter. Even an hour of training can reduce muscle glycogen levels considerably.

The muscles of trained endurance athletes generally contain 120 to 160 g of stored glycogen per kg of wet muscle tissue. Estimates are that this is enough glycogen to permit them to swim at an intense pace for approximately 1.5 hr. In practice, however, fat and to a lesser extent protein are metabolized for energy so that the muscle glycogen stores may not become depleted in this time. Nevertheless, an athlete can expect to lose more than two-thirds of the glycogen in his or her muscles during a typical 2 hr training session.

The graph in figure 11.6 shows the results of a study in which the glycogen content of the deltoid muscles of swimmers was measured before and after a set of 40 × 100 yd repeats with a 15 sec rest interval after each swim. The athletes were instructed to swim the repeats at the fastest possible average. The graph shows that their muscle glycogen decreased, on average, from a high of 160 mmols/kg of wet muscle tissue before the set began to less than 80 mmols/kg after the set ended. Muscle glycogen levels were also measured 24 hr after that training session. As shown in the graph, the swimmers were able to replace only about half of the muscle glycogen they lost after resting for 1 day. Therefore, swimmers engaged in day-to-day training are likely to have low muscle glycogen levels. The extent to which swimmers will deplete their muscles of glycogen will be greater, of course, if training is more frequent, that is, twice per day. Swimmers who train twice per day generally have no more than 13 hr of rest between training sessions, so they are even more likely to have low muscle glycogen levels than swimmers who train once daily.

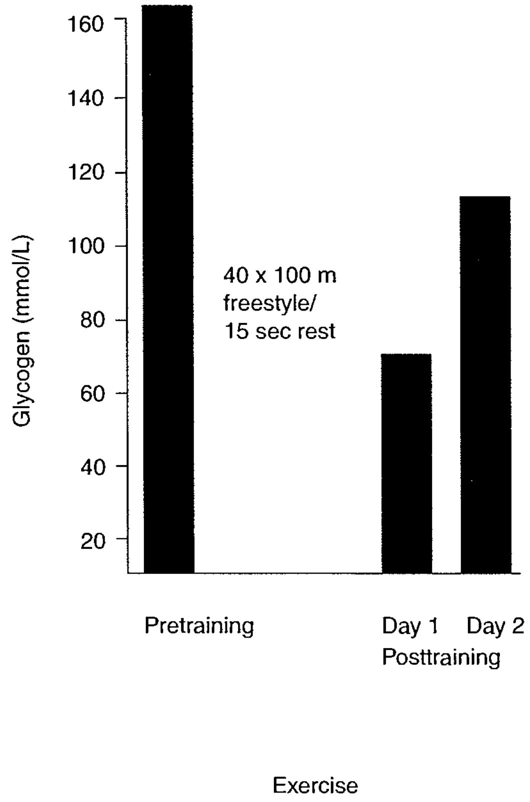


Figure 11.6 Glycogen depletion from the deltoid muscles of swimmers during a set of high-intensity endurance swims.

Adapted from Beltz et al. 1988.

The good news in this scenario is that endurance training increases the amount of glycogen that can be stored in the swimming muscles. Studies show that training can increase the amount of stored muscle glycogen by 40% to 60% (McArdle, Katch, and Katch 1996). The bad news is that this increase may be more potential than real. Athletes who train 2 or more hr per day probably deplete muscle glycogen faster than they can replace it from day to day. Therefore, the actual amount of glycogen stored in their muscles is probably always less than the maximum those muscles can hold. Consequently, swimmers probably realize the full potential of this increase in muscle glycogen only when they take a few days off or engage in a few days of extremely easy swimming. They then benefit from a supercompensating effect in which the amount of glycogen they store in their muscles exceeds their normal untrained values by the amounts indicated, 40% to 60%. Even with rest, however, athletes will not realize an increase of stored muscle glycogen unless they are eating a diet high in carbohydrates, one in which at least 60% of the calories they consume each day come from carbohydrates.

Another important effect of training pertaining to muscle glycogen is that athletes can reduce its rate of use. After several weeks of endurance training, athletes become capable of using greater quantities of blood glucose and fat to recycle ATP during long training sessions (Henriksson 1977; Henriksson 1992b; McArdle, Katch, and Katch 1996). This adaptation reduces the amount of muscle glycogen they lose from their muscles during each training session. As a result, they will have more muscle glycogen available for the next training session, and they will be able to train more intensely, more often, each week.

No special types of training are required to increase the amount of muscle glycogen that can be stored in muscles. A standard mixed program of endurance and sprint swimming will use large amounts of muscle glycogen each day and will provide adequate stimulus for increasing the amount stored in both fast-twitch and slow-twitch muscle fibers. Of course, the storage of glycogen will increase only in muscles used in training. Activities other than swimming may therefore be ineffective if they neglect important swimming muscles because the potential of those muscles to store glycogen will not improve.

Increased Fat Metabolism

The release of energy from fat metabolism is too slow to meet the demand for ATP replacement during even the longest swimming races. Fat metabolism can supply a substantial amount of energy for recycling ATP during the long hours of training, however, and less muscle glycogen will be used as a result. Consequently, fat metabolism spares muscle glycogen for use during the most intense repeats of the workout. Swimmers can thus perform those swims at faster speeds. Additionally, an increase in fat metabolism can reduce the amount of glycogen used during some workouts so that more will be available for subsequent sessions. With more glycogen available, athletes will be able to train intensely during more workouts each week.

One of the benefits of endurance training is that it will increase the amount of energy made available from fat at any submaximal swimming speed (Jeukendrup, Saris, and Wagenmakers 1998). Endurance training does this principally by increasing the amount of fat stored in the muscles and by increasing the muscle mitochondria so that more fatty acids can be oxidized (Holloszy et al. 1986). Before training, the percentage of the total energy furnished by fat during a normal 2 hr training session might be in the range of 35% to 40%. Training can increase this amount to 50% or 60% (Holloszy et al. 1986). Training increases fat use in males more than it does in females (Nicklas 1997). Generally, a greater percentage of a woman's body weight is made up of fat; therefore, women may naturally be more efficient than men are at using it for energy and less able to improve this function through training.

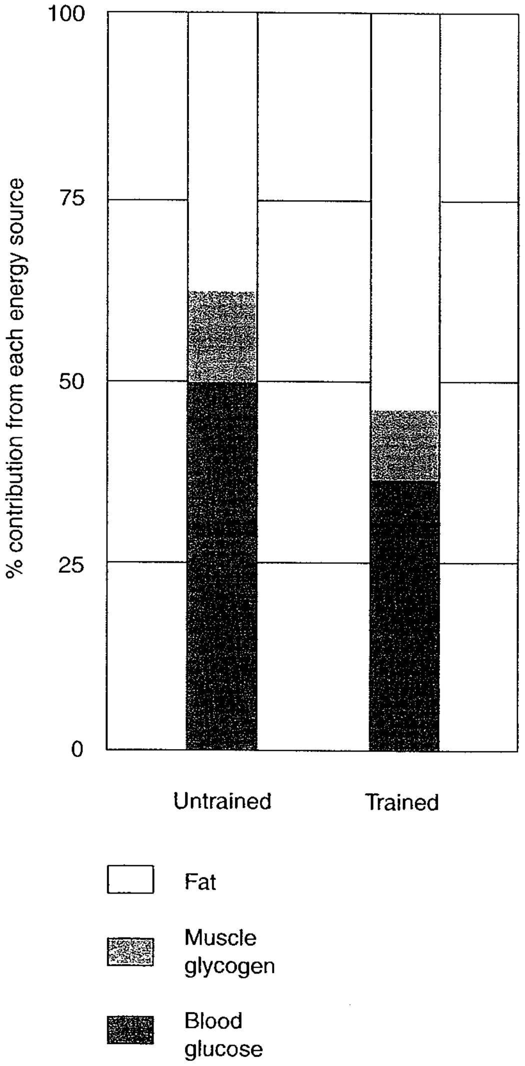


Figure 11.7 Changes in the percentages of fat, blood glucose, and muscle glycogen metabolized during moderate endurance efforts after training.

Adapted from McArdle, Katch, and Katch 1996.

The graph in figure 11.7 illustrates the change in percentages of energy supplied by fats, blood glucose, and muscle glycogen during exercise bouts at similar moderate intensity before and after training. The contribution from fat increases considerably, which in turn reduces the amounts of both muscle glycogen and blood glucose metabolized for energy.

The best training for improving fat metabolism is long, slow, distance swimming. This kind of training provides the best stimulus for increasing the rate of fat use because fat is a major source of energy at slow to moderate swimming speeds. In one study the greatest rate of fat metabolism occurred at efforts below 50% of maximum and at heart rates in the range of 130 to 150 bpm., or to be more accurate, at 70% of an individual athlete's maximum heart rate (Eisele et al. 1997).

The principal adaptation responsible for increasing the rate of energy release from fat is an increase in the activity of the enzymes of fat metabolism. This adaptation is specific to the fibers used in training; therefore, swimming is the best way to produce them.

Training Effects That Can Improve Performance

The following is a summary of training effects that contribute to improved performance in races and training.

Technique Effects

Improvements in stroke techniques reduce the energy required to swim at any speed below an all-out sprint.

Power Effects

Increased stroking power makes greater speed possible. Several factors can increase power:

1. Increases in muscular strength and contractile speed
2. An improved recruitment pattern so that the correct muscle fibers contract at the proper time
3. An increase in muscle creatine phosphate storage

Anaerobic Metabolism Effects

The primary training effect is an increase in the rate of recycling ATP by means of anaerobic glycolysis, which makes greater speed possible after the first 5 sec of a race. That effect results from an increase in the activity of anaerobic enzymes, primarily phosphorylase, phosphofructokinase, pyruvate kinase, and lactate dehydrogenase.

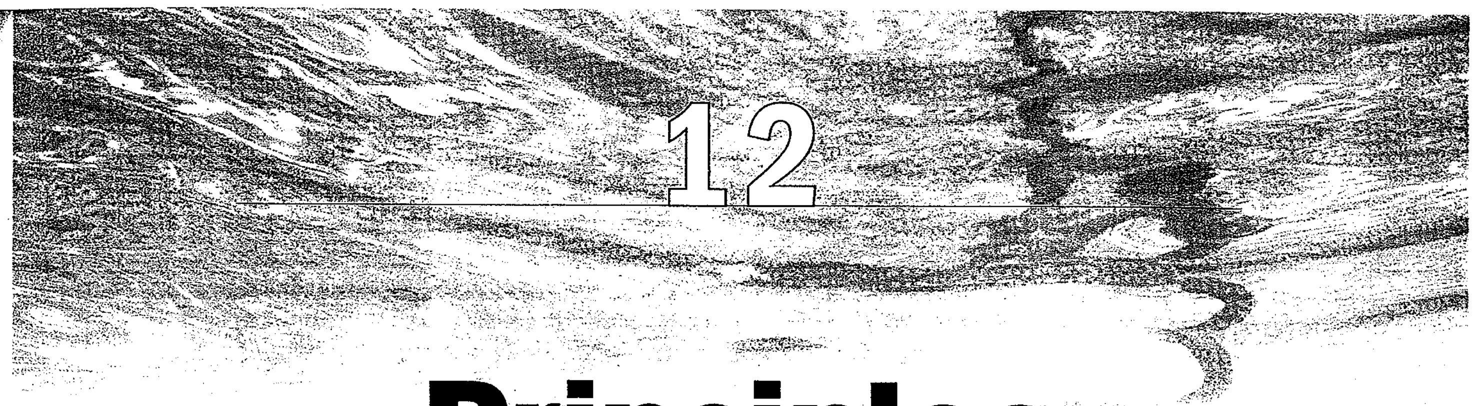
Aerobic Metabolism Effects

The desired training effect is to reduce the rate and severity of acidosis during races. That effect is the result of two factors—reducing the rate of lactic acid production within muscles and increasing the rate of lactate removal from them.

1. Many training adaptations reduce the rate of lactic acid production:
   - Increased diffusion of oxygen from the lungs, which results from improved volume of air exchanged each minute and an increase in the capillaries around the alveoli of the lungs
   - An increase in blood volume that permits blood to circulate through the body faster
   - An increase in red blood cells so that the blood can carry more oxygen
   - An increase in cardiac output so that the blood makes a quicker round-trip from the lungs to the muscles
   - An increase in capillaries around the muscles so that more oxygen can be made available for diffusion
   - Improved blood shunting so that more of the blood supply and its oxygen can reach the working muscles during each minute of exercise
   - An increase in myoglobin so that more oxygen can be transported to the mitochondria of the muscles each minute
   - An increase in the size and number of mitochondria in muscles so that the receptacles for aerobic metabolism will be larger and more numerous
   - An increase in the activity of the aerobic enzymes so that aerobic metabolism can proceed at a faster rate
   - An increase in the rate of the glucose-alanine shuttle so that more pyruvate can be removed before it combines with hydrogen ions to form lactic acid
2. Several training adaptations increase the rate of lactate removal from working muscle fibers:
   - Increased activity of the lactate transporter in working muscle fibers and in receptor fibers
   - Increased blood volume and improved cardiac output so that more blood can make the trip to and from working muscle fibers in a shorter time, thus transferring more lactate from the working muscle fibers to the blood and then to areas where it is removed during each minute of exercise
   - An increase in capillaries around the working and receptor muscle fibers so that more lactate can be transferred into and out of the blood during each minute of exercise
   - Improved blood shunting so that more lactate can be carried away from the working muscle fibers with each minute of exercise

Training Effects That Improve the Ability to Train

1. An increase in the amount of glycogen stored in working muscle fibers so that athletes can train more intensely more often
2. An increase in the rate of fat metabolism so that the muscles use more of this compound for energy and less glycogen, leaving more of the latter substance available for a greater number of intense training sessions



12

Principles of Training

New in this edition:

- An explanation of interval training
- The principles of individual responses to training and training reversibility
- A section on the training parameters of intensity, duration, and frequency

The previous three chapters were concerned with the *why* of training. The purpose of this and the chapters that follow in part II will be to describe *how* to train. I will attempt to apply the information from the preceding chapters to suggest training procedures based on sound scientific findings. The first step in this process is to describe the principles on which training is based.

Training Principles

No single method will best train each of the various energy systems of the human body. To be successful, however, all training programs must follow these principles:

- Adaptation
- Overload
- Progression
- Specificity
- Individuality
- Reversibility

Adaptation Principle

The purpose of training programs is to produce metabolic, physiological, and psychological changes that allow swimmers to perform better in competition. The term *adaptation* refers to changes that take place in response to training. The adaptive process occurs when the various organs and tissues of the body operate at a level greater than usual. Some functional insufficiency will occur initially because the organs and tissues are being asked to provide more force, more energy, more chemicals, and so forth than usual. Because of that insufficiency the organs and tissues will adapt in a variety of ways that will allow them to meet the demands being made.

Let me use the way that endurance training affects muscle mitochondria to illustrate the adaptation process. Proper types of endurance training will increase the demand for aerobic metabolism so that more energy can be provided for ATP recycling. In response, the available mitochondria will be stressed to the limit. Because of that stress, these "chemical factories" will become larger and more numerous. This change provides more and larger sites for aerobic metabolism so that the demand can be met. Thus, more oxygen will be taken from the blood passing by the muscle fibers and transported to the larger and more numerous mitochondria, where it can be used to oxidize more pyruvate before that pyruvate can combine with hydrogen ions to produce lactic acid.

As mentioned, some initial breakdown in function may occur early in development, a process called *catabolism*. Given sufficient time for recovery and an adequate supply of nutrients, however, those tissues will repair and rebuild to become larger, stronger, and more functional than before. The repair and rebuilding process is called *anabolism*.

Balance must be present between the catabolic and anabolic processes during training, or the desired adaptations will not occur. A loss of previously gained adaptations will occur if over time the catabolic process exceeds the ability of tissues to repair themselves. This process is termed variously as *failing adaptation* or *overtraining*, and athletes must avoid it. Steering clear of failing adaptation, however, is not so simple. The athlete must maintain a delicate balance between the catabolic and anabolic processes for tissues to adapt. If training is not sufficiently intense to cause some catabolism, stimulation for rebuilding will not occur and performance will not improve. On the other hand, if the rate of catabolism exceeds the rate of anabolism, the athlete's physiological systems and performance will deteriorate over time.

Some adaptations to training occur within days, whereas others may take weeks or months before they are of sufficient magnitude to improve performance. An athlete must generally train for 5 to 7 days before some kinds of improvements occur, such as increases in blood volume, blood shunting, and lactate removal. Those improvements can be significant within 10 to 20 days (Green 1996). Structural changes in and around the muscles, such as increases in enzymes, myoglobin, mitochondria, contractile protein, and capillaries, take more time. Significant changes can occur in 6 to 8 weeks, and improvements in some physiological functions may continue to occur for up to 4 yr with continuous training (Holloszy 1973).

The adaptation process includes at least three steps:

1. Create the need for specific adaptation with proper training.
2. Provide nutrients for growth and repair of tissues.
3. Provide enough rest for growth and repair to take place.

After an athlete has completed the adaptive process, the level of training that produced the adaptations will be sufficient only to maintain them and the level of performance they made possible. To improve performance even more, the athlete must increase the duration or intensity of training to create further adaptations. This idea brings us to the next two principles of training: overload and progression.

Overload Principle

The basis for the overload principle is that adaptations will not occur unless the demands of training are greater than the usual demands made on a particular physiological mechanism. When a person increases the usual demands on a system, we say that the system is *overloaded*.

Although simple in definition, the overload principle is complex in application. Although the demands of training must be sufficient to stimulate adaptation, they cannot be excessive or the training effect will be lost through injury or failing adaptation. In other words, if the amount of overload exceeds the tolerance of a particular physiological system by too great an amount, the system will simply break down, resulting in tissue injuries that will require a break from the current level or method of training so that repair can take place.

Progression Principle

As indicated earlier, a particular training load will overload a physiological system only until the system adapts to the load. At that point, the intensity or duration of the training load must increase if further adaptation and improvement in performance are to take place. The systematic process of increasing the overload of training is referred to as the principle of *progression*.

Athletes, including swimmers, cannot train at the same speed week after week and expect to continue improving their aerobic capacity or, for that matter, other physiological capacities. They must gradually increase their training intensity throughout the season to provide a progressive overload that will stimulate further improvements.

The typical approach to applying the principles of overload and progression to training is simply to ask swimmers to swim faster or farther or to swim their repeats with shorter rest periods. This type of training is often done with no regard to the type of overload being produced. The assumption is that athletes will improve if they are constantly challenged to exceed their best previous training performance. This method can be successful, but training can be more effective if coaches and athletes consider the type of overload being produced and the rate of progression being applied.

The nature of the desired training effect can be distorted by overloading incorrectly or by trying to progress too rapidly. For example, a repeat set designed to stress aerobic metabolism can instead become one that taxes anaerobic metabolism, buffering capacity, and pain tolerance by reducing the rest interval too much or by increasing the speed too rapidly. By the same token, a repeat set designed to improve anaerobic metabolism can easily turn into one that stresses aerobic metabolism if the distance is increased too far or the rest interval decreased too much. In other words, the training effect can become different than the one desired. Consequently, athletes may not achieve the desired balance between sprint and endurance training that produces optimum performance.

Progressive overload should be applied to sprint training and endurance training in different ways. For example, training designed to improve aerobic capacity should not be forced. Increases should take place as athletes demonstrate the ability to swim faster without additional stress. Many aspects of aerobic endurance improve best when athletes train slightly beyond their present ability to maintain a balance between lactic acid production and removal from the muscles. If athletes exceed that balance by too great an extent, they will simply go into acidosis before they have trained long enough to stimulate improvements in the various physiological mechanisms that reduce lactic acid production and increase its rate of removal.

Unlike training for endurance, training designed to improve sprint speed should be forced. Overloading by increasing the volume or density of such training serves no useful purpose. The most direct method to increase swimming speed is to try to swim faster. Finally, training designed to increase buffering capacity and pain tolerance must be forced. Swimmers will improve these abilities only by testing their limits. They can do this by swimming faster or with less rest between repeats, producing greater acidosis. They can also test their limits by swimming longer and extending the time of acidosis.

The most common form of training used by swimmers is interval training, a method that lends itself well to the application of progressive overload.

Interval Training

Interval training involves completing a certain number of swims or repeats with a period of rest after each swim. This combination is referred to as a *set of repeats.* Four variables govern the construction of such a set:

1. the *number* of repeats in the set,
2. the *distance* of each repeat,
3. the *rest interval* between each repeat, and
4. the *speed* of each repeat.

Example: 10 × 200/3:10 at moderate speed

The example indicates a repeat set that consists of 10 swims of 200 m. A send-off time of 3:10 is used in place of a specific rest period. This time would provide 5 to 15 sec of rest after each swim for athletes who swim the repeats in times of 2:50 to 3:05. Coaches typically use send-off times rather than rest times for ease of administration with large groups of swimmers in crowded lanes. The example specifies the speed of the repeats as moderate, which means that the purpose of the repeat set is to improve aerobic capacity. An actual time could be prescribed if previous testing or experience had identified a particular swimming speed that would accomplish this purpose. Other speed regulators could be ratings of perceived exertion or heart rates in the middle of the range between resting and maximum.

Simply manipulating the four variables can change the desired training effect for any set of repeats. The set of repeats in the example is designed to encourage aerobic swimming by maintaining a short rest period, 5 to 15 sec; by using a large number of swims, 10; and by using a medium length repeat distance, 200 m. Generally, rest periods of 15 sec or less tend to make the training effect more aerobic when the repeat distances and number of repeats are reasonably long. Increasing the number or distance of repeat swims will have a similar effect.

Increasing the rest will generally shift the training effect from aerobic toward anaerobic. When rest periods are extended to 30 sec or more for shorter repeats and 1 min or more for longer swims, athletes can usually swim sets of repeats so fast that they produce a steady accumulation of lactic acid. Decreasing the number of repeats or the distance of each repeat encourages faster training speeds and thus shifts the effect from aerobic toward anaerobic. Table 12.1 summarizes the general effects of manipulating the variables of interval training.

Generally, an increase in the number or the distance of repeats will tend to make the training effect more aerobic, whereas a decrease in either will have the opposite effect and make the training effect more anaerobic. Increasing the rest interval between repeats or the speed of the repeats will tend to increase the anaerobic training effect, whereas reducing both will tend to increase the aerobic training effect.

The effects of variable manipulation just mentioned are general in nature. Coaches who understand interval training can design hundreds of repeat sets that would be exceptions to these generalizations. For example, decreasing the send-off time to 3:00 for the set of 10 × 200 m repeats in the earlier example could make the training effect more anaerobic because the athletes would have to swim much faster to finish each swim before they were due to start the next one.

Progressive Overload With Interval Training

Athletes can manipulate interval training variables to continue overloading various aspects of their physiological systems in three ways:

Table 12.1 Effect of Increasing or Decreasing the Variables of Interval Training

VARIABLE	CHANGE IN VARIABLE	
	Reduction	Increase
Number	Increases anaerobic training effect	Increases aerobic training effect
Distance	Increases anaerobic training effect	Increases aerobic training effect
Rest interval	Increases aerobic training effect	Increases anaerobic training effect
Speed	Increases aerobic training effect	Increases anaerobic training effect

1. By increasing the *speed* of swimming repeats. This form of overload is commonly referred to as increasing training *intensity.*
2. By increasing the number of repeats in a repeat set. This method is referred to as increasing training *volume*. Training volume can also be increased in another way, that is, by increasing the training distance devoted to improving a particular physiological mechanism, such as aerobic endurance, lactate removal, buffering capacity, and so on. Training distance can be increased on a daily, weekly, or seasonal basis. Distances can also be increased during certain cyclic phases of the season when a particular training outcome is emphasized. The chapter on season planning will discuss methods for manipulating training volume for these purposes.
3. By decreasing the *rest interval* between repeats. This overloading procedure is referred to as increasing training *density.*

The most common method for producing continued overload is to increase one variable while maintaining the others at their usual level. For example, a progression system based on changing intensity can be accomplished by increasing the average repeat speed for a particular type of training set without reducing its volume or density. A progression system based on changes in volume is achieved by increasing training volume without changing training speed or density. A progression system based on density can be executed by reducing the rest interval between repeats in a particular type of set while training speed and volume remain unchanged. Of course, more than one progression system can be incorporated by increasing two or more variables at one time without changing the remaining variables. Swimmers often do this for themselves.

Any method that produces a progressive increase in the overload of training will improve performance only if the amount of overload does not increase so dramatically that failing adaptation occurs. For this reason, it is best to increase the overload in small, manageable steps. Coaches should use evaluation procedures similar to those used in weight training to determine when and how much to increase the overload. A later chapter on monitoring training will provide suggestions for developing evaluation procedures for this purpose.

Let me make it clear that no one best method exists for applying progressive overload to the training process. Each of the procedures described earlier is in some ways superior to each of the other methods. At the same time, however, each of those procedures is inferior to the others in certain ways. In the next sections, I will describe the strengths and weaknesses of each of the methods of progression—increasing intensity, increasing volume, and increasing density.

Increasing Training Intensity

The most direct method for improving performance may be increasing training intensity because improving repeat times in practice mirrors the swimmer's ultimate goal of improving times in competition. Although this method can be effective for improving aerobic endurance, anaerobic endurance, and sprint speed, it is probably most effective for increasing sprint speed and anaerobic muscular endurance. When the goal is to improve aerobic metabolism, problems can arise if changes in training intensity are not monitored carefully. For one thing, faster speeds encourage a shift toward anaerobic metabolism and the acidosis produced by that process. This kind of training could in time cause some deterioration in aerobic capacity if endurance repeat sets are not constructed properly or if swimmers are allowed to swim the sets incorrectly. Improperly constructed endurance repeat sets would contain too little mileage or excessively long rest intervals that would not stress aerobic metabolism in a nearly continuous manner for a long period. Increases of training intensity can actually harm aerobic endurance when athletes (1) swim the first part of the set too fast and are forced by acidosis to slow to a snail's pace for the remainder of the set or (2) swim most of the set at a slow speed so that they can swim the final few repeats fast.

Another problem in using intensity as an overloading procedure is that swimmers tend to improve rapidly but only for a short time. Most improvements in repeat speeds take place during the first 4 to 6 weeks of training, after which athletes reach a point of diminishing returns or stop improving altogether. This occurs because the early adaptations to training generally result from better neuromuscular responses (recruiting the correct motor units in proper sequence) and faster circulorespiratory and metabolic responses that more rapidly adjust such factors as tidal volume, stroke volume, blood shunting, and thus oxygen uptake. Improvements do not result from important structural changes in muscles such as increases in myoglobin, mitochondria, and contractile protein. Several months, or perhaps even several years, of continuous training are required to produce all the muscular adaptations that improve aerobic endurance. Of the two types, muscular adaptations probably have a more long-lasting effect on endurance. Adaptations created quickly are also lost quickly because they are simply neuromuscular and metabolic adjustments to exercise. On the other hand, structural adaptations, once they occur, can be maintained for several weeks and months with greatly reduced training.

Strengths and Weaknesses of Overloading by Increasing Training Intensity

Strengths

- Most direct method for improving competition times.
- Best method for improving sprint speed.
- One of the best methods for improving aerobic and anaerobic muscular endurance.
- Physiological adaptations occur more rapidly than they do with any other method.

Weaknesses

- Least effective for improving aerobic capacity because increasing swimming speeds cause a shift in ATP recycling away from aerobic metabolism and toward anaerobic metabolism.
- Physiological improvements tend to plateau quickly.
- Emotionally stressful.

Sample Progression Methods

- Swim original repeat set of 15 × 200 on a 3 min send-off at an average speed of 2:45 per 200. Try to reduce this average repeat time gradually over a number of weeks until it is 2:30 per 200. To improve aerobic capacity, do not attempt to reduce the repeat time until a noticeable reduction in effort is required to swim the set. To improve aerobic or anaerobic muscular endurance, reduce average repeat times by 2 to 4 sec per 200 each 2 weeks until reaching the goal time of 2:30.
- Swim original set of 8 × 25 on a 2 min send-off. Try to reduce the average repeat time for the set by 0.50 sec over a period of 6 weeks.

Finally, trying to swim increasingly faster is the most stressful form of overload emotionally. This sort of training requires swimmers to compete against themselves and their teammates day after day. Although this is certainly a valuable part of the training process for competitive swimmers, it can also be overdone, in which case the athletes may become saturated and lose interest in improving their training times.

For these reasons, increasing repeat speeds is a procedure for applying progressive overload that should be employed for improving endurance, principally during the second half of a season after other methods have been used.

Increasing Training Volume

The best procedure for improving aerobic capacity seems to be increasing training volume because increasing the training distance for a particular repeat set increases the demand on aerobic metabolism and reduces the demand on anaerobic metabolism. Increasing volume is not an effective method for improving sprint speed, however, for just the opposite reasons. Greater volume reduces the demand on anaerobic metabolism, which is essential to sprint speed, and it increases the demand on aerobic metabolism, which is involved only in a minor way during short, fast sprints.

A system of progressive overload that involves increasing training volume has two important advantages over other overload procedures. First, athletes are able to improve both aerobic metabolism and anaerobic muscular endurance steadily for a longer period before they reach a point of diminishing returns. When using this method of overload, athletes can improve at a steady rate for up to 16 weeks before plateauing (Nikitin, personal communication, 1997).

The second advantage is that increasing training volume is the least stressful method for applying progressive overload. Athletes find it easier both physically and emotionally to increase the number of repeats they can swim at a certain speed than to strive constantly to swim those repeats faster.

The major weakness of overloading through increased training volume is that it does little to improve anaerobic capacity, muscular power, and therefore swimming speed. Increasing the number of swims that can be performed at a set speed is the antithesis of procedures for increasing swimming speed. Physiologically, maximum swimming speed is dictated by muscular power, which in turn is a combination of available muscular force and its rate of application. Athletes improve these attributes best by striving to swim faster.

Strengths and Weaknesses of Overloading by Increasing Training Volume

Strengths

- Good procedure for improving aerobic capacity, aerobic muscular endurance, and anaerobic muscular endurance.
- Physiological adaptations tend to continue at a steady rate for a longer time than they do with other methods.
- Least stressful method physically and emotionally.

Weaknesses

- Has little if any value for improving sprint speed.
- Can become boring.
- Requires progressively more practice time.

Sample Progression Method

Start with an original repeat set of 4 × 400 on a send-off of 5 min at an average speed of 4:48.0. Increase the number of repeats from 4 to 8 over a period of weeks while maintaining the same send-off time and approximately the same swimming speed. Increase the number of repeats by 2 every other week for 6 weeks.

The second weakness of this method is its tendency to cause boredom. Swimming the same speed for an increasing number of repeats is not as exciting as swimming those repeats faster and faster. To ensure their cooperation and motivation, swimmers must be convinced that increasing volume is a valuable overloading procedure that can improve performance more effectively than other methods can.

Finally, increasing volume to produce overload requires progressively longer training times. Most coaches have limited training time available to their athletes, and they cannot always afford to increase the volume of training in one area of a program without reducing the time spent in another area.

Increasing Training Density

Gradually reducing the rest period between repeats is probably the most effective overload procedure for improving both aerobic and anaerobic muscular endurance because the swimmer's goal in training more closely approaches his or her goal in competition—to swim continuously at some designated percentage of maximum speed over the distance of a particular race. Short rest periods tend to increase the amount of energy that aerobic metabolism supplies while reducing the amount that the anaerobic process supplies. Reducing rest periods is a particularly good overloading procedure to use with race-pace training because, as mentioned earlier, reducing the rest interval works toward the athlete's goal of swimming each segment of a race at some desired pace with no rest between segments.

Swimming with progressively less rest is also a challenging way to complete repeat sets. Athletes, particularly middle distance and distance swimmers, take great pride in swimming a set of repeats at a particular speed with less rest than they had previously had.

This method has little value for improving sprint speed for the reasons cited previously with regard to increasing training volume; it does not fit the nature of the training adaptations that increase swimming speed. Adaptations that increase speed include more muscular force and a faster rate of anaerobic metabolism.

Another weakness of this method is that swimmers can reach acidosis too frequently with its use. This weakness applies only when a training set is designed to improve aerobic capacity, during which acidosis should be avoided, and then only if the reduction in rest is not gradual enough. When improving aerobic endurance is the goal, rest periods should only be reduced when the physiological responses of swimmers demonstrate that the previous rest interval is no longer overloading aerobic metabolism. To provide an overload, the rest intervals on sets designed to improve aerobic and anaerobic muscular endurance must be short enough to produce a significant amount of acidosis. But the goal of these sets is to reduce the severity of that acidosis. Therefore, rest periods should not be reduced until a reduction in the severity of acidosis is noticed.

Strengths and Weaknesses of Overloading by Increasing Training Density

Strengths

- Very effective for improving aerobic and anaerobic muscular endurance.
- Can be effective for improving aerobic capacity if sets are designed and conducted properly.
- Very challenging and motivating form of training.

Weaknesses

- Procedure has little value for improving sprint speed.
- Can interfere with improvements in aerobic capacity if rest intervals are shortened before aerobic adaptations allow the athlete to swim the repeats with less rest and not produce severe acidosis.
- Difficult to administer to large groups in crowded swimming lanes.

Sample Progression Method

Swim an original set of 30 × 100 on a send-off of 1:30 with an average repeat speed of 1:13.00. To improve aerobic capacity, reduce the send-off time by 5 sec when the athlete is able to swim the set with noticeably less effort. To improve aerobic or anaerobic muscular endurance, reduce the send-off time by 5 sec every other week for 6 weeks until it is 1:20.

The final weakness with this method is its administrative difficulty. When the group is large and the lanes are crowded, constructing repeat sets in which the rest interval is proper for each swimmer is difficult, if not impossible. Invariably, some swimmers in each lane will be unable to keep up and will have little if any rest between their repeat swims.

Combining Overloading Procedures

Perhaps the best method for ensuring continued improvement is to use some combination of the three overloading procedures just described. Using them in combination should be more effective for improving performance than relying on only one method, for at least two reasons:

1. The rate of improvement in any particular physiological function reaches a point of diminishing returns after a certain period. Experience has shown that athletes are able to improve only so much with a particular overload procedure. After that point, using a different method will often result in a greater amount of further improvement than sticking with the original procedure.

2. The other reason for using a variety of overloading procedures is to avoid boredom and saturation. Both can reduce the motivation of athletes for training, whereas an entirely new overloading procedure may restore their motivation.

One way to combine these overload procedures is to use a progression system similar to one used in weight training. In that sport, athletes lift a particular weight an increasing number of times until they reach some predetermined limit. This system of progressive overload is based on increasing volume. Athletes then increase the weight, a system of progressive overload by increasing intensity, and start the process again with the original number of repetitions. In a similar way, swimmers could increase the number of repeats in a particular set to some predetermined limit. They could then return to the original number and start the process again, only this time swimming the repeats faster than before.

Athletes could also use a system in which they first increase the average speed of a set of repeats and then return to their original swimming speed and do the set with a shorter rest interval. The possible ways of combining the three variables—speed, volume, and rest—to produce progressive overload are limited only by imagination. Some examples of swimming sets that apply progressive overload by using two or more training variables are provided in table 12.2.

Specificity Principle

The principle of specificity refers to the fact that physiological adaptations will occur only in the tissues and organs stressed during the training process. Like overload, the

Table 12.2 Examples of Combined Overloading Procedures

	SPEED-VOLUME COMBINATIONS
For improving aerobic capacity or aerobic muscular endurance	Start with original set of 10 × 200 on a send-off of 2:30 sec at an average repeat speed of 2:20 sec. Increase the number of repeats by 2 each week over a period of 5 weeks until the swimmers are now doing 20 × 200 on the same send-off and at the same speed. Then, return to the original set of 10 × 200 and increase the average repeat speed by 2 to 5 sec per 200 and start the process again.
For improving anaerobic muscular endurance	Start with original set of 10 × 50 on a one min send-off, at an average speed of 28.0 sec. Build the number of repeats by 4 per week over a period of 3 weeks until a goal of 22 × 50 is reached. Then return to the original set of 10 × 50 on a send-off of one minute and try to repeat faster than 28.0 sec.
	SPEED-DENSITY COMBINATIONS
For improving aerobic muscular endurance	Start with an original set of 20 × 100 on a send-off of 1:30 sec at an average speed of 1:20 sec. Try to improve the average repeat speed to 1:15 or faster over a period of three weeks. When that has been accomplished, reduce the send-off time to 1:25 sec and start the process again, swimming at an average speed of 1:20 or faster.
For improving anaerobic muscular endurance	Start with an original set of 6 × 100 on a send-off of 2 min, at an average repeat speed of 1:00. Try to increase the average repeat speed to 58.0 sec or faster over a period of three weeks. Then, reduce the send-off time by 10 sec and start the process again swimming the repeats at an average speed of 1:00 or faster.

principle of specificity is straightforward in definition but complex in application. Let me provide an example of the specificity principle in operation with regard to weight training.

If an athlete desires to produce an adaptation such as an increase in strength for a particular muscle group, he or she must engage in strength-training exercises that involve that group of muscles. For example, biceps curls will increase the strength of the biceps muscles that flex the lower arm. Curls will not increase the strength of the triceps muscles that extend the lower arm. The athlete must perform a different exercise for that purpose.

The preceding was an example of training specificity based on the muscle groups used. What about training specificity for adaptations that will produce endurance and strength in the same muscle group? Can an athlete increase the strength of the biceps muscle by doing endurance exercises that involve a large number of curls? Can an athlete increase the endurance of that muscle group by doing strength exercises? The answer to both questions is a qualified yes. I say qualified because, as one would expect, endurance training will be more effective for improving endurance, and strength training will be more effective for improving strength.

Any type of training will improve both the strength and endurance of muscles, at least in the early stages of training. If the athlete's biceps strength is low, any exercise, even exercise designed to improve endurance, will increase the strength of that muscle group. But if the athlete's strength level is already reasonably high when endurance training of biceps muscles begins, any further improvement in strength will be minimal, although improvement in muscular endurance will be considerable for those muscles. Consequently, if the ultimate goal is to improve strength in the biceps muscles, the athlete should be doing strength training rather than endurance training. When the goal is to improve endurance, endurance training is the approach to use.

At least four aspects of specificity must be considered when planning a training program for swimmers:

1. the activity that the swimmer is training for,
2. the stroke the swimmer will use in competition,
3. the competition speed, and
4. the portions of the metabolic system that need to be stressed.

Regarding the activity, swimming is the most specific form of training for swimmers. That statement may seem obvious, but I make it to emphasize the point that all other forms of training will be effective only to the extent that they use the same organs, bones, and muscles that swimmers use in competition. Running, cycling, and other land activities can improve the functions of the heart and circulatory system as well as swimming does, but some of the muscle fibers that swimmers use in competition will be neglected when training does not include swimming. Therefore, land activities should supplement water training, not substitute for it.

Training can also be specific to the stroke that swimmers use in competition. Although the carryover in muscle use is probably considerable from stroke to stroke, some fibers are not stressed as extensively by one stroke as they are by another. The fact that swimmers experience a sense of relief when they change strokes in training adds support to this statement.

I have already mentioned training specifically with regard to speed. We do not know the extent to which different swimming speeds involve different motor units within the same muscle groups. But research indicates that reasonably fast swimming speeds are required to recruit certain types of fast-twitch muscle fibers. Therefore, swimmers must do some training at race speed to be certain that they train all the fibers they will use in competition. Training in a speed-specific manner is also important for conditioning athletes to swim each particular race with the most economical combination of stroke rate and stroke length. They must identify a combination that produces the desired speed with the least expenditure of effort.

Finally, training must be specific to energy systems. I have already explained that metabolism is really one large operating unit with three major parts: the ATP-CP system, anaerobic metabolism, and aerobic metabolism. Training one of these systems without involving the other two is impossible because they all function at the actual start of exercise. An athlete can target one of those systems, however, so that the training stimulus will improve the operation of that system much more than it improves the other two. I make this point because some swimmers may need to focus on improving one aspect of the metabolic process more than they do the others, regardless of the stroke and events they are training for. Take, for example, the case of a swimmer who has an exceptional anaerobic system and can take races out fast. Suppose, however, that this swimmer's aerobic system is not as well developed and that consequently he or she cannot maintain a fast pace for the remainder of the race. That swimmer needs to target the aerobic system early in the training season because it will ultimately be the weak link in performance.

On the other hand, suppose that a second swimmer has a well-developed aerobic system but has difficulty getting races out fast and finishing races with a strong sprint because his or her anaerobic system is not as well developed. That swimmer should take the opposite approach and target the anaerobic system in training.

Both athletes will improve most by swimming repeats that target their weak metabolic systems. Therefore, they should put different degrees of emphasis on endurance and sprint training even though they may be training to swim the same event or events.

Years ago, various exercise physiologists gave us a simple rule for training specifically: Train at race speed. We realize now, however, that specific training should not be limited to race-pace swimming. It also includes swimming both slower and faster than race speed in certain types of training sets. For example, the first swimmer in the preceding example should include more endurance training in his or her program to target and train the aerobic system, even though that means the swimmer will be spending a large amount of time swimming slower than race speed. Similarly, the second swimmer should probably include more sprint training in his or her program, which would involve swimming more repeats faster than race speed.

In light of recent studies it seems clear that swimmers must do most of their training in the water. I also recommend that they swim a large percentage of their training mileage in their main stroke or strokes because that is the only way they can be certain that they are training the muscle fibers they will use in races. A final important point about specific training concerns the various phases of the metabolic system. Endurance training and sprint training emphasize different aspects of those systems. As one would expect, endurance training stresses aerobic metabolism, whereas sprint training stresses anaerobic metabolism. For that reason, athletes must swim both endurance and sprint repeats in their primary stroke or strokes. By using that approach, swimmers will target all phases of the metabolic system for optimum improvement.

How Specific Should Training Be?

The evidence that athletes should swim their major strokes in both sprint and endurance training seems irrefutable, yet athletes of all specialties typically swim the freestyle during the majority of their training repeats, and this method seems to work. I am sure we all know butterflyers and breaststrokers who have performed well in their specialties while swimming freestyle during most of their training. In a similar manner, coaches have all had the experience of training swimmers in one stroke only to have them perform much better in another stroke in which they did little training. Finally, most coaches have worked with swimmers who after training for a particular race distance, for example, a 100 m sprint, performed poorly in that event while posting a lifetime best performance in a distance event. The purpose of this section is to offer some thoughts on these seeming conflicts between scientific evidence and practical experience.

I suspect that at least two reasons explain why some athletes swim slower when they train extensively in a particular stroke. The first is that too much of the wrong kind of training or too little recovery time may have damaged some aspects of the muscle fibers involved in swimming that stroke. Second, some depletion of neurotransmitters involved in the sequence of contraction for those muscle fibers in that particular stroke may have occurred. In both cases, the trained fibers will have lost some of their aerobic and anaerobic adaptations, causing the athlete to swim slower in his or her specialty. In contrast, the swimmer's performances in other strokes might be excellent because other fibers and nerve cells that have not been overtrained or mistrained are more heavily involved in those strokes.

The same notion could apply to different race distances. When swimmers overtrain or mistrain a particular phase of the metabolic process, they may swim more slowly in events in which that particular phase is dominant. For example, too much intense endurance training may actually lower swimmers' aerobic capacity so that they swim slower in the distance events they have trained for and faster in sprint events. The same result could occur in reverse for athletes who overtrain for sprint events. Their performance may suffer in sprint events in which anaerobic metabolism is paramount, but they may improve in distance events in which aerobic metabolism plays a larger role in supplying energy.

I realize that this explanation is highly theoretical. Nevertheless, the evidence for training specificity is so compelling that some form of overtraining or mistraining seems the only possible explanation when swimmers do not improve after focusing their training on only one or two strokes. I have two recommendations that might help coaches and swimmers apply the principle of specificity to their training without overdoing it.

1. Assuming a season of 24 weeks, swimmers should probably concentrate on mixed stroke training during the first 8 to 12 weeks. They should concentrate on their main stroke or strokes during the middle 6 to 10 weeks, performing perhaps 60% to 70% of their total yardage in that style. Training in this way will provide a good base for all organs, muscles, and joints, preparing them for the specific training that will come later. At the same time, the span of time for specific training will be sufficient to produce significant adaptations but not so long that severe overtraining or mistraining is likely to occur.
2. In their training, swimmers should swim stroke-specific sets for all energy systems. For example, butterfly, backstroke, and breaststroke swimmers should not swim all their endurance sets with freestyle and only their sprint sets in their main stroke. They need to swim a reasonable portion of their endurance training in their main stroke so that they do not neglect the aerobic capacity of some specific muscle fibers.

Individuality Principle

Many factors cause individual athletes to respond differently to the same training stimulus. Two important factors are (1) the athlete's state of conditioning when the training begins and (2) his or her genetic makeup.

With regard to level of conditioning, it is well known that athletes will improve quite rapidly if they have taken a long layoff and are out of condition when training begins. Most research indicates that they will improve dramatically during the first 6 to 12 weeks. Furthermore, all aspects of performance—power, endurance, speed, and so on—will improve dramatically regardless of whether the training emphasizes speed or endurance. Their rate of improvement will slow considerably after the first several weeks. At that time, some will plateau and seem to make little progress for long periods because they have approached their genetic limits in certain physiological mechanisms. They will improve further, although at a slower rate, if they persist and do not overtrain. For example, $\dot{V}O_2max$ will increase by 20% to 30% during the first 8 to 12 weeks of training. After that, athletes can continue to improve that measure by an additional 20% to 30%, but it may be 1 to 2 yr before that occurs (McArdle, Katch, and Katch 1996). Experience also indicates that after the first several weeks of a new season, endurance training may slow sprint speed and vice versa. One type of training can interfere with the results of another.

With regard to genetic makeup, studies with identical twins have repeatedly demonstrated that heredity largely determines the maximum training response for various physiological mechanisms, both aerobic and anaerobic. Genetic factors such as the percentage of each type of muscle fiber certainly affects the way an individual athlete responds to certain types of training. For example, an athlete with a large proportion of fast-twitch muscle fibers will tend to respond favorably to strength, speed, and power training but lag behind the group in improving aerobic capacity. In a similar manner, athletes with a large proportion of slow-twitch muscle fibers will usually respond favorably to endurance training but may have difficulty matching the improvements of the majority of the group in strength, speed, and power. In one study, the responses of identical twins to sprint training were compared with those of a nonrelated control group (Simoneau et al. 1986). Although the control group demonstrated wide variation in training responses, each twin responded in a way similar to the other twin. According to the researchers, more than half of all adaptations (50% to 60%) were similar within each set of twins. In another study, Bouchard and coworkers (1992) concluded that heredity determined between 25% and 50% of improvements in $\dot{V}O_2max$ after training.

These studies and others like them suggest that heredity plays a major role in the determining the extent to which training can improve the physiological functions of athletes. We are learning, almost on a daily basis, that genetic makeup dictates the responses of individuals to every aspect of life. So I feel that future research will show that heredity largely dictates the extent to which individuals respond to training. We have long assumed that good or poor training habits caused different individual responses to training. Yet all coaches have seen some athletes with poor training habits improve more than the most conscientious trainers on their teams. Of course, athletes who train conscientiously are more likely to maximize their potential than those who do not. Unfortunately, however, training longer, harder, and even more intelligently than others does not guarantee superior results. For this reason, unrelated athletes will undoubtedly respond in somewhat different ways to particular training because of their different genetic makeup. In any group of athletes, some will respond normally to certain types of training, others will respond very well, and still others will respond minimally. Research studies typically control training consistency and effort much more carefully than does a typical athletic team, yet it is not unusual to see individual improvements that range from 0% to 70% (Simoneau et al. 1986; Wilmore and Costill 1994).

Age and gender also affect the way athletes respond to training, although not to the extent that has been assumed in the past. The training responses of children, teenagers, and seniors are much more similar to those of young adults than they are different. The same is true in comparing the improvements of males with females. Nevertheless, children and females, on average, respond to strength and power training with less improvement than do young adult males (Simoneau et al. 1986). The reason usually given for age- and gender-based difference in training response is that children and females have less muscle tissue to respond with.

Reversibility Principle

Just as proper training results in adaptations that improve performance, lack of training leads to a reversal of those adaptations and causes performance to decline. Significant reductions in certain training adaptations will take place within 1 to 2 weeks after training ends. The rate of loss will be slower if the intensity or frequency of training is only reduced, but only if the reduction is not too great. People can maintain training effects for a long time if they reduce training volume by only one-third to one-half, provided training intensity remains at its previous level. Reductions in training intensity will result in faster loss of adaptations.

Several studies have shown losses in aerobic and anaerobic adaptations between 7% and 10% when athletes stopped training for only 3 weeks (McArdle, Katch, and Katch 1996). This level of reduction led to losses in endurance performance in the neighborhood of 25% to 30% and to declines in sprint performance of 8% to 12%. Performance losses were considerably greater when training was discontinued for a longer period. After 4 to 12 weeks of no training, aerobic adaptations declined by 15% to 20% and anaerobic adaptations decreased by 18% to 50%. Endurance performance fell by up to 40%, and sprint performance declined by 14% to 30%. Longer periods with no training cause even greater decrements in performance. In one study with college-age swimmers, 85 days with no training resulted in their swimming 3.4% slower for 50 m (about 0.80 sec slower) and 7% slower for 400 m (17 sec slower). Peak lactates also declined by 22% (2 to 3 mmol/L lower), and tethered swimming power fell by 12%. An interesting aside to this study was that the swimmers' times for 400 m had returned to their trained levels after 91 days of retraining, but they were not able to equal their previous times for 50 m or their previous best scores for tethered swimming during this retraining (Hsu and Hsu 1999). This result suggests that swimming power, once lost, requires longer to regain than endurance does.

Several studies have linked these decrements in performance directly to reductions in certain physiological mechanisms. For example, researchers report that the activity of aerobic enzymes and the amount of glycogen stored in muscles decrease rapidly when training ends. They can decrease between 40% and 60% after only 4 weeks with no training (Wilmore and Costill 1999). The amount of blood in the body also tends to decline when an athlete discontinues training. This change leads to a reduction in stroke volume and thus cardiac output. Less oxygen is delivered to the muscles, and less lactic acid is removed from them. $\dot{V}O_2$max can decline by approximately 6% within 2 to 4 weeks after training ceases because of decreases in blood volume and stroke volume of approximately 9% and 12% respectively.

The number of mitochondria, which are so important to aerobic metabolism, can decrease rapidly when athletes cease training. For example, in 1 week of no training athletes can lose 50% of additional mitochondria produced during 5 weeks of training (Olbrecht 2000). Once lost, up to 4 weeks of additional training is required to regain those mitochondria.

When training ceases, the activity of the enzymes involved in anaerobic metabolism declines slowly and to a much lesser extent than their aerobic counterparts do. Anaerobic enzymes maintained their previous training levels of activity for up 12 weeks of no training in one study (Coyle et al. 1984). But other adaptations of an anaerobic nature will be lost during this time. For example, 4 weeks of no training caused a significant drop in bicarbonate levels, which in turn caused a decline in buffering capacity. This effect together with a loss of $\dot{V}O_2$max caused larger drops in muscle pH during races so that the effects of acidosis caused a greater reduction in swimming speed (Wilmore and Costill 1999).

Gains in strength do not appear to decline as quickly, and athletes can maintain them with considerably reduced training. Power, however, is another matter. In a study with swimmers (Costill et al. 1985), arm and shoulder strength did not decrease even after 4 weeks of inactivity. On the other hand, swimming power fell by 8% to 13.5% during the same period. Muscular strength was evaluated on land with maximum-effort arm pulls on a biokinetic swim bench. On the other hand, swimming power was measured with tethered swimming in the water. Apparently, as indicated by the results of their land tests, the swimmers did not lose strength when they stopped training, but they lost some aspect of the expression of that strength when they were actually swimming. Figure 12.1 illustrates the results of this study for one swimmer.

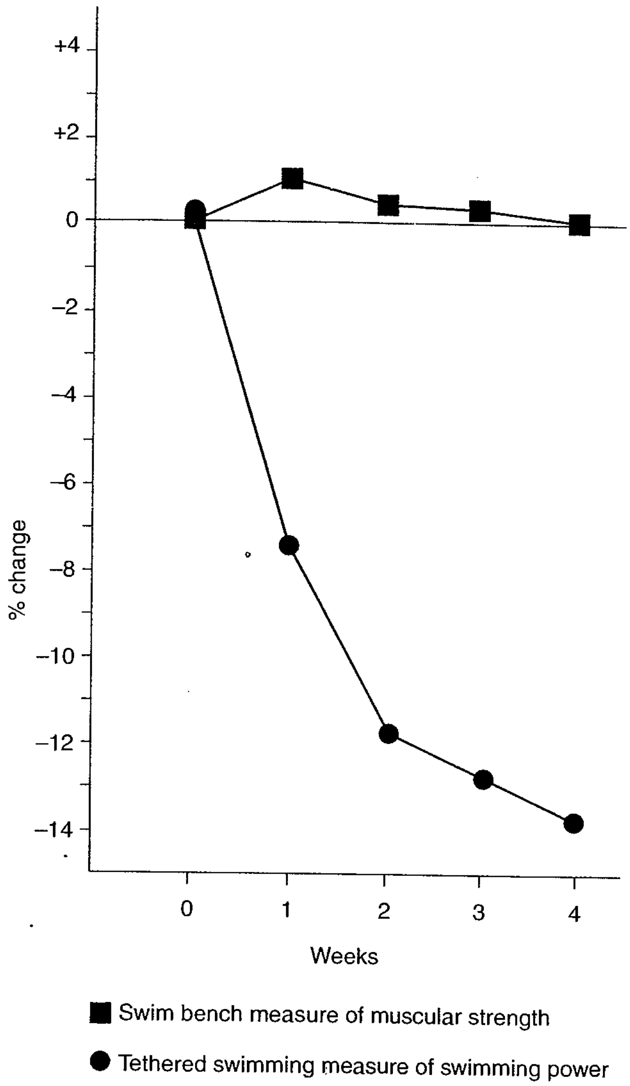


Figure 12.1 Changes in arm strength, as measured on a swim bench, and swimming power, as measured during tethered swimming, for one subject after 4 weeks of no training. Arm strength changed little, whereas swimming power declined by 13.5%.

Adapted by permission from D.L. Costill, D.S. King, R. Thomas, and M. Hargreaves 1985. Effects of reduced training on muscular power in swimmers. *Physician and Sports Medicine* 13(2): 94–101.

At least two causes can explain this result. Measurements of muscular strength on land, even when they simulate stroke mechanics, may represent a different aspect of strength expression than actual swimming. In this regard, Sharp (1986) reported low correlations between land strength measurements with a biokinetic swim bench and sprinting speed in the water.

Another possibility is that detraining has a greater effect on the rate of force development than it does on muscular strength. The rate of force development is not a measure of maximum strength. Slow rates of contraction speed provide the best expression of maximum strength. In contrast, the rate of force development is a measure of how quickly an athlete can develop near-maximum levels of force once exercise begins. Dopsaj and coworkers (1998) determined that the rate of force development was the only one of several land measures of strength and power that showed a high relationship with sprint speed.

Joint flexibility also declines rapidly once training stops. Measures of shoulder and ankle flexibility that I have conducted over three decades indicate that people lose the range of motion in these joints within 2 to 4 weeks after they terminate stretching exercises.

The principle of reversibility illustrates the need for training year-round with infrequent breaks of short duration. Serious athletes should never take breaks from training longer than 1 to 2 weeks, and they should take breaks of that length no more than two or three times each year. Longer breaks will cause athletes to lose a large percentage of the training adaptations they worked so hard to gain, with the result that they will spend a good portion of their subsequent training time regaining those adaptations rather than building on previous improvements. In this respect, Mujike and coworkers (1996) reported a significant relationship between a high starting level of conditioning and the amount by which swimmers improved during a typical season.

The advice to train year-round is more applicable to highly trained athletes than it is to those who are only moderately trained. Highly trained athletes have the most to lose when they stop training because they reach a higher level of physiological function. Additionally, highly trained athletes will need much more time to regain their previous level of performance once they lose certain physiological adaptations. Research indicates that an equal, and in some cases greater, amount of time is required to regain physiological adaptations once they are lost. Playing catch-up following long or frequent breaks in training is no way to realize one's potential.

Athletes need discipline to continue training after the initial period of major improvement has occurred in the first 8 to 12 weeks of training. Many athletes lose interest in training when their rate of improvement slows. Some are also eager to take long breaks when their seasons end. But the time differences between swimmers who win medals and those who finish behind them are small in our highly competitive sport. Thus, although the rate of improvement may slow considerably after the first 8 to 12 weeks of training, the additional training adaptations that a swimmer can produce by training year-round may make the small difference in performance that leads to success.

Training Parameters

The parameters of training refer to guidelines used to construct conditioning programs. The parameters that swimmers and coaches should be concerned with when planning a training program are

- duration,
- frequency,
- intensity, and
- mileage.

Training duration and frequency refer to the number of hours per day and number of days per week that athletes spend in training. Training intensity relates to the speed of training, and training mileage concerns the numbers of yards or meters that athletes swim per day, per week, and per season.

Training Duration and Frequency

High-level competitors and those who wish to compete at national and international levels typically train twice each day for 6 days each week and for 10 to 12 mo each year. Nevertheless, some scientists feel that athletes can improve just as much or more by training less often for shorter periods. They believe that optimum combinations of training duration will allow athletes to adapt physiologically to the limits of their potential. Two authorities in the field, J.H. Wilmore and D.L. Costill (1994), wrote that "the rate at which an individual can adapt to training is limited and cannot be forced beyond the body's capacity for development."

Using research with distance runners, those scientists reported that the optimum might be equivalent to a weekly energy expenditure of 5,000 to 6,000 Calories. This translates to between 80 and 95 km of running per week. For swimmers, an expenditure of 5,000 to 6,000 Calories would correspond to a weekly mileage of 20,000 to 30,000 m. This amount is less than half of the training mileage performed by most of today's world-class swimmers. Most outstanding middle distance and distance swimmers presently cover between 60,000 and 80,000 m weekly, and during certain periods of the year they may exceed a weekly total of 100,000 m.

Obviously, a huge discrepancy exists between the recommendations of Wilmore and Costill and the training practices of successful swimmers. The scientists' opinions may be incorrect. On the other hand, athletes may be training far more than necessary in their desire to outdo one another. Let us examine the arguments on both sides. We can separate these arguments into three categories:

1. Is training year-round more effective than training for only 2 to 3 mo?
2. Is training twice daily for 6 days of each week superior to training once daily for a fewer number of days each week?
3. What is the optimal daily duration for training?

Year-Round Versus Seasonal Training

The previous section on reversibility of training effects really answered the question of year-round versus seasonal training. Nevertheless, the fact that the major improvements in physiological function take place during the first several weeks of training has prompted some people to question whether it is necessary to train longer than 8 to 12 weeks to reach peak performance. I feel that longer periods of training are necessary because, as stated, athletes can continue to improve after 8 to 12 weeks, albeit at a slower rate. For example, an athlete can improve $\dot{V}O_2max$ between 15% and 30% after only 8 to 10 weeks of training. But the athlete can increase the amount of improvement by another 20% to 30% by continuing training for 1 to 2 yr with only short, infrequent breaks (Holloszy 1973).

Less information is available about the value of year-round training for sprint events. The literature has reported increases of 3% to 10% in sprinting speed after 6 to 10 weeks of training (Cadefau et al. 1990; Medbo and Burgers 1990; Nevill et al. 1989; Nummela, Mero, and Rusko 1996). Only one researcher (Olbrecht 2000) has reported further increases in the rate of anaerobic metabolism after 1 or 2 yr of nearly continuous training. Obviously, more studies are needed to determine whether continuous training over long periods can improve sprinting speed more than will intense training for 1 to 3 mo.

Training Twice Daily Versus Training Once per Day

The optimal number of training sessions per day is one of the most debated topics in swimming. Costill and his associates (1991) reported the results of a 4 yr study in which the rate of improvement for swimmers who trained twice per day with an average daily volume in excess of 10,000 m was compared with that of a group who trained once per day at 5,000 m or less. The average improvement for both groups was approximately the same in a variety of events ranging from 100 yd sprints to the 1,650 yd freestyle. This was one of the few studies to address the topic in competitive swimming. Other research that compared the effects of twice-daily and once-daily training for runners produced similar results (Mostardi, Gandee, and Campbell 1975; Watt, Buskirk, and Plotnicki 1973). In one of these, Mostardi and coworkers found that groups of runners who trained twice and three times daily did not improve their times for the mile run as much as did a group who trained only once daily. The researchers suggested that training more than once per day reduced muscle and liver glycogen stores and interfered with the development of some physiological adaptations. The groups who trained twice and three times daily increased their $\dot{V}O_2max$ less than the group who trained once daily. In addition, blood glucose was significantly lower for the groups who trained twice and three times daily.

Despite these results, the experience of swimming coaches strongly favors training two or more times daily. The reasons for this are many. Training volume can generally be greater, and athletes can swim more yardage at a higher rate of intensity if they have a rest period between training sessions. Others point out that a multitude of training drills can be conducted each day without some interfering with others. For example, fast endurance and sprint training can be conducted in the afternoon without interference from long endurance training. Another reason often cited is that athletes can spend more time drilling and learning the skills of competitive swimming when they train more hours each day. Clearly, some well-planned research should be conducted to resolve whether training once per day or several times daily is more beneficial for improving performances.

Continuing to train twice daily seems like a wise approach until research shows conclusively that swimmers can achieve the same results with less training. Several reasons stand behind this recommendation. I mentioned earlier that increasing training volume is perhaps the best method for applying progressive overload to the endurance training of swimmers. Most important, increasing volume tends to increase the role of aerobic metabolism and decrease the role of anaerobic metabolism in training.

Swimmers can thus maximize improvement of aerobic capacity with less interference from acidosis. Training in this way results in well-defined and long-lasting improvements in the mechanisms of aerobic metabolism, whereas training for shorter periods tends to improve aerobic capacity quickly and to a lesser extent. Additionally, athletes seem to lose those improvements more quickly during breaks in training.

Also important is the fact that increasing training volume is one of the easiest ways to achieve progressive overload. Over long periods, swimmers find it easier to swim longer at the same speed than to swim faster for the same length of time. Thus swimmers, particularly those who swim middle distance and distance events, may improve aerobic capacity to a greater extent over several years of year-round training by incorporating gradual increases of volume into their training plans.

Finally, training twice per day provides time to incorporate aspects other than endurance into the daily training of athletes. The fact that swimmers are training for 4 hr or more per day does not mean that they should spend every minute of that time engaged in endurance training. Endurance training should be only one part of a complete program. Athletes must also have time for sprint training, which may require a half to 1 hr daily. Technique work, which should also be part of a good training program, will require additional daily training time. Even warming up before training and swimming down afterward can add an additional 30 min or more to the daily time requirement, yet they are important in promoting better performance during training and faster recovery after training. Additionally, swimmers need 3 hr or more per week for land training, including strength and flexibility training.

Optimal Daily Duration for Endurance Training

Another topic that pertains to training duration concerns the amount of time athletes need to spend training each day. Some have suggested that training longer than 1 hr per day will not produce any better results than training for longer periods. Although research supports that opinion, the results of other studies suggest that longer daily durations are more beneficial.

In a study by Dudley, Abraham, and Terjung (1982), groups of rats were trained daily for different lengths of time. One group of rats trained for 30 min daily, a second for 60 min, and a third ran for 90 min each day. The results of this study indicated that 60 min of daily training was more effective than 30 min for improving the activity of cytochrome c (an aerobic enzyme used as a marker for improvements in aerobic capacity), whereas training for 90 min daily did not result in any further improvement beyond training for 60 min daily.

Unfortunately, that study did not include additional measures of aerobic endurance and measures of performance. The notion of a duration threshold of 60 min for improving aerobic capacity is at odds with the results of other studies (Baldwin et al. 1972; Fitts et al. 1975; Harms and Hickson 1983; Hickson 1981; Hickson and Rosenkoetter 1981). All these scientists reported that improvements in various components of aerobic metabolism were considerably greater when rats trained for 2 hr per day as compared with 1 hr per day.

Note that the greater increases of aerobic enzymes reported by these scientists after 2 hr of training took place in the slow-twitch and fast-oxidative-glycolytic (FOG) muscle fibers of the rats. The activity of aerobic enzymes in fast-glycolytic (FG) fibers did not change much even after training up to 2 hr daily. Fast training speeds are apparently more important than training duration for increasing the quantity of aerobic enzymes in the fast-glycolytic muscle fibers of rats. The FTa fibers of humans function similarly to the FOG fibers of rats during exercise, whereas the FTb fibers of humans are similar to the FG fibers of rats.

Clearly, training for 2 hr per day is superior to training for lesser periods for improving the aerobic endurance of rats. A training duration of 2 hr per day probably also provides the same benefit for humans. Unfortunately, no studies contrast even longer periods of training, that is, 4 to 6 hr daily, with lesser durations. The studies with rats that I cited in this section demonstrate only that training once per day for 2 hr is superior to training once per day for 1 hr or less. These results do not resolve the issue of whether training more hours per day is beneficial.

Weekly Training Frequency

Swimmers in their teens and older commonly train for 5 or 6 days of each week. On the other hand, subjects in research studies have made impressive improvements in endurance by training only 2 to 4 days per week. These results have led some researchers to suggest that training two to four times per week can be just as effective as training more frequently. For example, the results of one study showed that training twice per week improved $\dot{V}O_2$max just as much as training five times weekly (Fox et al. 1973). Little research with humans is available to refute these results. An excellent study with rats, however, suggests that training for 6 days weekly is far superior to training for either 2 or 4 days per week in producing improvements in aerobic capacity and endurance performance.

Hickson (1981) reported that rats that were trained 6 days per week for 14 weeks improved considerably more on measures of aerobic capacity and running time to exhaustion than rodents that had been trained for either 2 or 4 days per week for the same length of time. Training speeds and daily training durations were the same for all groups during each day of training. The rats ran on a treadmill up to 120 min per day at an intensity equal to 75% of their $\dot{V}O_2$max.

The rats that trained 6 days per week achieved running times to exhaustion that were, on average, 136% longer than the times achieved by the rats that trained only 2 days per week. Running times to exhaustion were also 34% greater for the rats that trained 6 days per week when compared with the rodents that trained for 4 days per week. The rats that trained 4 days per week also improved their running time to exhaustion 76% more than the rats that trained 2 days per week. The rats that trained 6 days per week were also superior to the other groups of rats on certain measures of aerobic capacity. The results of this study certainly suggest that athletes should train 6 days per week for maximum results.

Again, the increases in aerobic enzymes with training 2, 4, or 6 days per week occurred only in the slow-twitch (ST) and fast-oxidative-glycolytic fibers (FOG) of the rats. The increase in cytochrome c activity was the same for all training groups in the fast-glycolytic fibers (FG). Hickson believed that the training speed used in study—44 m/min, which corresponds to a training intensity of approximately 95% of $\dot{V}O_2$max—was not sufficient to stimulate these fibers.

Training Intensity

From what I have reported to this point, one can probably guess that fast swimming is extremely important for improving the aerobic and anaerobic capacity of FTb muscle fibers. Fast swimming is also probably important for improving the anaerobic capacity of slow-twitch and FTa muscle fibers, although the aerobic capacity of slow-twitch muscle fibers may improve only if the athlete achieves a certain threshold speed.

Again, I believe that the best research pertaining to this subject has been done with rats. Two studies, one by Dudley, Abraham, and Terjung (1982) and the other by Harms and Hickson (1983), showed that training duration and frequency are probably more important than intensity for improving the aerobic capacity of slow-twitch and FTa muscle fibers as long as a certain minimum intensity is achieved. At the same time, the results of these two studies suggest that fast training speeds are more important than duration and frequency for improving the aerobic capacity of FTb muscle fibers. The results of these studies, which were surprisingly similar, can be summarized as follows:

1. Training of moderate intensity caused the greatest improvement in the aerobic capacity of the rats' slow-twitch muscle fibers. The most significant improvements occurred in response to increases in the duration and frequency of training, provided the rats maintained a minimum intensity of approximately 60% of $\dot{V}O_2$max. The effects of training appeared to peak at an intensity of 85% of $\dot{V}O_2$max. Increases in certain markers of aerobic capacity actually decreased at faster training speeds, whereas increasing the duration of training from 1 to 2 hr daily while maintaining moderate intensity resulted in improvements between 40% and 100% greater (Harms and Hickson 1983).
2. The aerobic capacity of the fast-oxidative-glycolytic (FOG) muscle fibers of rats (FTa in humans) seems to be trained equally well at moderate or high work intensity. These fibers also appear to be recruited at a training intensity as low as 60% of $\dot{V}O_2$max, and the training effect peaks at an intensity equal to 85% of $\dot{V}O_2$max. Unlike the response of slow-twitch muscle fibers, however, the markers for aerobic capacity did not decrease in the FOG fibers of rats when training intensity escalated to between 90% and 116% of $\dot{V}O_2$max. Apparently, these fibers can be trained equally well with moderate and fast endurance training, whereas slow-twitch muscle fibers are trained best with endurance training conducted at slow to moderate speeds.
3. The aerobic capacity of the rats' fast-glycolytic (FG) fibers (FTb in humans) responded best to increases in the intensity of training. Unlike what occurred with other fiber types, aerobic capacity did not increase in the FG muscle fibers of the rats until running speeds reached 30 m/min in a study by Dudley, Abraham, and Terjung (1982). After that, their aerobic capacity continued to increase linearly, with the greatest improvement occurring at the fastest running speed, which was 60 m/min, equivalent to efforts of approximately 116% of $\dot{V}O_2$max in rats.

If we could extend these results to humans, it would mean that the duration of training is important in improving the endurance of slow-twitch and FTa muscle fibers but that training speed is more important than duration for improving the endurance of FTb muscle fibers.

The study by Harms and Hickson discussed earlier included a measurement of performance, running time to exhaustion, that provides even more direct evidence of the importance of training intensity for improving endurance. The rats that trained at the fastest speed (44 m/min) outperformed the slower training groups by a whopping 348% and 81% respectively on this test. They ran nearly 7 1/2 hr longer than the rats that trained at a speed of 11 m/min (569 versus 127 min) and 4 1/3 hr longer than the rats that trained at 22 m/min (569 versus 314 min). A running speed of 44 m/min corresponds to a training intensity near $\dot{V}O_2$max for rats.

The results of these research studies certainly point to the need for swimmers to include some very fast endurance training in their programs to improve the aerobic capacity of FTb muscle fibers. The slow-twitch and FTa fibers can be trained reasonably well at submaximal speeds between the swimmer's aerobic and anaerobic thresholds, but speeds in excess of 100% of $\dot{V}O_2$max may be required to improve the aerobic capacity of FTb muscle fibers.

A word of caution is necessary here. Although fast endurance training may be necessary to maximize aerobic endurance, a large body of evidence indicates that fast endurance training conducted too often for long periods can lead to acidosis, muscle injury, and poor performance. Therefore, to prevent severe acidosis, athletes should train at speeds in excess of 100% of $\dot{V}O_2$max only for short periods in a training session.

Quality Versus Quantity

This issue of whether better results are obtained by training longer or by training faster has been debated in our sport for a long time, and no solution is on the horizon. Some coaches and athletes believe that the value of training programs should be judged according to the number of yards or meters swum each day. They reason that swimming more meters produces more endurance and faster times. Others assert that swimmers can reduce training mileage with no loss of endurance if they simply swim their repeats at faster speeds. These polar positions oversimplify the training process. A good program must have a balance of slow, medium, fast, and superfast swimming. This balance, more than total mileage, determines the magnitude of the training effect.

Large volumes of training will not automatically bring success, nor will swimming faster obviate the need to train with an adequate number of yards or meters per day. As far as sprint and race-pace training are concerned, a swimmer cannot make up for fast swimming simply by swimming more yards. Intensity is the most important aspect of these two types of training, and swimming more meters at slower speeds simply will not produce the same improvements in aerobic and anaerobic endurance. At the same time, training at too intense a pace may damage many of the training adaptations that improve aerobic capacity.

Concerning improvement of aerobic capacity, increasing the speed of training can only substitute to a limited extent for reduced mileage. Although never conclusively proven, it may be true that swimming fewer meters closer to threshold speeds will produce improvements of aerobic capacity similar to or even greater than those produced by swimming longer at slower speeds. But even if that observation is true, athletes can swim near threshold speeds for only a limited amount of time each week because training at that intensity rapidly depletes muscle glycogen. Consequently, swimmers can maintain threshold speeds for only a few hours at a time before they require 24 to 48 hr of rest to replace the energy drained from their muscles. This small amount of endurance training is probably not sufficient to produce maximum improvements of aerobic capacity; therefore, most of a swimmer's training time must still be made up of slower endurance training if the swimmer wants to maximize endurance performance.

At the same time, the principles of overload and progression must be applied to slow and moderate endurance training to produce maximum improvements of aerobic capacity. The best way for swimmers to overload without swimming at threshold speed or faster is by increasing mileage instead of training speed.

I see the issue of quality versus quantity in training as a moot point because, as I have tried to explain, it is not possible to replace one with the other and still train adequately. All types of training, from slow endurance training to ultrafast power training, are necessary for the complete development of swimmers. The more important question concerning the issue of training mileage would be this: "Is there an optimum that will improve aerobic endurance to the greatest extent that it can be improved?"

Training Mileage

The matter of training mileage is another issue that currently has no answer. Of course, people have opinions. Many coaches throughout the world seem to have settled at a weekly training mileage of 80,000 to 85,000 m for training distance swimmers, 60,000 to 70,000 m weekly for training middle distance swimmers, and 40,000 to 50,000 m weekly for training sprinters. Still, successful swimmers in all categories train with both greater and lesser weekly mileage. For example, some successful distance and middle distance swimmers train in excess of 100,000 m per week for short periods during each season. At the same time, an examination of the training of medalists in the distance events at recent Olympic Games shows that some have prepared for their races by training as little 40,000 to 50,000 m per week. The same discrepancies are evident with middle distance and sprint swimmers. Some medalists in these groups have prepared for competition by swimming only 30,000 to 40,000 m per week, and others have trained well in excess of those amounts.

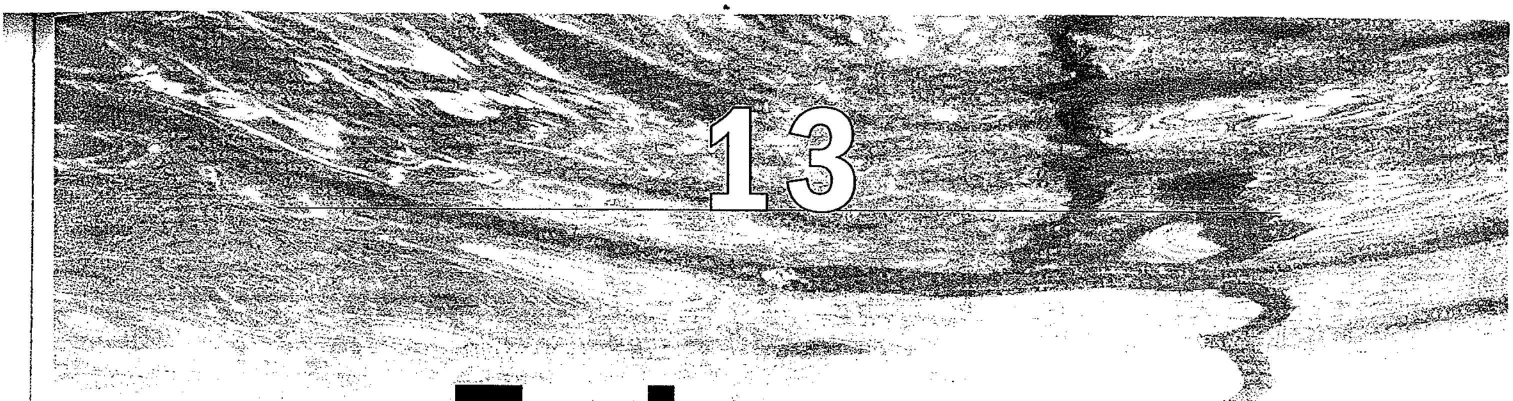
One approach that people have used to establish an optimum weekly mileage is based on what we know about the availability of energy for training. The available information on the rate of muscle glycogen depletion and replacement during training suggests that between 10 and 16 hr are required to replace the energy used during every hour of high-intensity swimming. But even when their muscle glycogen is low, swimmers can train effectively by swimming endurance repeats at slow speeds and by performing very short sprints. In either case, swimmers would use so little glycogen during a day of training that they would be able to finish the day with a net increase of muscle glycogen from a previous training day. Swimmers can also increase their training mileage by engaging in swimming activities that use other muscle groups while they replace the glycogen in the muscles that have been depleted.

Another approach to this problem was to determine the optimum mileage for producing certain training effects. Research with runners, reported earlier, suggests that between 60 and 90 mi of running per week will improve aerobic capacity as much as it can be improved (Costill 1986). An equivalent weekly volume in swimming is between 30,000 and 50,000 yd or m, calculated by using the 4-to-1 rule for converting running mileage to swimming mileage (a trained runner can run four times as far as a trained swimmer can swim in a given amount of time). Unfortunately, these data with runners cannot be considered conclusive evidence of an optimum training mileage for improving endurance because only one measure, maximum oxygen consumption, was used as the criterion for improvement of aerobic capacity. Speed at the anaerobic threshold has had a consistently higher relationship to endurance performance than $\dot{V}O_2$max in several studies (LaFontaine, Londeree, and Spath 1981; Sjodin 1982; Sjodin and Jacobs 1981; Sjodin, Schele, and Karlsson 1982). And, of course, performance is the ultimate criterion.

Even if this mileage should represent an optimum for improving aerobic endurance, mileage for sprint training, warming up, and swimming down would have to be added to these numbers to get accurate estimates for swimmers. These additions take the weekly mileage to between 50,000 and 70,000 yd or m, which is close to the amount of training that most senior-level competitors in middle distance and distance events currently use. Many swimmers trained with much greater mileage during the 1980s and early 1990s, but most coaches now seem to have settled at 50,000 to 70,000 yd or m of weekly mileage. Perhaps coaches have found the true optimum by trial and error.

Unfortunately, no studies with humans compare the effects of various durations of weekly training with performance. The studies with rats described earlier in this chapter show only that 2 hr per day of running training improved the performance of rats considerably more than did shorter periods of training. The studies do not suggest an optimum because they did not examine longer periods of training.

The desire to outdo the successful swimmer across town or across the world has long dictated the training volume of swimmers. This motivation will probably continue to influence training volume until research provides conclusive evidence of an optimum training mileage.



13

Endurance Training

New in this edition:

- A reevaluation of the anaerobic threshold theory of training
- New information and research applied to endurance training

In the last two decades there has been a movement away from judging the worth of training by the physical challenge it presents to judging training by its effect on the physiological mechanisms of the human body. At one time training was designed to place maximum stress on athletes. Coaches designed programs around the concept of pushing athletes to the limit of their pain tolerance and then motivating them to go beyond it. Programs had athletes swimming faster, farther, or with less rest in training than they or their competitors had ever swum before. In many cases, those trends have now given way to designs that target specific phases of energy metabolism (energy systems). These programs involve targeting each of the major phases of energy metabolism and other aspects of physical conditioning, such as power and flexibility, with specific training procedures designed to develop each to their optimum potential. This seems to me a more intelligent approach to training design and one that should evolve in time into the most effective approach. Athletes must use six broad categories of training to maximize the potential of the various physiological systems in their bodies:

1. Endurance training
2. Sprint training
3. Race-pace training
4. Recovery training
5. Strength and power training
6. Flexibility training

Each of these categories plays an important and somewhat different role in the training process. The purposes of this and the next several chapters are to describe the purpose of each training category and the principal training effects it produces, and to suggest procedures for constructing workouts that will achieve those purposes. I will also make some suggestions concerning the proper dosage for each training category and methods for monitoring training.

Procedures for improving endurance will be the focus of this chapter. Chapter 14 will cover methods for increasing sprint speed, adding swimming power, and using race-pace and recovery training.

Anaerobic Threshold Theory of Training

In the mid-1970s Dr. Alois Mader (Mader, Heck, and Hollmann 1976) introduced a theory of endurance training that has had considerable influence on the training of athletes in all endurance sports, including competitive swimming. One of the tenets of the theory was that people could best improve aerobic endurance by training at a certain submaximal speed that overloaded aerobic metabolism but did not trigger anaerobic metabolism to cause acidosis. The term *anaerobic threshold* became associated with this concept, and the speed that produced the overload in aerobic metabolism was termed the *anaerobic threshold speed.*

I mentioned in chapter 10 that the term *anaerobic threshold* was an unfortunate choice for this concept. The words give an impression different from the one Mader intended. A common misunderstanding is that the anaerobic threshold represents a training speed at which anaerobic metabolism begins. Actually, some anaerobic metabolism occurs in muscles at rest, substantiated by the fact that lactic acid is in the muscles of humans even when they are resting. Therefore, anaerobic metabolism does not begin at any specific intensity. The term *anaerobic threshold* was meant to indicate the maximum training speed at which the processes of lactate production and lactate removal remained in balance so that little or no net accumulation of lactic acid occurred in the muscles.

Over the years people have developed many tests to estimate the anaerobic threshold speed of athletes. Some include measurement of oxygen. Others require the measurement of blood lactate or heart rates. Long swims and long sets of repeats on short rest have also been put forth as devices for measuring anaerobic threshold speed. The most well known of these is the T-3000 swim. Chapter 16, which concerns monitoring training, will describe the various tests for measuring anaerobic threshold speed.

Originally, many scientists and coaches, including me, misinterpreted Mader's work in two important ways. First, we assumed that the bulk of athletes' endurance training should be performed exactly at anaerobic threshold speed, and second, we believed that it was not necessary to train at a faster speed to improve endurance as much as it could be improved.

Training only at the anaerobic threshold is not the most effective way to improve endurance. Nevertheless, the anaerobic threshold speed represents an effective training pace for improving aerobic endurance for the following reasons:

- Training at this speed will improve the aerobic capacity of both FTa and slow-twitch muscle fibers, whereas training only at slower speeds will not improve the aerobic capacity of FTa muscle fibers to the same extent.
- Athletes can maintain training for a long period, 30 to 60 min, at anaerobic threshold speed without producing acidosis and attendant muscle damage. Therefore, athletes should be able to stress aerobic metabolism for a period sufficient to produce adaptations that can improve the process.

For these reasons, training at threshold speed is certainly an effective way to improve some aspects of aerobic endurance, particularly in the fast-twitch muscle fibers. Training only at this speed, however, will not improve aerobic endurance to its maximum potential. Certain links in the process of delivering oxygen to the muscles, using that oxygen within the muscles, and removing lactic acid from the muscles require training at speeds both faster and slower than anaerobic threshold speed. The multitude of training adaptations that produce an increase of endurance are simply too complex and varied to respond optimally to only one intensity of training.

Why Train Faster Than Threshold Speed?

One major reason for training faster than anaerobic threshold speed is to improve the aerobic capacity of FTb muscle fibers and perhaps some of the higher threshold FTa muscle fibers. If we can extend the results of studies with rats to humans, and I believe we can, all the fast-twitch muscle fibers, in particular the FTb fibers, are probably not recruited until endurance training speed is near maximum. Dudley, Abraham, and Terjung (1982) showed that the aerobic capacity of the fast-glycolytic muscle fibers of rats improved most when training speed was beyond anaerobic threshold speed. The fast-glycolytic fibers of rats correspond to FTb fibers in humans. In another study, Harms and Hickson (1983) reported no significant increase in the quantity of myoglobin and certain aerobic enzymes in the fast-glycolytic fibers of rats that were trained at three different speeds. The fastest of those speeds was equivalent to 100% $\dot{V}O_2$max, which, of course, exceeded anaerobic threshold speed.

Why Train Slower Than Threshold Speed?

Athletes need to train slower than anaerobic threshold speed to improve their endurance. Adaptations such as increases in stroke volume, capillarization around slow-twitch muscle fibers, and increases of mitochondria and aerobic enzymes in slow-twitch muscle fibers respond best to training at slow to moderate swimming speed. An athlete may even lose many of these adaptations by training too intensely. In one study with runners, the relationship between the runners' performance in distances from 800 m to the marathon was significantly related their performing long, moderate runs at a reduced pace. That is, the better runners tended to be those who did their long continuous aerobic training at slower paces (Hewson and Hopkins 1996).

Perhaps the most compelling reason for training at speeds slower than anaerobic threshold speed is that athletes cannot train at those or faster speeds on a daily basis without depleting their muscles of glycogen. One anaerobic threshold repeat set will reduce glycogen in muscles by approximately two-thirds, and the body will require 24 to 36 hr to replace the lost glycogen. Therefore, athletes probably cannot swim long repeat sets at anaerobic threshold speed more often than three to four times weekly without depleting their muscles of glycogen. Thus, although threshold training speed may be optimum for endurance training, athletes cannot use it frequently. Swimmers should swim at slower but adequate speed to improve the aerobic endurance of slow-twitch muscle fibers, using more fat and less muscle glycogen for energy on days when they are trying to replace the latter substance.

Aerobic Threshold

As part of the anaerobic threshold theory of training, a second threshold, termed the *aerobic threshold*, has been postulated by some exercise scientists to quantify the minimum speed that will produce an improvement in the aerobic endurance of slow-twitch and some low-threshold FTa muscle fibers. Kindermann, Simon, and Keul (1979) proposed this minimum training speed at which blood lactate first increased noticeably above resting levels. In their opinion the increase in blood lactate above resting levels indicates that training intensity has sufficiently stimulated the metabolic process to produce adaptations that will increase aerobic capacity. That speed generally corresponds to an effort that produces oxygen consumption between 50% and 60% of maximum (Gaesser and Wilson 1998). Some experts use a blood lactate of 2 mmol/L to estimate the training speed that corresponds to the aerobic threshold. A millimole is equal to 1/1000 of a mole. A mole is equal to the molecular weight of lactic acid in grams.

The assignment of the term *aerobic threshold* was also unfortunate because it implies that aerobic metabolism does not begin until a person exceeds the aerobic threshold. This suggestion, of course, is not accurate. Aerobic metabolism goes on at all times, even when we are sleeping. We would die if aerobic metabolism were not making energy available every minute of the day.

Does the aerobic threshold really represent the minimum speed for endurance training? No clear answer to this question is available. According to the overload principle, any exercise intensity beyond that of a person's normal daily activity should improve aerobic capacity. Similarly, any exercise intensity, even one within the normal daily level, should improve aerobic metabolism if the person continues it beyond the normal daily duration. Consequently, an exercise intensity that produces the first increase of blood lactate above resting probably does not represent a threshold speed for improving aerobic metabolism because swimming slower for longer periods could probably also improve that process. Nonetheless, the concept of aerobic threshold is useful because it provides a convenient and effective way to communicate an effective minimum speed for endurance training. The increase of blood lactate above resting provides quantifiable evidence that aerobic metabolism is stimulated, yet training at that intensity creates no danger of producing severe acidosis or muscle damage. In addition, depletion of muscle glycogen is unlikely unless the exercise continues for several hours.

I have presented this explanation of the aerobic and anaerobic thresholds to illustrate why athletes need to perform their endurance training at a variety of speeds. With that introduction let me move on to a description of the levels (speeds) for effective endurance training.

Levels of Endurance Training

I believe that athletes should use three levels of endurance training to achieve their goal of improving endurance. I have termed the first level *basic endurance training*, or *Endurance 1 (En-1)* training. An athlete does this kind of training at a speed slower than the speed that corresponds to his or her anaerobic threshold but faster than the aerobic threshold training speed.

The second level of endurance training is termed *threshold endurance training* or *Endurance 2 (En-2)* training. An athlete does this kind of training at a speed that approximates his or her anaerobic threshold. I used the term *approximate* because it is not necessary to swim exactly at the anaerobic threshold speed to overload aerobic endurance in the slow-twitch fibers and many of the fast-twitch muscle fibers without producing acidosis. This recommendation is different from the one I made in previous editions of this book. In earlier years, I stressed that each athlete should perform threshold endurance training at exactly his or her individual anaerobic threshold. I have since realized that this level of precision is not required to produce the desired training adaptations. Athletes need only train in proximity to their individual anaerobic thresholds. The training effect should be the same whether that level is slightly below or slightly above the threshold, provided that athletes train for a sufficient amount of time each day and each week. Coaches need not concern themselves with pinpointing the individual anaerobic threshold of their athletes except for the purpose of evaluating improvements in aerobic endurance. The knowledge that they do not need to be precise to be effective should make it easier for coaches to prescribe threshold training for their athletes. Many noninvasive methods, such as heart-rate counting, swimming speed, and perceived exertion, can estimate the range of speeds for threshold training accurately enough for effective administration of such training.

I have termed the third level of endurance training *overload training*, or *Endurance 3 (En-3)* training. Overload repeats should be swum faster than threshold speed.

Three Levels of Endurance Training

1. **Basic**—En-1
2. **Threshold**—En-2
3. **Overload**—En-3

Basic Endurance Training

Basic endurance training involves swimming long distances at moderate speed.

Training Effects

Because swimming speeds are submaximal, most of the work and thus most of the muscular adaptations to training will take place in the slow-twitch muscle fibers. The involvement of FTa fibers will be moderate, and the training effect on FTb muscle fibers will be minimal at best.

In this regard, basic endurance training serves another important purpose. Because slow-twitch muscle fibers do most of the work, fast-twitch fibers have time to replace the muscle glycogen they lost during earlier bouts of more intense training. When basic endurance training is performed at minimum speed, it is also possible that the muscle glycogen supply of slow-twitch muscle fibers can be replaced. Because fat metabolism will deliver more energy at that speed, the amount of glycogen stored in slow-twitch muscle fibers could, by the end of the day, conceivably be greater than the amount used in training. Fat can account for 50% to 75% of the total amount of energy expended during basic endurance swimming depending on the length and the average speed of the swimming sets (Holloszy et al. 1986).

Basic endurance training also increases the amount of energy delivered by fat at all submaximal training speeds, which should cause the muscle fibers to use less muscle glycogen during sets of this type. In one study, muscle glycogen depletion during 1 1/2 to 2 hr of cycling was 42% less after 12 weeks of endurance training, and fat use nearly doubled (Hurley et al. 1985).

The primary training effects achieved in slow-twitch fibers and some low-threshold FTa muscle fibers will be an increase in the rate of oxygen delivery to the muscles through the respiratory and circulatory systems and an increase in the rate of oxygen utilization by slow-twitch muscle fibers. Changes in the respiratory system are increases in tidal volume and maximum minute volume so that more air can be exchanged during each minute of exercise. Circulatory adaptations involve an increase in pulmonary capillaries, an increased stroke volume, and an increased maximum cardiac output so that more oxygen can be delivered to the muscles during each minute. The fluid content of blood also increases so that it continues to flow easily. Another important training effect is an increase in hemoglobin, but apparently a person can gain that effect only by swimming at basic endurance speed at altitude (Wilmore and Costill 1999). Other adaptations include improved blood shunting, which permits a greater percentage of the blood supply to reach the working muscles during each minute of exercise, and an increase in the number of capillaries around working muscle fibers, which causes more oxygen to pass by them during each minute of exercise. The amount of myoglobin may also increase so that more oxygen can be transported to the mitochondria of the slow-twitch muscle fibers for use in aerobic metabolism. At the same time, the size and number of mitochondria will increase so that the "chemical factories" where aerobic metabolism occurs are larger and more numerous.

Basic endurance training will also improve the rate of lactate removal from working muscle fibers and blood. The quantities of lactate transporter proteins will increase so that more lactate is both removed from those fibers to the blood and metabolized within their mitochondria. The diffusion rate of lactate from slow-twitch muscle fibers should also improve. An increase in the number of muscle capillaries will make more blood available to those fibers so that more lactate can diffuse from them and into the bloodstream during each minute of exercise.

Effects of Basic Endurance Training

Primary

- Increased stroke volume and cardiac output
- Increased blood volume
- Increase in capacity of pulmonary capillaries
- Improved blood shunting
- Increase in number of capillaries around slow-twitch fibers
- Increased myoglobin and mitochondria in slow-twitch fibers
- Increased rate of lactate removal from slow-twitch fibers
- Increased rate of lactate removal from blood

Secondary

- More time available for replacement of muscle glycogen in fast-twitch muscle fibers
- More time available for replacement of muscle glycogen in slow-twitch muscle fibers
- More energy provided by fat at all submaximal speeds

Adaptations that involve the respiratory and circulatory systems can be achieved by any sensible, nonspecific form of endurance training, whether it be swimming, running, cycling, or some other activity. Adaptations that involve blood shunting, increases in the number of capillaries around slow-twitch muscle fibers, increases in their lactate transporters, and increases of myoglobin and mitochondria within those fibers can be achieved only by specific training, that is, by swimming and then only by using the same muscle fibers that the athlete will use in competition. That statement may seem obvious, but many athletes and coaches overlook its significance. Although it might be possible to train all the muscle fibers swimmers used in competition through a variety of other activities, even a well-designed plan might neglect some of them. If that happens, those fibers will become weak links in the metabolic chain, which can prevent athletes from swimming as fast as they wish. Consequently, the best way to be certain that the athlete is training the slow-twitch fibers used in competition is for him or her to swim the competition stroke or strokes during basic endurance training.

Season Planning

Both nonspecific and specific basic endurance training should be stressed early in the season for two reasons. First, basic endurance training will increase the amount of oxygen that can be made available to the muscle fibers later in the season. Second, increasing the rate of fat metabolism will reduce glycogen use during endurance sets so that swimmers will be able to restock muscle fibers more quickly. Both of these adaptations will improve their ability to tolerate greater amounts of the more intense training that they will need to perform later in the season.

Basic endurance training should be used extensively during the first 8 to 12 weeks of each new season, making up perhaps 60% to 70% of the total training yardage during that time. After swimmers have increased their aerobic capacity and rate of fat metabolism, the percentage of this form of training can decrease to between 50% and 60% of the total. Greater amounts of threshold and overload endurance training can replace it.

Guidelines for Constructing Basic Endurance Repeat Sets

Repeat sets include four variables:

1. Set length
2. Rest interval
3. Repeat distance
4. Training speed

Set Length The length of any endurance training set can be expressed in yards or meters or by the time required to complete the set. The first method of expression is useful only for adolescents and young adults with at least reasonable swimming ability. The second method has the advantage of being adaptable to swimmers of any age and ability. The way that swimmers stress their metabolic processes depends on time and intensity more than it does distance. For example, a national-level 20 yr old swimmer would have to swim 2,000 m at basic endurance speed to produce the same physiological stress that a 10 yr old swimmer experiences by swimming 1,000 m at a similar intensity. An older swimmer should be swimming faster at the same intensity and should therefore cover more distance than a younger swimmer even though both will be training for approximately the same length of time, perhaps 27 to 30 min. Although expressing training distances in time may be more useful, most of us are in the habit of communicating them in yards or meters. I will use both distance and time when suggesting guidelines for this and other levels of training so that those guidelines can be used to structure training sets for swimmers of any age or ability. The distances that I recommend will be those suitable for experienced swimmers between the ages of 13 and 50.

Distances for basic endurance training sets can be anywhere from 500 yd or m, or approximately 6 min of swimming, up to the maximum distance that swimmers can cover during a particular training session. A swim of less than 6 min is probably too short to produce a significant training effect. At moderate speed a swimmer requires 2 to 3 min to stimulate the respiratory, circulatory, and muscular systems sufficiently to produce a training effect.

Because speed is low, longer distances and training times should produce a greater training effect than shorter times and distances. If an optimum time or distance for basic endurance training exists, we currently do not know what it is. Athletes may be able to improve their endurance by training at submaximal intensity if they have sufficient energy to support that training.

Rest Interval Swimmers can perform basic endurance swims continuously or as sets of repeats if the rest intervals are very short. Repeats of any distance, even those as short as 25 yd or m, should produce the same training adaptations as longer swims if the rest periods between those repeats are so short that the swimmers' rates of metabolism do not slow appreciably before the next swim. For this reason, send-off times should be short, allowing no more than 5 to 10 sec of rest on repeats of 25 to 50 yd or m. Rest intervals can be similar in length or slightly longer as the repeat distance increases. When athletes spend more time swimming between rest periods, they can rest slightly longer without experiencing a significant reduction in metabolic rate. For basic endurance repeats of 800 yd or longer, rest intervals may be as long as 1 min.

Repeat Distance Although repeat distances of 25 to 50 yd or m can improve endurance, I do not recommend such distances for basic endurance training. Swimmers too often train at or above threshold intensity when they rest frequently, even if rest periods are short. Costill and his coworkers (1988) have shown that athletes tend to swim faster when repeat distances are less than 200 yd or m or when rest intervals are 60 sec. For the most part, basic endurance repeats should be 200 yd or m and longer (2 min or longer). Repeats of 100 yd or m and shorter tend to be overused for this purpose because many swimmers and coaches prefer them. They are easier to do both physically and administratively. Crowded lanes clog up less frequently when swimmers stop more often, so coaches find it easier to manage a large training group with shorter repeats and more frequent rest periods.

Another reason for favoring longer repeat distances is because their training effect is less likely to be influenced negatively by the rest period. Send-off times must often be set according to the middle level of ability within a team or lane. Therefore, the best swimmers will be working with a more generous rest-to-work ratio than the others. Metabolic rates of these swimmers are less likely to slow appreciably during the rest period when repeat distances are longer.

Training Speed The proper speed for basic endurance training can be determined in ways that vary from being quite precise to somewhat precise. Blood lactate testing is the most precise method available for selecting those speeds, but this method is not available to most coaches. The proper speeds for basic endurance swimming range from those at which the first rise in blood lactate above the resting level occurs up to those that are comfortably below the swimmer's anaerobic threshold. For most swimmers, then, the proper training speeds for basic endurance training will be those that produce blood lactate levels in excess of 1 mmol/L and less than 3 mmol/L.

Another method for determining the proper range of repeat speeds for this level of endurance training is to add between 2 and 6 sec per 100 yd or m to each athlete's threshold training pace, if it is known. My experience has been that for most swimmers this method will provide intensity above the aerobic threshold and below the anaerobic threshold.

Heart rates can also be used to determine the proper speed for basic endurance training. For most swimmers, heart rates in the range of 120 to 150 will encourage swimming intensity above the aerobic threshold and below the anaerobic threshold. A somewhat more precise method for monitoring training is for each swimmer to swim at a speed that produces a heart rate 30 to 60 beats below his or her maximum rate.

Breathing rates and perceived efforts are other methods that can determine the proper range of speeds for basic endurance training. Breathing should be faster and deeper than it is during rest, but swimmers should not be gasping for breath. Using a scale of 1 to 20, athletes should feel that they are swimming at a perceived effort between 12 and 14.

Progressive Overload

Increasing the daily and weekly volume of basic endurance training is the most efficient way to ensure continued improvement of aerobic capacity. To increase the training load gradually, athletes can swim progressively longer repeat distances and include more full-stroke swimming and less pulling and kicking in basic endurance sets. Of course, both the kicking and pulling muscles can be targeted for overload by following the same procedure with kicking and pulling sets.

Other methods for maintaining an overload are to swim basic endurance repeats at a faster pace or to rest less after each repeat. Swimmers must be careful not to change the nature of the training effect when using these methods. Over time, the repeat speed or lack of rest might produce training intensity at or beyond the anaerobic threshold, which would alter the training effects and definitely increase the training stress.

The time to apply additional overload can be determined by monitoring training with one or more of the methods described earlier—by measuring blood lactate concentrations, counting heart rates, counting breathing rates, or rating perceived exertion. Swimming faster or resting less is permissible as long as the athlete remains in the desired stress range, that is, with blood lactates that do not exceed 3 mmol/L, heart rates that do not exceed 150 beats or 30 beats below maximum, breathing rates that are not excessively labored, or a perceived exertion that is not greater than 14.

Summary of Guidelines for Constructing Basic Endurance Sets

- **Set length:** 600 yd or m or 8 min and longer. I recommend minimum distances and times of 2,000 yd or m and 15 min.
- **Rest interval:** 5 to 10 sec for short repeats, 10 to 20 sec for middle distance swims, and 20 sec to 60 sec for long repeats.
- **Repeat distance:** Any distance can be used, but I recommend repeats of 200 yd or m and work times of 2 min or longer.
- **Training speed:** Sufficient to produce blood lactates greater than 1 and less than 3 mmol/L, slower than threshold speed by 2 to 6 sec for 100 yd or m, heart rates in the range of 120 to 150 bpm or 30 to 60 bpm below maximum, breathing rates faster than resting but not labored, or a perceived exertion of 12 to 14 on a scale of 1 to 20.

Threshold Endurance Training

Training in this category should be done at a speed that approximates the swimmer's individual anaerobic threshold.

Training Effects

Certain training effects produced by threshold training are similar to those produced by basic endurance training. For example, improving the delivery of oxygen from the lungs to the muscles should increase aerobic capacity.

One of the most important differences between threshold endurance training and basic endurance training is that threshold training extends the adaptations that improve oxygen utilization and lactate removal to the fast-twitch fibers. The increased speed of threshold training causes fibers from the fast-twitch group, particularly FTa fibers, to rotate in and become involved in the work (Ivy et al. 1987). At the same time, the fact that the production and removal of lactic acid are in balance prevents any severe drop in muscle pH, minimizing muscle damage, and the stimulus for additional capillaries, myoglobin, mitochondria, and increased transport of lactate out of the muscles is quite high.

Effects of Threshold Endurance Training

Primary

- Increased percentage utilization of $\dot{V}O_2max$
- Increased lactate removal from muscles and blood
- Increase in number of capillaries around slow-twitch and fast-twitch muscle fibers
- Increased myoglobin and mitochondria in slow-twitch and fast-twitch muscle fibers

Secondary

- Increased stroke volume and cardiac output
- Increased blood volume
- Increased pulmonary capillaries
- Improved blood shunting
- Increased $\dot{V}O_2max$, particularly in fast-twitch muscle fibers

Threshold training may also improve some aspects of the aerobic endurance of slow-twitch muscle fibers more than basic endurance training does because the intensity of threshold training causes those fibers to operate at the highest levels of oxygen consumption and lactate removal they can maintain without accumulating large amounts of lactic acid in the muscles.

Season Planning

Swimming is the best method for threshold training because, besides improved blood shunting, it produces training effects primarily in and around the muscle fibers used in that training. Some threshold endurance training should occur during all phases of the swimming season so that the aerobic capacity of fast-twitch muscle fibers can improve concurrently with that of the slow-twitch fibers. The quantity of threshold endurance training should decrease during the final 3 or 4 weeks before the taper to provide time for the ST and FTa fibers to regain some of the anaerobic capacity they may have lost through endurance training.

At threshold speed the major source of energy for ATP recycling will be muscle glycogen. Working muscles, therefore, will lose 50% to 70% of the amount they have stored when swimmers complete one threshold swimming set of 1,500 m or longer. This reduction will be particularly true of the FTa fibers. Once that glycogen is lost, 24 to 48 hr of reduced activity will be required to replace most of it, depending on the carbohydrate content of the swimmer's diet. Thus, it is obvious that the increased use of glycogen and the time required to replace it will not permit athletes to train at threshold levels workout after workout without depleting their muscles. If they try to swim at threshold speed when their muscles are depleted of glycogen, they may suffer loss of muscle tissue, myoglobin, and mitochondria, causing their power and endurance to recede rather than improve.

For this reason, swimmers should not attempt to complete threshold sets when their muscle glycogen supply is greatly depleted because doing so will encourage more use of muscle protein which, in time, may lead to overtraining. Swimmers will know that their muscle glycogen supplies are low when they have difficulty swimming at or near previous threshold speed. When that happens, the amounts of threshold and overload endurance training should be reduced for a day or two to provide time for replacement of muscle glycogen.

Each set or two of threshold swimming should be followed by 1 to 1 1/2 days of training that permits the replacement of muscle glycogen in the fibers that were depleted. Based on what we know about glycogen depletion and replacement, athletes training 12 sessions per week (twice per day, 6 days per week) could not hope to swim endurance repeat sets at threshold level or faster during more than four or five of those sessions without severely depleting their muscles of glycogen. Athletes who are training once per day should probably limit their threshold endurance sets to three or four per week for the same reason.

Guidelines for Constructing Threshold Endurance Repeat Sets

The following are suggested set and repeat distances, rest intervals, and training speeds for threshold endurance training sets.

Set Length The distance for threshold endurance training sets can vary anywhere from 500 to 4,000 yd or m, although the ideal distance is probably between 2,000 and 4,000 yd or m. The effective time for these sets can be anywhere between 6 and 45 min, and the ideal duration is between 20 and 45 min.

Although training for short periods near threshold pace can certainly produce adaptations, the disadvantages of shorter distances and short time spans is that athletes will tend to swim considerably faster than threshold speed simply because they can tolerate the progressive increase in acidosis for those short periods. On the other hand, longer set distances and times make it difficult for even highly motivated athletes to swim faster than threshold speed. Swimming at threshold speed will usually cause both a rapid loss of glycogen and a gradual accumulation of lactic acid in the muscles. Therefore, athletes cannot maintain that speed for much longer than 20 to 40 min before becoming fatigued. Faster speed would cause them to fatigue even earlier. Stegmann and Kindermann (1982) reported that athletes could not swim continuously at speeds above their individual anaerobic thresholds for more than 30 min without a severe reduction in speed. My experience is that many sprint-oriented swimmers cannot maintain threshold pace for much more than 20 min before this happens, although some distance swimmers can maintain threshold speed for 40 to 45 min. Sprinters, because they have a greater percentage of fast-twitch muscle fibers, probably produce more lactic acid even at slow speed and thus cannot maintain a balance between lactate production and removal as long as distance swimmers can. Distance swimmers are probably able to swim at threshold speed for a longer time because they have a large percentage of slow-twitch muscle fibers. Those fibers produce less lactic acid at any submaximal speed, so they are better equipped to maintain a balance between lactate production and removal for a longer time.

Repeat Distance Threshold endurance repeats can be done as one long continuous swim or as sets of repeats with very short rest intervals. As with basic endurance repeats, threshold repeats of any distance, even 25 yd or m, should produce the desired training adaptations if the rest period is short enough that the rate of metabolism does not slow appreciably between swims. Nevertheless, repeat distances of 200 yd or m and longer are recommended for threshold endurance training for the same reasons mentioned with regard to basic endurance training. Shorter repeats make it possible to swim faster than threshold speed because of frequent rest periods. This approach encourages more anaerobic metabolism and less aerobic metabolism, thus reducing the training effect somewhat.

Rest Interval The same advice provided concerning rest intervals for basic endurance swimming applies to threshold endurance training. The rest intervals should be no more than 5 to 10 sec on repeats of 25 to 50 yd or m and can be slightly longer as the repeat distance increases. Rest intervals of 15 to 30 sec should probably be the maximum for any repeat distance simply because shorter rest periods allow more time for training. Longer rest intervals should not lessen the training effect on repeats of 500 yd or m and longer, however, because each repeat by itself is long enough to produce a training effect. Still, I do not recommend long rest intervals because with additional recovery time, athletes can swim faster than threshold speed for the length of the set, probably resulting in additional glycogen use and unwanted acidosis.

Training Speed Several methods can be used to estimate each swimmer's individual anaerobic threshold swimming speed. Blood lactate testing is the most precise method for selecting and monitoring swimming speed for threshold endurance training. That speed will produce blood lactic acid levels of 3 to 5 mmol/L for most swimmers, although some sprint swimmers may be able to swim at blood lactate concentrations between 5 to 7 mmol/L and maintain a balance between the rates of its appearance in and disappearance from the blood. As mentioned earlier, however, a swimmer need not train exactly at his or her individual anaerobic threshold. Training at a speed in proximity to this value should produce results that are just as beneficial.

Several procedures that do not require blood testing are available to estimate a swimmer's individual anaerobic threshold. A few of these have good validity, but others are inaccurate. The chapter on monitoring training will review these procedures.

Heart rates and perceived efforts can also be used to monitor threshold training speed, although these methods have more margin for error. In general, a heart rate between 10 and 20 beats below a swimmer's maximum rate corresponds to a near-threshold swimming speed. Training that close to the maximum heart rate, however, may cause some swimmers, particularly sprinters, to train well above threshold speed. The chapter on monitoring training will also discuss procedures for using heart rates to monitor training speed.

Perceived efforts of 15 to 16 on a scale of 1 to 20 are usually indicative of threshold training speed. For greater accuracy, athletes must learn what a 15 or 16 should feel like before perceived exertion can be used to indicate threshold training speed. The idea is to identify the sensation of effort that accompanies threshold swimming. To do this, the threshold speed must be determined with a more accurate procedure, such as blood testing or one of the tests described later, and then the athlete must learn to associate that speed with a particular level of perceived exertion. I should mention that a perceived exertion of 15 or 16 refers to the sensation of effort swimmers should experience during the middle of a threshold set, not near the beginning or at the end. The effort will feel easier than this at the beginning of the set, and it will feel like a maximum effort later if the set is a long one (25 min or longer) on short rest.

Finally, the simplest procedure to ensure that athletes will swim near threshold speed is to construct the repeat set so that they cannot swim faster even with maximum effort. A set that requires 20 min or longer to complete with very short rest intervals will accomplish that. Swimmers will be unable to swim faster than threshold pace for most of the set for the reasons given earlier. If swimmers swim too fast, glycogen depletion and acidosis will force them to slow down. The only mistake that swimmers can make is to swim too slow in a long repeat set. But if athletes are motivated to swim these sets at the fastest possible average speed and they maintain that speed throughout the set, most will be swimming close to their individual anaerobic threshold speed, not slower or faster. Table 13.1 provides some examples of swimming sets that should encourage athletes to swim near threshold speed.

Table 13.1 Threshold Endurance Repeat Sets

20–40 × 100 with approximately 10 sec rest between each 100

10–20 × 200 with approximately 10 sec rest between each 200

5–10 × 400 with 10 to 15 sec rest between each 400

3–4 × 800 with approximately 30 sec rest between each 800

5 × 200/10 sec + 3 × 300/15 sec + 2 × 400/20 sec

These sets are designed for swimmers between the ages of 13 and 30. The rest intervals are designated as approximate because it is understood that, for purposes of administration, most swimming sets are constructed with send-off times that provide somewhat different rest intervals depending upon swimming speed.

Progressive Overload

The goal for threshold training is to increase the swimming speed gradually so that swimmers can maintain balance between lactic acid production and removal. The swimming speed at which the anaerobic threshold occurs indicates that adaptations are taking place that will allow athletes to use more oxygen and remove more lactic acid during races.

The usual methods for overloading—increasing volume, increasing speed, and reducing rest—do not work well with threshold swimming. Athletes can swim faster than threshold speed but only with increasingly greater amounts of energy provided from anaerobic metabolism. This circumstance defeats the purpose of threshold sets because it switches the training effect from one that emphasizes greater oxygen consumption and lactate removal to one that emphasizes improved buffering capacity. Consequently, progressive overload should not be attempted by forcing athletes to swim threshold sets faster or to swim longer threshold sets at the same speed. Coaches should wait until their athletes show signs of being able to swim these sets faster before asking them to do so. In the absence of blood testing, the three best methods to evaluate when it is time to increase the training speed, reduce the rest, or increase the set length are to monitor threshold speed with test sets, heart rates, or measures of perceived exertion.

Any of the repeat sets used as earlier examples could be used as a test set. Alternatively, coaches could develop one for themselves by using the guidelines. Swimmers should repeat this set every 2 to 4 weeks. Their threshold speeds will have improved when they can swim the entire set at an average faster speed. Rest intervals should not be adjusted upward to encourage improvement because longer rest will simply allow greater recovery from acidosis between repeats, thus permitting swimmers to provide more anaerobic energy and less aerobic energy throughout the set.

Another method for determining when to apply additional overload is to monitor heart rates during threshold sets. When athletes can swim these sets at the same average speed with consistently lower heart rates, their anaerobic thresholds have probably improved. Finally, when athletes can swim a threshold endurance set at the same speed with a sense of reduced effort, their thresholds have probably improved. When either of these changes occur, athletes can then swim threshold sets at a new and faster speed, one that produces a heart rate that is again within 10 to 20 beats of maximum or one at which they perceive the effort to be in the range of 15 to 16.

Summary of Guidelines for Constructing Threshold Endurance Sets

- **Set distance:** 500 yd or m or 6 min and longer. I recommend set distances of 2,000 to 4,000 yd or m or set lengths of 20 to 45 min.
- **Repeat distance:** Any distance can be used, but I recommend repeats of 200 yd or m and work times of 2 min and longer.
- **Rest interval:** 5 to 10 sec for short repeats, 10 to 20 sec for middle distance swims, and 20 to 60 sec for long repeats.
- **Training speed:** Sufficient to produce blood lactates in the range of 3-5 mmol/L, heart rates between 10 and 20 beats below maximum, or perceived efforts in the range of 15 to 16 on a scale of 1 to 20.

Overload Endurance Training

Overload endurance training should be done at speeds exceeding those at which the anaerobic threshold occurs. This sort of training is highly anaerobic and produces severe levels of acidosis.

Training Effects

What I just said about the anaerobic nature of overload endurance training may cause one to wonder why it is in the category of endurance training. I place it in this category because long swims or sets of repeats on short rest that are swum faster than anaerobic threshold speed will increase the oxygen use and lactate removal rates of FTb fibers and cause similar improvements in slow-twitch and FTa fibers. Overload endurance training will also increase the buffering capacity of all three categories of muscle fibers.

Treffene and his coworkers (1980) reported that the maximum rate of lactate removal from muscles to blood occurred at swimming speeds 6% to 14% faster than anaerobic threshold speed. This result probably occurred because of the additional lactate removed from FTb fibers and high-threshold FTa fibers once those fibers began contracting. Clearly, swimmers must do some endurance training at a speed in excess of that at which the anaerobic threshold occurs to increase the aerobic capacity and lactate removal rates from FTb and high-threshold FTa muscle fibers.

Finally, the stimulus for an increase in the buffering capacity of all three categories of muscle fibers is acidosis. Athletes can create that condition only by swimming at speeds at which the lactic acid accumulates in muscles faster than it can be removed. Consequently, training at overload endurance speed should improve muscle buffering capacity better than swimming at a slower speed does.

Effects of Overload Endurance Training

- Increase in the maximal oxygen consumption of all trained muscle fibers, including FTb fibers
- Increase in the number of capillaries around all trained muscle fibers, including FTb fibers
- Increase in the amounts of myoglobin and mitochondria in all trained muscle fibers including FTb fibers
- Increase in the rate of lactate removal from all trained muscle fibers, including FTb fibers
- Increase in the buffering capacity of all three categories of muscle fibers

Season Planning

As with threshold training, swimming is the best method for overload endurance training because it is the only way to be sure that the same muscle fibers used in competition are being trained in practice. Swimmers should perform some overload endurance training during all phases of the swimming season so that the aerobic capacity of FTb muscle fibers can improve concurrently with that of other fiber types. Major emphasis on overload endurance training should not occur, however, until athletes have significantly improved their aerobic capacity with basic and threshold endurance training. That emphasis should begin 4 to 6 weeks before most of the important competitions will occur so that swimmers will have sufficient time for the desired training adaptations to take place before they compete. The quantity of overload endurance training should decrease during the final 3 to 4 weeks before the taper to provide time for FTb muscle fibers to regain some of the anaerobic capacity they may have lost during the time they were being trained aerobically.

Overload endurance training can deplete the glycogen supply of muscles as quickly as threshold training reduces it, perhaps even faster because of the greater use of FTb fibers. An additional problem is muscle damage that the severe acidosis of overload endurance training may have caused. Consequently, after one or two consecutive sets of overload endurance training, 1 1/2 to 3 days of easier training should follow to permit the replacement of muscle glycogen in the fibers and the repair of muscle tissue. For this reason, athletes should schedule only one or two major overload endurance sets during each week of training, although they may swim at overload endurance speed for short periods several times each week. For example, they can swim at overload speed during the last few repeats of some basic and threshold endurance sets several times during each week.

The number of threshold endurance and lactate tolerance sets (described in the next chapter) scheduled each week must also be taken into account when determining the number and placement of overload sets. As mentioned earlier, threshold sets also reduce muscle glycogen significantly. Athletes would not have sufficient time to replace that glycogen if they swam one or two overload sets each week in addition to three or four threshold sets. Instead, the overload sets should take the place of one or more of those threshold sets.

Lactate tolerance sets also cause acidosis and tissue damage; therefore, they should not be scheduled during the time a swimmer is supposed to be recovering from an overload set or in addition to the weekly maximum number of overload sets.

Guidelines for Constructing Overload Endurance Repeat Sets

The following guidelines can be used when creating overload endurance repeat sets.

Set Length My experience is that the minimum distance or length of overload endurance repeat sets that will produce a reasonable training effect is 500 yd or m or 6 min.

The maximum distance and time are probably in the neighborhood of 1,200 to 2,000 yd or m or 15 to 20 min. Several researchers have reported similar opinions (Madsen and Lohberg 1987; Stegmann and Kindermann 1982).

As with threshold endurance sets, distance swimmers tend to be able to swim somewhat longer above threshold before acidosis causes a severe reduction in swimming speed. Middle distance swimmers and sprinters will generally experience a greater reduction in muscle pH in a shorter time when they swim faster than threshold speed.

Repeat Distance Athletes can also do overload endurance repeats as continuous swims of 1,000 to 2,000 yd or m or as sets of repeats with very short rest intervals. Repeats of any distance will produce the desired training adaptations as long as the effort is at or near maximum and the rest interval is reasonably short. Swimming too fast on these sets is not a concern. Therefore, short repeat distances are probably just as effective as longer swims for improving the endurance of all types of muscle fibers.

Rest Interval The rest intervals can be similar to those recommended for basic and threshold endurance. They could be somewhat longer or ultrashort without disturbing the training effect. Increasing the rest interval to 20 or 30 sec on shorter repeats and to between 30 sec and a few minutes on longer repeats will not change the training effect because the athletes will be swimming at a higher rate of effort. Consequently, they will need more time to recover to the same level they might have reached with a shorter rest when they were swimming slower. Increasing the rest interval may even improve the training effect on some types of repeat sets because with slightly more time to remove lactic acid from their muscles during the rest interval, athletes will be able to complete somewhat longer sets at faster average speeds before acidosis forces them to shut down.

Ultrashort rest intervals can be used during these sets to help athletes simulate continuous swimming at or near race speed for longer periods. Swimming a set of repeats totaling 1,000 to 2,000 yd or m on the shortest send-off that the swimmer can make is one of the most motivating and effective ways to perform overload endurance training.

Training Speed Measuring blood lactate concentrations is not necessary when monitoring overload endurance training. When they are performing these sets at the proper speeds, most swimmers will have blood lactate concentrations of 6 mmol/L up to whatever their individual maximum blood lactate concentration may be.

My experience is that swimming times 2 to 3 sec per 100 yd or m faster than a swimmer's individual anaerobic threshold speed are adequate for engaging and training the FTb muscle fibers. Research has not determined whether swimming faster is even more effective, although indications are that it is.

Heart rates should be maximum during overload endurance sets, and perceived efforts should be 17 to 20 on a 20-point scale. Examples of swimming sets that should encourage athletes to swim at overload endurance speeds are provided in table 13.2.

Table 13.2 Overload Endurance Repeat Sets

20–40 × 50 with 15 sec rest between each 50

15–20 × 100 with 10 to 30 sec rest between each 100

6–10 × 200 with 10 to 30 sec rest between each 200

3–5 × 400 with 15 sec to 1 min rest between each 400

2 × 300/30 sec rest, 3 × 200/30 sec rest, 5 × 100/30 sec rest

10 to 20 × 100 on shortest possible send-off

Progressive Overload

In contrast with the methods used for threshold training, the usual methods for overloading, increasing volume, increasing speed, and reducing rest work well for applying progressive overload to overload endurance training. When athletes can swim faster during one of these sets, they are getting better and it is time to apply an overload in some manner. Coaches should establish a test set to evaluate whether improvements have taken place. Any of the sets presented in table 13.2 will work for this purpose.

Blood testing has also been used to monitor improvements resulting from overload endurance training. Experts have compared speeds that produce blood lactate concentrations between 6 and 10 mmol/L for this purpose because those values are above the anaerobic thresholds of most athletes.

Monitoring heart rates and perceived effort will not be effective for determining improvements from overload endurance training. Athletes should have maximum heart rates when they perform these sets, and they should experience maximum levels of perceived exertion, although their heart rates and particularly their sensation of effort may drop somewhat on standardized overload sets as they improve. Evaluating those improvements by increases in speed, however, is much easier administratively.

Summary of Guidelines for Constructing Overload Endurance Sets

- **Set distance:** 500 yd or m or 6 min and longer. I recommend set distances of 1,200 to 2,000 yd or m or 15 to 20 min.
- **Repeat distances:** Any distance up to 2,000 yd or m can be used effectively.
- **Rest intervals:** 5 to 30 sec for short repeats, 15 sec to 60 sec for middle distance swims, and 30 sec to 2 min for longer repeats.
- **Training speed:** Faster than threshold speed. Times 1 to 2 sec per 100 yd or m faster than threshold speed usually indicate that FTb fibers are activated. Heart rates should be at maximum, and perceived efforts should be 18 to 20 on a scale of 1 to 20.

Harmful Effects of Swimming Above Threshold Speeds Too Often

I have attempted to explain why it is necessary to do some very fast training to improve aerobic endurance to a maximum level. Doing so too often, however, can produce the opposite effect. The results of several studies suggest that athletes can actually lose endurance by swimming faster than threshold speeds too frequently in training.

Madsen and Olbrecht (1983) reported that athletes who trained at speeds that produced blood lactate concentrations in the neighborhood of 6 mmol/L (which was probably above the anaerobic threshold for most of the athletes) exhibited deteriorations in performance on measures of aerobic endurance. Hollmann and coworkers (1981) reported that subjects who trained for 6 weeks at blood lactates in excess of 4 mmol/L, which is also above the anaerobic threshold for most athletes, did not improve their aerobic endurance. Heck and his associates (1985) reported similar results when subjects trained for 20 weeks at speeds above those that produced blood lactates of 4 mmol/L.

In another study designed to investigate the effects of training above the anaerobic threshold, Gabriel and coworkers (1998) found that subjects "suffered from typical overtraining symptoms" after just 4 weeks of training at speeds above those corresponding to their anaerobic thresholds. In addition, their performance declined 3% on a maximum effort test of 60 sec and by 14% on a test of time to exhaustion at a pace equal to 110% of each subject's anaerobic threshold. Urhausen and associates (1998) also reported decrements in performance after 4 weeks of training above the anaerobic threshold. In addition, they disclosed that training above the anaerobic threshold caused a significant decline of 20% to 42% in the secretion of several hormones, including epinephrine, norepinephrine, and growth hormone. Mikesell and Dudley (1984) also reported that runners who did their endurance training at fast speeds lost aerobic capacity.

Four principal reasons explain why aerobic capacity may deteriorate if an athlete trains above the anaerobic threshold too frequently. First, intense training reduces the quantity of endurance work that the athlete can accomplish. When swimmers complete training sets above the anaerobic threshold, a steady increase of muscle lactate occurs that reduces pH and causes fatigue within 10 to 20 min. After swimmers become fatigued, they will probably require 10 to 30 min of easy swimming before muscle pH will normalize and they will be able to perform another intense set of repeats (Hermansen and Osnes 1972). So, swimmers spend a small amount of time swimming fast and a large amount of time swimming at recovery levels that are too slow to improve aerobic capacity. The slow speeds are usually inadequate for overloading aerobic metabolism, and the swimmers cannot maintain fast repeats long enough to overload aerobic metabolism adequately.

The second reason that frequent training at speeds beyond the anaerobic threshold can be detrimental concerns the effect on slow-twitch muscle fibers. As I described earlier, evidence suggests that swimming faster than threshold speed may reduce some aspects of aerobic capacity in slow-twitch muscle fibers even as it improves the aerobic capacity of fast-twitch muscle fibers. This finding reinforces the importance of training at speeds both slower than and faster than threshold speeds. Training in that way can increase the aerobic capacity of all muscle fiber types.

A third reason may be the effect of training with low levels of muscle glycogen. One or two repeat sets swum near anaerobic threshold speed or faster will considerably reduce muscle glycogen. If athletes try to swim fast in subsequent training sessions before their muscle glycogen has been replaced, they will burn significantly greater amounts of protein for energy, cannibalizing their own muscle tissue for energy. The muscle will lose some mitochondria that provide their endurance and some structural proteins that give them strength and power. When that loss becomes extensive, performance will suffer.

The fourth reason concerns wear and tear on the endocrine and immune systems and the potentially damaging effects of severe and frequent acidosis on muscles. Several pieces of research have shown a reduction in the secretion of certain hormones, principally human growth hormone and the hormones of the adrenal glands involved in the fight-or-flight reaction—cortisol, epinephrine, and norepinephrine—when athletes overtrain. The adrenal hormones are involved in the fight-or-flight reaction that prepares the body for exertion. Training faster than threshold pace initially causes an increase in secretion of these and other hormones. Over time, however, the rate of secretion decreases. These reductions in secretion are usually accompanied by symptoms of overtraining, including decreased performance, weight loss, lack of interest, and lowered motivation. Because growth hormone stimulates tissue growth and the adrenal hormones facilitate the release of energy from glycogen and fat, their suppression may cause a reversal of training adaptations and a reduction in performance. A reduction in the adrenal hormones will also make it difficult for athletes to mount maximum efforts in training and competition.

Experience and the available evidence suggest that athletes should not swim at threshold speed and faster too often. They should be sure to provide sufficient time to replace the glycogen their muscles used for energy during those sets, repair the damage to the muscles, and replenish the hormones they used.

Should Swimmers Compete With One Another During Endurance Training?

The concept that certain types of endurance repeats should be swum at optimum rather than maximum speeds is difficult for some coaches and athletes to accept because it conflicts with the competitive nature of the sport. Many of us grew up believing that success results from pushing ourselves to swim faster during all phases of our training. We were encouraged to race our teammates in practice and to try to beat as many of them as possible. Although this approach was good for some aspects of the training process, it can be detrimental in other aspects, particularly endurance training. Swimmers can and should perform overload endurance training at the highest level of effort. Competition with teammates can improve that effort. Basic endurance and threshold endurance training, however, should not be conducted in a similar manner.

Racing faster teammates during basic endurance and threshold endurance repeats simply causes slower swimmers to train in or beyond their overload endurance zones, where they will experience severe acidosis too frequently. As mentioned several times earlier, the aerobic capacity of slow-twitch muscle fibers improves best by training at optimum, not maximum, speeds.

Athletes should not be concerned with racing teammates during basic and threshold endurance repeat sets. Their goal should be to swim at optimum ranges of speed that will overload various aspects of aerobic capacity without producing severe acidosis. They should swim at those speeds for progressively greater distances or swim with progressively less rest between repeats. They should increase their training speeds in these two categories of endurance training only when some form of self-monitoring indicates that they are physically prepared to do so.

Casual observers may doubt the wisdom of this advice. Swimmers who race in training, even when they are supposed to be swimming at basic and threshold speeds, will generally improve quite rapidly during the first 4 to 6 weeks. Those early improvements may limit their potential performance later in the season. Swimmers who do not first build a strong foundation for aerobic endurance with basic and threshold endurance training performed at optimal speeds will limit their ability to perform sufficient volumes of fast endurance training later. Ultimately, their performances in middle distance and distance events will suffer.

Having said this, let me reiterate that swimmers should swim fast and compete with their teammates during overload endurance and all forms of sprint training. Training in that way will improve not only the endurance of fast-twitch muscle fibers and buffering capacity in all fibers but also the competitive spirit. Competitive spirit is essential to improving performance, and it should be encouraged in those aspects of training in which its expression will not disrupt swimmers' training goals.

Special Types of Endurance Training

In this section I would like to discuss the values of different types of endurance training in common use. The first of these is *marathon and fartlek training*. This category really encompasses two types of training. They are similar in their effects and administration, however, so I have combined them into one category.

Marathon and Fartlek Training

Marathon and fartlek swimming are training methods that involve swimming continuously for long periods. The major difference between the two methods is that the pace of the swim is constant in marathon training, whereas in fartlek training athletes can vary it in several ways—by alternating swimming speeds, by alternating swimming strokes, and by alternating swimming with kicking and pulling. *Fartlek* is a Swedish term that means "speed play."

Swimmers rarely use either method. Interval swimming is the principal type of training used in our sport, but some experts feel that it is overused and that swimmers should perform more long, continuous swims. They reason that swimming long distances without periodic breaks may be a better method for improving aerobic capacity. For support, they point to distance runners in track and field, who use long, continuous runs of a marathon or fartlek nature for a good portion of their training.

One of the reasons given for using long, continuous swims is that athletes can stress their aerobic systems more effectively with less interference from acidosis. By taking frequent rests, athletes can swim each segment of a repeat set at a faster speed than they could if they swam the total distance continuously. Consequently, motivated athletes tend to swim beyond their aerobic capacity simply because the periodic rest periods afford a partial recovery from acidosis. With marathon training most of the improvements of aerobic capacity will take place in the respiratory and circulatory systems and in the slow-twitch muscle fibers only. Swimmers can overcome that limitation, however, simply by swimming the last portions of long swims at a fast speed. The fast-twitch fibers will be forced to contract, thus improving their oxygen utilization and lactate removal rates. Fast-twitch muscle fibers will receive a similar training effect during the fast portion of fartlek training.

Disagreeing with that reasoning, proponents of interval training believe that the ability to swim a distance at a faster average pace by breaking it into segments with short periods of rest after each swim provides a greater training stimulus. They also point to the fact that swimming training is different from running training in that swimmers become isolated and bored more easily during long, continuous training. They lose contact with their teammates and their surroundings, whereas runners can engage in conversations and enjoy the changing scenery on long runs.

I agree with the experts who believe that long, continuous swims can provide an effective vehicle for improving aerobic capacity. Because of the isolation and boredom that swimmers experience, however, they should also use other methods for this purpose. Nevertheless, long, continuous swims performed in a marathon or fartlek manner should probably have a larger role in the training programs of middle distance and distance swimmers. Interval training remains the best procedure for improving endurance because of the added speed of each segment of the total distance and because swimmers gain motivation from the immediate feedback of seeing their times periodically during the set.

Marathon and fartlek swims should take a minimum of 15 min to complete, although 30 min or longer is preferable. Swimmers should perform marathon swims at a moderate pace when the purpose is to improve the endurance of slow-twitch muscle fibers while encouraging glycogen replacement and tissue repair in fast-twitch muscle fibers. The final 300 to 800 m of these swims should be performed at a very fast speed when the goal is to improve the endurance of all fiber types.

Swimmers should perform their fartlek swims with a large difference between the fast and slow segments when the purpose is to improve the endurance of both slow-twitch and fast-twitch muscle fibers. The fast segments should be long enough to stimulate oxygen consumption near maximum rates, and the slow segments should be slow enough to permit partial recovery from the resulting acidosis. Athletes can do this by swimming fast segments for 2 to 6 min followed by slower segments three to four times longer.

Fartlek training can also serve several other purposes. By interspersing fast segments with shorter recovery segments, fartlek can be a form of overload endurance training. For example, fast segments of 100 to 200 yd or m can be followed by slower segments of 50 to 100 yd or m.

Fartlek training can also improve buffering capacity and sprinting speed. For improving buffering capacity, the fast segments should be 25 to 200 yd or m and the recovery segments should be 50 to 600 yd or m. For sprint training, the fast segments should be short and very fast and the slow segments should be long. The fast segments should be short enough and fast enough to cause a near-maximum rate of anaerobic metabolism, and the slow segments should be long enough and slow enough to permit nearly complete recovery from the resulting acidosis. Fast segments of 10 to 50 yd or m and slow segments of 50 to 200 yd or m are ideal for this purpose.

Finally, fartlek training can be conducted by mixing competitive strokes during the fast and slow segments or by mixing full swimming with kicking or pulling of the same or a different stroke during the fast and slow segments. The athletes should swim their major strokes during the fast segments and use off-stroke swimming or kicking or pulling during the slower segments for recovery. The change in stroke or the switch to kicking or pulling during the slow segments will allow more recovery so that athletes can swim the fast segments at faster speeds, thus providing greater stimulation to fast-twitch muscle fibers, and requiring a greater contribution from anaerobic metabolism. Table 13.3 provides examples of fartlek swims for each of these purposes.

Cruise Intervals

Dick Bower of New Orleans, Louisiana, developed cruise intervals. Mr. Bower and many other coaches have used them with success over the last three decades. Cruise

Table 13.3 Examples of Fartlek Swims

For improving aerobic capacity

1. Swim 1 hr continuously. Alternate swimming 200 m of freestyle approximating anaerobic threshold pace with 100 m of freestyle swum no slower than aerobic threshold speed.
2. Swim 2,000 yd continuously. Alternate swimming 100 yd of freestyle approximating anaerobic threshold speed with 100 yd of freestyle no slower than aerobic threshold speed.

For improving aerobic muscular endurance

1. Swim 30 min continuously. Alternate 150 m of backstroke at a fast speed with 50 m of any stroke at a slow speed.

For improving anaerobic muscular endurance

1. Swim 1,000 m continuously. Alternate swimming 50 m butterfly very fast with 50 m of any stroke at a slow speed.
2. Swim 800 yd continuously. Alternate swimming 75 yd of backstroke fast with a 25 yd stroke drill.

For improving sprint speed

1. Swim 700 yd continuously. Alternate a 25 yd freestyle sprint with an easy 75 yd stroke drill.

interval swimming is one of the best procedures for individualizing endurance training for groups of swimmers of different ages, genders, and abilities.

In many training programs the send-off times for a set of repeats are set for the slowest swimmers in the group, the average swimmers in the group, or the best swimmers in the group. All these methods have inherent weaknesses. The majority of the swimmers in a group generally get too much rest between repeats when send-off times are set for the slowest swimmers. As a result, some of the less motivated swimmers in the group can swim slower than their optimum speed for endurance training, and the highly motivated members can swim so fast that they change the nature of the set from one that improves aerobic capacity to one that improves anaerobic metabolism. When send-off times are set for the average of the group, the best swimmers can still swim too slow or too fast, and the slower swimmers will be forced to swim anaerobically in their efforts to keep up with the others. Slower swimmers generally do not complete these sets. Send-off times set for the fastest swimmers in the group extend this response to all but a few of the swimmers in the fast group.

Cruise intervals allow coaches to individualize training speeds and send-off times for a large number of swimmers with a wide range of abilities who are all training together in a limited number of lanes. The first step in using this procedure is for swimmers to complete a test to determine their ideal training speeds and send-off times. The early version of this test required athletes to swim a set of 5 × 100 yd or m on the fastest possible send-off time. Although this test worked fine for well-trained endurance athletes, a test of 10 × 100 swims has since replaced it because the longer duration was determined to be more appropriate for a wider range of athletes (Bower 1997). Swimmers should complete the test at the fastest possible pace they can hold while taking exactly 10 sec rest after each repeat swim. Experienced swimmers can time themselves on a pace clock, but novices may need help from coaches and teammates on the deck.

The coach should record the total time for the complete set of 10 × 100, including the rest time, for each swimmer when he or she finishes the 10th repeat. Ten seconds is then added to this time because the swimmer rested only nine times. The total is then divided by 10, and the quotient is recorded. An example of the procedure follows on page 436.

The usual procedure is to round the quotient up to the nearest multiple of 5 sec to provide the same cruise interval for several swimmers with similar quotients. The quotient of 1:24 has been rounded up to 1:25 in the cruise intervals test for this reason. A quotient of 1:26 would be rounded up to a cruise interval of 1:30.

Procedure for determining a cruise interval send-off time from the cruise intervals test

Test = 10 × 100 with 10 sec rest between swims

Total time for swimmer = 14:00

14:00 = 840 sec

840 ÷ 10 = 1:24 per 100

Round up to a cruise interval of 1:25

All swimmers with a particular cruise interval are then assigned to the same lane for their endurance training repeats. Those repeat sets will usually require 15 min of swimming time. For purposes of overload, those sets should increase to 30 min, in 5 min steps, as the swimmers improve. The athletes should swim each set as instructed by the coach. Usually the coach will ask them to try to swim as easy as possible and still make the send-off time. In that case, athletes can swim their repeats slower than the average swimming speed they achieved during the test without reducing the value of the set for improving endurance. For example, a swimmer with a total time of 14:00 for the cruise interval test would have been swimming each of the 10 × 100 repeats in approximately 1:14 (1:24 – 10 secs rest). It would not be necessary for the swimmer to swim sets of 100 repeats at 1:14 in training, however. The send-off time of 1:24 would permit him or her to swim those repeats at any time from 1:15 to 1:23 without changing the training effect.

The athletes can swim their training repeats at any speed that permits them to make the assigned send-off time of 1:25, even if that speed is slower than their average repeat time for the cruise interval test. Training in this way would correspond to basic endurance training. On some days, the coach may ask the swimmers to try for the best average repeat time they can achieve on the assigned send-off time. In that case, they will be training at the threshold or overload endurance level depending on whether the set is longer or shorter than 20 min.

The cruise interval test will be more valid if swimmers start the set by swimming slightly slower times and then finishing with faster times. Swimmers who start too fast and lose speed during the set may want to repeat it a few days later to get results that are more accurate.

The repeat distance does not have to be 100 yd or m for the cruise interval test. Any distance that swimmers can complete in a time of 1:00 to 1:45 is fine. Of course, this range of times means that most swimmers will be repeating 100 yd or m swims during the test. However, in large groups, some of the younger and less experienced swimmers may need to swim repeats of 50 or 75 yd or m to make the upper limit of the time range.

Once cruise intervals have been established for each swimmer, the pool can be set up so that each lane or two is made up of athletes with the same cruise interval. For example, in a six-lane pool, the faster team members may be swimming in lanes 1 and 2 on send-off times of 1:10 and 1:15, respectively. The majority of the group may be swimming in lanes 3, 4, and 5 on a send-off time of 1:20, and the slower swimmers could swim in lane 6 on a send-off time of 1:25. If the length of the set is 20 min and the repeat distance is 100 yd, the faster swimmers could be expected to complete 16 or 17 repeats of 100 yd or m. Most of the swimmers will complete 15 repeats in the allotted time, and the slower swimmers will complete 14 repeats.

The administrative and physiological advantages of training with cruise intervals are twofold. All the swimmers will start and finish at almost the same time, and they will be training at a pace and send-off that are sufficiently challenging to improve their endurance without causing them to fail. Every swimmer in the pool can train at the proper level regardless of age or ability, and swimmers can train with few obstructions and collisions.

Repeat distances in excess of 100 yd or m can be used in cruise interval sets by doubling each swimmer's 100 send-off time for 200 repeats, tripling it for 300 repeats, and so forth. By completing a cruise test in the desired style, cruise intervals can also be established for each competitive stroke, for the IM, and for kicking and pulling repeats.

In his printed material concerning cruise intervals, Bower cautioned that the result of a cruise interval test is not suitable for butterfly training. He suggests that the repeat distances be shorter than 100 yd or m, the rest interval longer, and the times based on the athlete's present 200 yd or m butterfly pace. For example, good butterfly swimmers should do 50 repeats on 1 min or longer until they can do 20 at an average speed faster than their pace for a competitive 200 butterfly event. When they can do this, they can drop the send-off time by 5 sec and start the process again, progressing toward the fastest send-off time that permits them to repeat 20 × 50 under their 200 pace. A worthy goal for good butterfly swimmers who are teenage and older is to reach a point where they can swim 20 × 50 yd of butterfly on a send-off of 50 sec.

The cruise interval test was designed to encourage swimmers to train near their anaerobic threshold speeds, but no data have ever been presented to verify that it was achieving its purpose. Therefore, Richard Firman and I tested its validity for this purpose. Our subjects were 12 male university competitive swimmers (Firman and Maglischo 1986). We tested the group with the "old" method of 5 × 100 on the shortest send-off in common use at the time of our study.

After we determined the cruise interval for each swimmer, we asked the subjects to swim a set of 20 × 100 on their cruise interval send-off times. We recorded the average speeds for each repeat of the set and compared them to the anaerobic threshold paces that had been calculated from blood testing just a few days earlier. We also took samples of blood lactate near the end of each cruise interval set to find what blood lactate concentrations were being produced by the swims.

We found that the repeat speeds during the cruise interval set of 20 × 100 were generally slower than the swimmers' threshold paces as determined from blood testing. For 5 of the 12 subjects, however, blood lactate concentrations were slightly above those they had produced when swimming at their anaerobic thresholds. Blood lactates were the same or near those associated with their anaerobic thresholds for the remaining 7 subjects.

Our conclusion was that cruise intervals are an effective method for encouraging swimmers to train at or near their individual anaerobic thresholds. Although we have not investigated its validity, the test of 10 × 100 described earlier would probably increase the number of swimmers in any group who are training near their anaerobic threshold speeds simply because the longer test distance puts more emphasis on endurance.

Bower (1997) has also proposed the addition of cruise-plus and cruise-minus intervals to the cruise interval training procedure to extend its use to basic endurance and overload endurance training. Cruise intervals designed to simulate basic endurance training are designated *cruise-plus,* and those designed to simulate overload endurance training are indicated by the term *cruise-minus.* Cruise-minus repeats are swum with a reduction of 5 sec per 100 to the cruise interval send-off time. Thus, athletes must swim faster to make the send-off, which should put most of them in the metabolic range for overload endurance training. The set length should be less than 15 min when cruise-minus send-off times are used. An additional 5 or 10 sec is usually added to the tested cruise interval send-off time when the cruise-plus procedure is used. This additional time allows athletes to swim slower and still make the send-off time. By swimming each repeat very fast and using the additional rest for recovery, cruise-plus send-off times can also be used for training at overload endurance speed and for sprint repeats. For this reason, coaches should specify the purpose of cruise-plus repeats so that athletes will swim these sets properly. When the purpose is to swim at basic endurance speed, athletes should swim slower than they do on standard cruise interval sets. When the purpose is to train in the overload endurance ranges with cruise-plus intervals, the sets should be shorter than usual and athletes should swim faster than usual.

Last-one-fast-one is another modification to the cruise interval procedure that Bower has introduced in the past several years. This method involves swimming the last repeat of a set faster than the others. In some cases, the swimmers have an additional 1 min of rest before this repeat so that they can swim it faster. This procedure serves many purposes. It adds a dimension of sprint training to every cruise interval set and thus improves anaerobic metabolism. Attempting to swim the last repeat faster than the others can also indicate potential training problems. When athletes cannot swim the final repeat faster than they can the others, they have probably been overreaching during the set. Overreaching will be beneficial only when the purpose of the set has been to swim at overload endurance speed or faster. It is certainly not desirable for sets designed to encourage swimming at threshold and basic endurance speeds. When an athlete cannot swim the last repeat of cruise-interval or cruise-plus sets very fast, he or she may be experiencing several negative reactions to training. The athlete may have entered a state of failing adaptation. An inability to swim the last repeat fast could also signify a serious depletion of muscle glycogen, a nutritional deficiency, a lack of motivation that may be hormonal in origin, or the imminent appearance of a debilitating illness.

Australian Heart-Rate Repeat Sets

Dr. Bob Treffene, a noted Australian exercise scientist, developed the Australian heart-rate repeat sets. The method consists of a set of endurance repeats swum faster than anaerobic threshold pace with a medium-length rest interval. The name for the set comes from the fact that training speeds are monitored by counting the athletes' heart rates during the repeats. Heart-rate sets were designed principally to improve the lactate removal rate from muscles and blood. Treffene and associates (1980) reported that the maximum rate of lactate removal from muscles to blood takes place at speeds that are 6% to 14% faster than those at which the anaerobic threshold occurs. Consequently, heart-rate sets were designed with the idea that athletes would swim endurance sets at speeds that would encourage a maximum rate of lactate removal from muscles and thus provide stimulation to improve that physiological mechanism.

Other researchers have questioned the validity of heart-rate sets for this purpose. Their results show that maximum rates of lactate removal are reached at speeds slower than those at the anaerobic threshold. Supporting anecdotal evidence is strong for heart-rate sets, however, as noted by the fact that all Australian medalists at the 1992 and 1996 Olympics Games used heart-rate sets in training.

Heart-rate sets would be classified as overload endurance training (En-3). As such, the training adaptations they produce should be those that I described for that training category. The principal advantage of heart-rate sets over slower endurance training is probably that heart-rate sets involve all the fast-twitch muscle fibers as well as the slow-twitch muscle fibers, thus encouraging adaptations in those fibers that will increase oxygen utilization and lactate removal rates.

Heart-rate sets are constructed in the following manner.

- The set should last no less than 15 min of actual swimming, although 30 min is the optimal swimming time for most athletes. Teenage and young adult freestyle swimmers can usually complete 2,400 to 3,000 m in 30 min, but swimmers in other strokes may be able to swim only 2,000 to 2,400 m in 30 min.

- The suggested repeat distances for endurance swimmers are between 100 and 400 m. For middle distance swimmers, ideal repeat distances are between 50 and 200 m, and for sprinters the repeat distances should be between 50 and 100 m. I recommend these because they permit athletes to swim closer to race speed in heart-rate sets.

- Rest intervals should be shorter than the time required to swim the repeats. At the same time, they should be somewhat longer than those typically used during basic endurance swimming so that athletes can repeat closer to race speed. For example, good freestyle swimmers may select send-off times between 1:30 and 2:00 for 100 m repeats. Send-off times in this range generally provide between 30 and 40 sec of rest between swims for most swimmers. Swimmers should do 50 m repeats on send-off times of 1:00 to 1:30 so that they have between 30 and 45 sec of rest between repeats.

- All athletes should swim their heart-rate sets at a speed that exceeds their anaerobic threshold pace and as near race pace as possible. Distance swimmers will usually be able to swim heart-rate sets near race speed when the repeats are short. They should be able to swim repeats faster than 1,500 m pace for 50 m repeats and very close to that pace for 100 m repeats. They will generally swim longer repeats somewhat slower than race speed, but they should still exceed their anaerobic threshold speed. Middle distance swimmers will also be able to swim their heart-rate sets near race speed when the repeat distance is 50 m, and they should be able to swim only slightly slower than race speed when the repeat distance is 100 m. Repeat speed will always be slower than race speed for sprinters. Nevertheless, like swimmers in the other groups, they should be swimming these sets faster than their individual anaerobic threshold paces.

- The real indicator of the proper speed for athletes during these sets is heart rate. Those rates should be within 10 to 20 bpm of each individual swimmer's maximum rate after the first 500 m of the repeat set, and swimmers should maintain their rates at 10 bpm below maximum for most of the set. Swimmers should strive to reach maximum heart rates during the last 200 m of each set. High but submaximal heart rates are specified for most of the set to make certain that athletes are swimming at sufficient intensity to encourage high rates of lactate removal yet not so fast that they cannot complete the set. Consequently, swimmers should slow down if their heart rates exceed maximum minus 10 bpm before the last 200 m of each repeat set.
- Middle distance and distance swimmers should do heart-rate sets two or three times weekly. Sprinters should swim only one heart-rate set each week. These sets tend to deplete muscle glycogen, particularly in the fast-twitch muscle fibers, so sprinters may find that swimming heart-rate sets too often interferes with the quality of the sprint work they perform at other times during the week. They need sufficient time to replace the principal energy source in their muscles.

An example of a heart-rate set completed by a breaststroke swimmer with a best time of 1:09 is shown in table 13.4. The set consists of 15 × 100 m of breaststroke on a send-off time of 2 min.

For purposes of administration, a maximum heart rate of 200 can be assumed for swimmers the first few times they perform heart-rate sets. Once they have completed a set, the maximum heart rate they attained can be used for all later sets. After that,

Table 13.4 Results of a Heart-Rate Set for a Breaststroke Swimmer

The swimmer's best time for the 100 m breaststroke is 1:09.
Maximum heart rate = 211
Set: 15 × 100 on 2 min, short-course meters

NO.	TIME SEC	HEART RATE BPM	NO.	TIME SEC	HEART RATE BPM
1	1:20.9		9	1:18.2	195
2	1:20.6	181	10	1:17.7	195
3	1:19.5	185	11	1:17.7	197
4	1:19.2	186	12	1:17.3	198
5	1:19.0	187	13	1:17.2	199
6	1:18.4	190	14	1:17.2	200
7	1:17.9	191	15	1:15.5	205
8	1:17.6	192			

Adapted from Treffene 1995.

however, each athlete should have identified his or her maximum heart rate to promote more effective swimming of these sets. An individual's maximum heart rate can be determined by counting heart rates for the last few repeats during the first two or three heart-rate sets that each athlete performs. That maximum can be revised upward any time the swimmer achieves a higher value during a subsequent heart-rate set.

Experience with this training procedure has resulted in the development of another heart-rate set used by many of the most successful Australian swimming coaches. With this method, swimmers decrease their times periodically throughout the set, using their heart rates to monitor the amount by which they increase their swimming speed. The usual procedure is to divide the repeat set into three parts. Athletes swim the first third of the repeats at a heart rate of maximum minus 30 bpm, the middle third at a heart rate 20 bpm less than maximum, and most of the final third of the set at maximum minus 10 bpm. Swimmers try to attain maximum heart rates on the last one or two repeats of the set.

This method of swimming is not quite as intense as the traditional type of heart-rate set. Consequently, athletes can use it more frequently during the week. The first two-thirds of this type of heart-rate set probably corresponds to threshold swimming, as I have defined it. The final third corresponds to my definition of overload endurance swimming.

Descending Speed Repeat Sets

Descending speed repeat sets are much like the one just described. Some coaches prefer the term *progressive set* when they refer to swimming repeats that become progressively faster. An example of a descending speed set would be to swim 6 × 300 m on a send-off of 3:45, trying to swim each one or two repeats slightly faster than the previous ones.

Sets of this type are an excellent form of endurance training for coaches and swimmers who do not wish to concern themselves with monitoring training speed or intensity with blood lactates, heart rates, or perceived efforts.

The set distance should take at least 15 min to complete, so most teen to adult swimmers would swim at least 1,000 yd or m. The repeats can be any distance deemed appropriate. Rest intervals should be short so that they fit the endurance nature of the set, although they can be somewhat longer near the end of the set to encourage faster speeds.

Repeat speeds can be descended in a variety of ways. They can be increased progressively, every repeat or two, from start to finish, or, they can be increased in stages in the same way described for the alternate form of heart-rate sets in the previous section. Finally, repeat speeds can be descended by swimming at a constant speed for most of the set and then finishing with a few very fast repeats to emphasize improving aerobic capacity, buffering, and the rate of anaerobic metabolism. Descending progressively throughout the set will allow the athlete to train for improvement of aerobic capacity and lactate removal in the slow-twitch muscle fibers early in the set and then shift the emphasis toward improving the same mechanisms in fast-twitch muscle fibers later in the set.

The advantage of descending sets is that swimmers can swim through the entire spectrum of endurance training speeds from basic to overload endurance training in one set. They can also include some sprint training by swimming very fast on the last few repeats. Consequently, they know they are training their circulatory and respiratory systems and all the various facets of energy metabolism in both their slow-twitch and fast-twitch muscle fibers in one repeat set. And they can accomplish this without testing or monitoring their training speeds.

My experience has been that successful athletes train more with this type of set than with any other method. The big advantage of training in this way is that athletes can stress several phases of metabolism with one set of repeats in both the slow-twitch and fast-twitch muscle fibers. A second advantage is that athletes swim at submaximal speed for most of the set so that they stress aerobic metabolism with little interference from anaerobic metabolism until the set is almost complete. Thus, they can be reasonably certain that acidosis will not interfere with attaining the endurance training adaptations they seek, even if they do not monitor their training progress in any way.

One possible disadvantage of swimming sets in a descending manner is that some athletes may swim too slowly, for too much of each set, too often. Some swimmers tend to train very slowly for most of the set so that they can swim very fast during the last few repeats. Swimming most of the repeats in a descending set at basic endurance speed is acceptable, even desirable, if the purpose is to improve the endurance of slow-twitch muscle fibers while recovering from previous sets that were more intense. Athletes must descend their repeat times earlier in these sets, however, when the goal is to improve the endurance of fast-twitch muscle fibers.

One of the biggest mistakes that motivated swimmers can make during descending and other types of endurance repeat sets is to *overreach*. Overreaching is a term used to describe a situation in which athletes try to swim repeat sets at an unrealistic speed. Swimming too fast too early during descending endurance sets can cause swimmers to go into acidosis before they have completed most of the set. When this happens they must slow down to recovery speed for the remainder of the set. The result is that athletes train anaerobic metabolism, particularly buffering capacity, more than they train the mechanisms responsible for delivering oxygen and removing lactate. Acidosis usually occurs so early in the set that aerobic metabolism will actually slow and the desired adaptations will not occur.

Many swimmers mistakenly believe that they are training correctly when they overreach because they have pushed themselves to the breaking point during the repeat set. The reality is that their rapid speed in the early portions of the set emphasizes anaerobic metabolism and reduces the training effect on aerobic metabolism. After that, their slow speed during the last several repeats will not be sufficient to stimulate further improvement in aerobic or anaerobic metabolism, despite the difficulty they experience in completing them. The only advantages to swimming a repeat set in this way are to improve pain tolerance, to increase buffering capacity, and to improve the ability to maintain good stroke mechanics when fatigued. The disadvantages are, first, that the training effects are all anaerobic and will do little to improve aerobic endurance and, second, that muscle damage and joint injuries may occur, which will curtail training for several days. For these reasons, athletes should not overreach during their descending sets very often, if ever. They can achieve anaerobic training effects more effectively with other methods, which will be described in the section on sprint training in the next chapter.

Descending Rest Repeat Sets

When swimmers train with descending rest repeat sets, they swim on a decreasing send-off time from the start to the end. The send-off time may be progressively decreased by a certain number of seconds with each repeat, or it can be lowered in stages by decreasing the send-off time after a specified number of repeats has been completed. The send-off time can be lowered with no interruption between stages, or a short recovery period can be provided between stages so that the long group of repeats are swum as several shorter sets. An example of a straight descending rest repeat set would be to swim 30 × 100 m. The send-off time would be 1:20 on the first 10 repeats, 1:15 on the middle 10, and 1:10 on the final 10 repeats.

Decreasing rest repeat sets fulfill much the same purposes described for descending time sets. They allow athletes to train through the full spectrum of aerobic and anaerobic metabolism, using both their slow-twitch and fast-twitch muscle fibers, without interference from acidosis. Athletes tend to swim the early portions of these sets at a slower speed because they know they will have to swim faster later, when the send-off time declines. Thus, they tend to train aerobically (in the basic and threshold zones) for the early portions of the set and anaerobically (in the overload zone) during the last several repeats.

Shortest Send-Off Repeat Sets

Because they are so challenging, shortest send-off repeat sets are a popular form of endurance training. The goal is for athletes to complete a set of repeats on the shortest send-off time that permits them to finish one repeat before it is time to start the next. An example of a shortest send-off repeat set would be to swim 20 × 100 m on 1:10, assuming that most of the repeats would be swum at speeds of 1:03 to 1:07.

Training in this manner offers many advantages. The short send-off time encourages swimmers to swim at speeds that overload aerobic metabolism most and anaerobic metabolism least, thus delaying severe acidosis until they have completed the set. Swimmers learn the value of pacing when they train. Inexperienced swimmers often make the mistake of thinking that swimming fast will provide them with more rest, thus making it easier for them to complete the set. What they fail to realize is that swimming too fast early in the set produces acidosis, which causes them to miss the send-off time later in the set. Following their first few attempts, swimmers quickly learn that swimming slower and barely making the send-off time early in the set will improve their ability to make the send-off later in the set. By applying this experience to racing, they can learn that even pacing or negative splitting will usually result in faster competitive performances in middle distance and distance races.

Another important advantage of shortest send-off repeat sets is that they overload metabolism in an effective manner for middle distance and distance swimmers. By swimming sets on very short send-off times, they train themselves to hold some predetermined submaximal speed with progressively less rest, working toward a goal of swimming that speed with no rest at all. They will be improving their ability to swim at a higher percentage of $\dot{V}O_2$max without producing severe acidosis (the respiratory anaerobic threshold). Additionally, they will improve their buffering capacity because of the manner in which acidosis develops progressively throughout the set.

Long repeat sets on the shortest possible send-off time probably emphasize improving aerobic endurance most. Shorter repeat sets on very short send-off times may not be long enough to stimulate aerobic muscle metabolism and lactate removal as effectively as they are stimulated by longer sets. Therefore, the primary training effect from the short sets is probably an improvement in muscle buffering capacity.

Mixed-Distance Repeat Sets

Mixed-distance repeat sets are constructed by combining repeats of different distances into one set that swimmers complete with short rest intervals. An example of a mixed-distance repeat set would be to swim 300 m on 4:00, 200 m on 2:45, and 100 m on 1:30. Swimmers could then repeat this set four times. They could move from the completion of one set immediately into the start of the next with no rest, or they could take a short recovery period between sets.

Sets of this type can be constructed for basic, threshold, or overload endurance training by requiring faster or slower speeds and by shortening or lengthening the send-off times. Shorter send-off times and long sets will encourage swimmers to train in the basic endurance zone. Somewhat longer send-off times or shorter sets (total distance less than 3,000 m) will allow them to swim at threshold speed, and they can swim in the overload endurance zones if the sets are even shorter (total distance less than 2,000 m) or if the send-off time is increased. Swimming a group of sets with no break between them encourages swimmers to stay in the basic and threshold endurance training zones so that they can complete all the sets. Taking short breaks between sets encourages swimmers to swim the last repeat of each set in the anaerobic zone because they will have some time to recover before the next set begins.

Mixed-distance sets generally function like descending sets. Starting with longer repeat distances and decreasing them throughout the set will encourage swimmers to increase their speed as they go along. Starting with shorter repeat distances and increasing them throughout the set will encourage swimmers to pace the early repeats slightly slower so that they can make the send-off time on the longer repeats. Consequently, mixed-distance sets, like descending sets, encourage development of endurance in all muscle fiber types while delaying acidosis until late in the set.

The principal advantage of mixed-distance sets is the variety they offer as compared with sets in which repeats are all the same distance.

Mixed-Speed Repeat Sets

A set in which speeds are increased or decreased for certain repeats within the set is a mixed-speed repeat set. This type of set could have athletes swim four sets of 5 × 100 m on a send-off of 1:30. Swimmers then swim the set in a variety of ways. One method might be to swim the first 3 × 100 repeats of each set at basic endurance pace and the final two 100s at threshold pace. Another methods could be to swim 4 × 100 m of each set at basic endurance or threshold endurance pace and the final 100 at race speed for a 200 or 400 m event. The same set could also be designed to improve buffering capacity by having swimmers perform the first 4 × 100 of each set at recovery speed and the fifth 100 at sprint speed.

Sets of this type are excellent for encouraging swimmers to combine all three levels of endurance training. The slower repeats improve oxygen consumption and lactate removal rates of slow-twitch muscle fibers, and the faster repeats do the same for both slow-twitch and fast-twitch muscle fibers. At the same time, the fast repeats help improve buffering capacity in all muscle fibers. Mixed-speed repeat sets are also effective for sprint training because swimming easy for a number of repeats between the fast repeats of a particular set provides faster recovery from acidosis. I will have more to say about using a mixed-speed repeat set for this purpose in the following chapter.

Mixed-speed repeat sets must be constructed carefully when the purpose is to improve endurance. If too much is expected on the final repeat of each set, athletes will tend to swim the other repeats of the set at recovery speeds that produce insufficient stimulation for improving aerobic endurance.

Mixed-Styles Repeat Sets

Various competitive styles are mixed together in one group of repeats in mixed-styles repeat sets. Table 13.5 provides examples of this type of set.

The first set is constructed primarily to improve aerobic capacity. Swimmers should do most of the repeats in the basic endurance zone, swimming only the last few repeats at greater speed. The second group of sets is also designed to improve aerobic capacity, although swimmers may swim the butterfly repeat at the end of each set at slightly greater intensity. Athletes should not swim that repeat so fast that they cannot maintain a basic endurance pace on the first repeat of the next set. Swimmers may mix the various competitive strokes as shown here or concentrate on only two or three styles. In example #3, kicking and pulling are mixed with swimming repeats in which two competitive styles, freestyle and butterfly, are used in a series of repeat sets. The purpose is to improve aerobic muscular endurance with the four series of 400 m freestyles and to improve buffering capacity with the four series of 100 m butterflys. The kicking and pulling repeats serve as active rest to aid recovery.

These sets are often combined with mixed-distance repeat sets as shown in example #1. In this case, athletes swim each competitive stroke at a different distance. With repeat distance becoming progressively shorter and with the butterfly last, swimmers should pace the early repeats and swim fast at the end of each set. Swimming such a set with a short send-off will encourage athletes to swim aerobically for most of the set and anaerobically at the end.

Either endurance or sprint training can be encouraged when the repeats are grouped together in a number of sets as illustrated by example #2. For endurance training,

Table 13.5 Mixed-Styles Repeat Sets

The swimmer in this example is assumed to have an anaerobic threshold pace of 1:10 per 100 m.

Example #1: Purpose is to improve aerobic capacity.

Swim 4 × 200 m freestyle on a 2:45 send-off
Swim 6 × 150 m backstroke on a 2:30 send-off
Swim 8 × 100 m breaststroke on a 1:45 send-off
Swim 10 × 50 m butterfly on a 50 sec send-off
Total = 3,000 m

Example #2: Purpose is to improve aerobic capacity. Swim this set four times.

Swim 1 × 300 m freestyle on a 4:00 send-off
Swim 1 × 200 m backstroke on a 3:00 send-off
Swim 1 × 150 m breaststroke on a 2:40 send-off
Swim 1 × 100 m butterfly on a 1:45 send-off
Total = 3,000 m

Example #3: Purpose is to improve aerobic muscular endurance and buffering capacity. Swim this set four times.

Swim 1 × 400 m freestyle on a 5:00 send-off
Kick 1 × 200 m freestyle on a 3:30 send-off
Swim 1 × 100 m butterfly on a 2:00 send-off
Pull 1 × 300 m stroke drill on a 4:30 send-off

The 400 m freestyle and 100 m butterfly should be swum in the overload endurance zone. The kicking and pulling repeats should be swum in the recovery zone.

Total = 4,000 m (1,600 m of overload endurance training, 400 m of buffer training, and 2,000 m of recovery swimming)

swimmers should swim at moderate speed until the final repeat of each set. Maintaining short send-off times and little or no rest between sets will encourage athletes to swim those repeats in the basic and threshold endurance zones. In this case, the final repeat of each set will not be extremely fast because swimmers will soon learn that they cannot afford to produce severe acidosis on that repeat and still swim in the basic and threshold endurance zones during subsequent sets of repeats. This type of set can be used for sprint training by designating only certain repeats as sprints and using the remaining repeats within the set for recovery.

Mixed-style repeat sets can also be constructed by mixing swimming, pulling, and kicking as in example #3. Sets constructed in this way can be used to train for endurance or sprinting by following the advice for construction provided in the previous paragraph.

Sets of this type are popular with swimmers and coaches because they tend not to be as boring as other types of repeat sets. They can be effective for basic endurance and sprint training, but they are one of the least effective methods for improving the endurance of fast-twitch muscle fibers. Changing strokes and mixing kicking and pulling with swimming tends to reduce the duration of the aerobic training stimulus received by any group of muscle fibers. Certainly, swimmers use some of the same muscle groups in all four competitive swimming strokes, but one style may not require muscle groups used in another. The effect of resting some fibers from repeat to repeat is even more exaggerated when full-stroke swimming repeats are mixed with pulling or kicking repeats.

As indicated previously, mixed-style repeat sets have two major uses. They are an excellent method for constructing unique and interesting sets for basic endurance training. They can also be very effective for sprint training. To accomplish that purpose, swimmers should swim only certain repeats in the set fast and complete others at a recovery level.

I believe that mixed-style repeat sets are overused for endurance training. Because they are not too effective for this purpose, I recommend that they be used infrequently. Sets in which swimmers perform all repeats in one style are much more effective for improving endurance.

Hypoxic Training

Hypoxia is the term used to identify reduced oxygen supply in blood and body tissues. *Hypoxic training* refers to swimming a repeat distance with a restricted breathing pattern in the belief that it will reduce oxygen supply. When they swim hypoxic repeats, swimmers do not breathe once during each stroke cycle, as is their common practice. Instead, they hold their breaths for one or more stroke cycles before taking a breath.

The original purpose of hypoxic training was to simulate training at altitude. Proponents thought that reducing the breathing rates of athletes would also curtail their oxygen supply and create the same kind of hypoxia that takes place at altitude. Research has shown that this assumption was incorrect. Several studies have shown that hypoxic training does not reduce the oxygen supply to the tissues (Craig 1978; Dicker et al. 1980; Stager et al. 1985; Stanford et al. 1985; Van Ness and Town 1989; Yamamoto et al. 1985). Although some of the studies reported small reductions in alveolar oxygen, those effects were not sufficient to simulate conditions at altitude.

Despite results like these, hypoxic swimming continues to be a popular form of training for competitive swimmers, perhaps because it produces other currently unidentified training effects. On the other hand, it may simply be that the difficulty of swimming with restricted breathing appeals to coaches and athletes because of the effort and discipline it requires. Some coaches reason that training that causes so much distress must be doing something worthwhile for swimmers.

Beneficial effects are not evident, however, at least as far as aerobic capacity is concerned. Because it does not simulate conditions at altitude, hypoxic training will not be any more effective than normal training for increasing red blood cells or for producing other adaptations that have been attributed to training at altitude. One could argue that restricting breathing can actually reduce the overall aerobic training effect. When they breathe less during long swims or long sets of repeats, swimmers must necessarily swim slower so that their muscle pH does not decline too early (Van Ness and Town 1989). A compromised oxygen supply will cause more production of lactic acid, which in turn will cause greater acidosis at slower speeds. Therefore, in trying to cover a long distance with restricted breathing, swimmers will have to swim slower than they would while breathing regularly. This circumstance could result in at least one unwanted physical reaction. They will be swimming slower than they could otherwise swim, so their stroke mechanics will be less racelike. If they try to swim at their normal training speed, they will create frequent and severe acidosis that may damage muscle tissue at a faster rate than it can be repaired. In time, they will experience a loss of strength, speed, and endurance.

All athletes have a finite tolerance for acidosis. They can reach that level by breathing less and swimming slower or by breathing more and swimming faster. I suggest that it is more effective to train by swimming faster while still accomplishing the goal of improving endurance. The swimmer's stroke mechanics will be more racelike, and acidosis is less likely to interfere with the attempt to produce aerobic training effects. Therefore, if the swimmer's goal is to improve aerobic endurance, I believe that swimming with regular breathing is more reasonable. Swimming with unrestricted breathing also makes more sense if the goal is to improve buffering capacity because the repeats will be more racelike.

Some coaches have suggested that hypoxic training can increase the buffering capacities of muscles and blood because of the acidosis that occurs when the oxygen supply is reduced. Hypoxic training is unlikely to be any more effective than free swimming for this purpose. In fact, it may be less effective for the reasons cited earlier, namely, that athletes can swim faster and thus with more racelike stroke rates and stroke lengths when they breathe regularly. At the same time, swimmers can produce the same degree of acidosis with normal breathing that they would produce with hypoxic training.

The one adaptation to hypoxic training that surely does take place is an improvement in breath-holding ability (Van Ness and Town 1989). Hypoxic training produces a condition called *hypercapnia*, which is an increase of carbon dioxide (CO_2) in the alveolar air. Hypercapnia produces a strong drive to breathe. When a swimmer is having difficulty holding his or her breath during races, it is the increase of CO_2, not a reduction in oxygen, that causes the person to feel starved for air. Frequent breath holding can increase a swimmer's resistance to this drive, allowing him or her to resist it and swim each length of a race with fewer breaths. For this reason, hypoxic training can be a valuable training aid for freestyle sprinters and butterfly swimmers, but not for the reasons usually espoused. Backstrokers may also gain an advantage from hypoxic training if they use the underwater dolphin kick in their races. Breaststrokers have no need for hypoxic training because only during turns do they need to hold their breaths. They can improve that ability more effectively with drills such as the double pulldown drill than they can by hypoxic training.

Swimmers can quickly develop the ability to swim races with fewer breaths. Estimates are that only a few weeks of breath-holding training is necessary to blunt the drive to breathe produced by a buildup of carbon dioxide in tissues. Examples of repeat sets that can improve breath-holding ability during sprint races are provided in table 13.6.

Because hypoxic training is physiologically stressful, I recommend that swimmers perform it only a few days per week during the season. Sprint swimmers should pick a 3- to 4-week period early in the season when they emphasize breath holding by doing some form of restricted breathing training almost daily. After they have decreased their sensitivity to hypercapnia, they should be able to maintain that training effect for the remainder of the season with just one or two short breath-holding training sets each week.

Occlusion Training

Just beginning to find its way into the programs of competitive swimmers is a new form of training known as occlusion training. This method involves training with tight, straplike devices around the upper arms or upper legs. The purpose of the devices is to occlude, or shut off, part of the blood supply. The rationale behind this training is that reducing the blood flow, and thus the oxygen and nutrient supply, to muscles will improve their adaptations to training. A limited number of studies have investigated the effects of occlusion training for both endurance and strength training. The results of those studies have been favorable. For this reason, some experts have suggested that training with bands on the arms or legs might improve both endurance and strength to a greater extent than regular, nonoccluded training. I have some doubt about whether this form of training is truly beneficial. Let me describe the results of some representative research on occlusion training and then discuss why I do not favor this procedure.

Sundberg (1994) conducted a study in which subjects performed 4 weeks of endurance cycling training in which the blood flow was occluded to one leg but not the other. A band was placed around one leg, and a pressure of 50mm Hg was applied so that the blood flow decreased by 13% to 20%. Several measurements were taken on both legs before and after training. These included $\dot{V}O_2$max, exercise time to exhaustion,

Table 13.6 Sample Repeat Sets for Improving Breath-Holding Ability

These sample repeat sets can be used for improving breath holding ability in 50 and 100 freestyle races and for improving underwater dolphin kicking in backstroke and butterfly races.

For 50 races

4 to 8 × 25/1 min send-off. Breathe only once during first several times the set is done. Swim with no breath later.

6 × 50/2 min send-off. Several different breathing patterns can be used. One breath on each length, or no breath on the first length, 2 breaths on the second, or no breath on the first length, 1 breath on the second length.

For 100 races

4 × 100/2 min send-off. Breath every 2, 3, or 4 stroke cycles.

10 × 100/1:30 send-off. Breath every 2 or 3 stroke cycles.

6 × 200/3 min send-off. Breath every 2 or 3 stroke cycles.

6 × 100/2 min send-off. Breathe every stroke cycle during the first 50 of each swim and every second or third cycle on the second 50.

4 × 200/3 min send-off. Breathe every stroke cycle on the first 50, every second stroke cycle on the middle 100, and every third cycle on the last 50.

Underwater dolphin kicking for backstroke and butterfly races

8 × 25/1 send-off. Underwater dolphin kicks.

4 to 6 × 50/2 min send-off. Kick 15 m underwater on each length.

4 × 100/3 min send-off. Kick 15 m of each length underwater.

3 × 200/5 min send-off. Kick 15 m of each length underwater.

capillarization, glycogen storage, strength, enzyme activity, and fiber type percentages. As one would expect, both legs improved with training, but in all cases the percentage improvements were greater for the occluded leg. The percentage increase in $\dot{V}O_2$max for the occluded leg was nearly double that of the nonoccluded leg. The increase in capillaries in the occluded leg was 42% greater, and glycogen storage was nearly 10% greater. The activity of aerobic enzymes increased by 20% in the nonoccluded leg and by 26% in the occluded leg. Occlusion also caused a change in fiber type percentages. The percentage of slow-twitch fibers increased by 4% in the occluded leg, whereas no change occurred in the percentage of slow-twitch muscle fibers in the nonoccluded leg. At the same time, the percentage of FTa muscle fibers decreased by 3% in the occluded leg. No change occurred in the percentage of FTa fibers in the nonoccluded leg.

The additional improvements in the occluded leg should have had a beneficial effect on endurance, and indeed they did. Each leg was tested separately before and after training. Work time to exhaustion increased by 25% in the occluded leg but by only 13% in the nonoccluded leg.

I should mention that endurance training produced some effects that would be detrimental to sprinting performance in the occluded leg but not in the nonoccluded leg. One of the most important of these was that activity of the muscle form of the enzyme lactate dehydrogenase (M-LDH) decreased by 25% in the occluded leg, whereas no change occurred in the activity of this enzyme in the nonoccluded leg. This change might result in a lower rate of lactic acid production. An important negative training effect was that strength fell by 8% in the occluded leg but remained unchanged in the nonoccluded leg. The authors felt the loss of strength may have been related to the decrease in size and number of the FTa muscle fibers in the occluded leg.

Several other effects of occluded training that could be considered detrimental concern the rate of energy use. Reductions in ATP and CP were greater in the occluded leg than in the nonoccluded leg during testing, and lactate levels were higher in the muscles of the occluded leg. Muscle glycogen use was also greater in the muscles of the occluded leg, most likely because their supply of blood glucose was restricted. The difference in glycogen use was not substantial between slow-twitch muscle fibers. The slow-twitch fibers of the occluded leg were 80% depleted of the glycogen supply after 45 min of hard exercise, whereas the slow-twitch fibers of the nonoccluded leg lost approximately 70% of their glycogen. Differences in glycogen use were much more dramatic in the fast-twitch muscle fibers. Those of the occluded leg lost approximately 30% of their glycogen supply, whereas the fast-twitch fibers of the nonoccluded leg lost approximately 10%.

Researchers have also studied the effect of occlusion with regard to strength training. Takarada and coworkers (1998, 2000) reported that human growth hormone increased significantly when an occluded body part performed several repetitions to exhaustion with a light weight. The same exercise produced no significant change in the concentration of this hormone in the body when body parts were not occluded (Takarada et al. 1998, 2000). Increases in human growth hormone should increase muscle size and strength.

In the first of these studies, subjects performed one-arm biceps curls with both their right and left arms. One arm was occluded during the training, and the blood flow was unobstructed in the other arm (Takarada et al. 1998). The training resistance for the occluded arm was 50% of the weight the subjects could curl for one repetition, and a resistance of 80% of their one-repetition maximum was used for training the nonoccluded arm.

The researchers reported a similar increase in the size of the biceps muscles of each arm. Muscular strength increases were also similar in both the occluded and nonoccluded arms. They concluded that occluded and nonoccluded training were equally effective for increasing muscle size and strength but that occluded training can produce the same results with considerably lower resistance. Unfortunately, the authors did not include a group that trained with low resistance and no occlusion, nor did they test a group that trained with high resistance and occlusion. The inclusion of subjects in such groups would have permitted us to determine (1) if low-resistance, nonoccluded training was as effective as low-resistance, occluded training for improving muscle size and strength and (2) if high-resistance, occluded training was more or less effective than high-resistance, nonoccluded training for the same purposes.

From these results, one could argue that several aerobic and anaerobic training effects can be produced more effectively with occlusion than with regular, nonoccluded training. I have doubts about this proposition, at least for swimming training, for three principal reasons:

1. Athletes can produce improvements of the same magnitude as those resulting from occlusion training simply by training at a higher intensity with no occlusion. In addition, training with a greater intensity should be more effective in other ways. The first part of this statement seems evident from the weight-training study. Subjects got the same results with their nonoccluded arm by training at 80% of their one-repetition maximum as they did by training the occluded arm with lighter weights. The reason that training at a higher intensity should be more effective is that athletes will be training at faster speeds that are closer to those they use in competition. Athletes would have to swim more slowly during occluded training because of the additional energy use and lactic acid accumulation. Such slow speeds and slow stroke rates would not be conducive to maintaining the stroke rates and paces for competition.

2. Occlusion training seems to produce more effects that many people would consider negative in regard to long-term training. Faster rates of muscle glycogen use would result in the need for more recovery swimming to provide time for replacement. This

requirement would reduce the average training intensity for each week, and athletes would not be able to swim threshold, overload, and race-pace sets as often. Trying to train intensely when muscle glycogen is low could also cause swimmers to lose some of their muscle tissue, which would ultimately reduce their strength and power. Higher rates of lactic acid accumulation could also cause more muscle damage, which would further increase the amount of recovery training swimmers would need each week. Another negative effect is that endurance-oriented occlusion training might reduce muscle strength and anaerobic power more than normal training would. Loss of strength and anaerobic power would cause a loss of speed that could be detrimental to middle distance and sprint swimmers. Finally, occlusion training may upset the delicate balance between lactate production and removal during exercise, causing more lactic acid to be produced at slower speeds and less to be removed from the muscles.

3. Perhaps the most compelling argument against occlusion training for swimming concerns the muscles affected. Occlusion training would affect only the muscles of the legs and arms. Athletes wear the bands that restrict circulation near the top of each thigh and just below the shoulder of each arm. This placement means that the large muscles of the shoulders, trunk, back, and hips, which provide most of the propulsive force for swimmers, would be largely unaffected by the occlusion. Consequently, the blood supply to the muscles that do most of the work in competitive swimming would not decrease.

I believe that the arguments against endurance-oriented occlusion training are persuasive, despite the fact that occlusion training appears to be effective for producing certain physiological adaptations. The arguments against using it for sprint training are even stronger. The more effective way to stress anaerobic metabolism and power production should be by swimming faster rather than swimming slower. When athletes swim faster in training, they will be using combinations of stroke rates and stroke lengths similar to those they use in races. In addition, the sensations they monitor for decreasing drag will also be similar to those they experience in competition. Additionally, occlusion training may be detrimental for improving the rate of anaerobic metabolism. Fast stroke rates and the application of substantial muscular force will stimulate the rate of anaerobic metabolism more than will swimming with slower rates and less force. In short, an evaluation of the physiological responses that occlusion produces suggests to me that occlusion training is not a viable procedure for competitive swimmers. In the long run, it has the potential to do more harm than good.

Running

Running and other land activities such as running hills and stairs have become common early season activities in some swimming programs. Many coaches and athletes believe that these activities will enhance endurance beyond what athletes could achieve by swimming alone. Running will certainly produce central adaptations that can improve a swimmer's aerobic capacity. Running will train the circulatory and respiratory systems, causing improvements in cardiac output, stroke volume, tidal volume, and pulmonary diffusing capacity, which will improve oxygen delivery during swimming. Running may do this as well as swimming itself does. Running will also produce adaptations in the muscles of the legs, such as increased capillarization, improved blood shunting, and increases in size and number of mitochondria. But swimming can produce all these adaptations equally well. More important, swimming will produce significant training effects in the muscles of the upper body. These are the muscles crucial to success in most competitive strokes, and running cannot produce significant training effects in them.

One might wonder how running became such a popular part of many swimming programs. The rationale for including running in the training of swimmers was originally based on research in which trained subjects achieved higher heart rates and higher rates of oxygen consumption when running than when swimming (Holmer 1974). Unfortunately, some people interpreted these results to mean that running was superior to swimming for improving aerobic endurance. That conclusion, however, is incorrect. The results of the study demonstrated only the principle of specificity. Most of the subjects in Holmer's study were trained runners; only a few were trained swimmers. No one noticed that Holmer also reported that the competitive swimmers in the group achieved higher heart rates and maximal oxygen consumption values when swimming than the runners were able to achieve.

Other studies have repeatedly supported the position that athletes make the greatest improvement in oxygen consumption by specific training (Magel et al. 1975; McArdle et al. 1978; Pechar et al. 1974). In one of these, Magel and his associates (1975) trained 15 men for 1 hr per day, 3 days per week, over a 10-week period with standard swimming repeats. Each subject's $\dot{V}O_2$max was measured before and after training, while they were swimming and while they were running on a treadmill. Swimming $\dot{V}O_2$max increased by 11%, and swimming times to exhaustion increased 34%. In contrast, the subjects showed no improvement in running $\dot{V}O_2$max.

Competitive swimmers should use running only as a supplemental form of training, never as a substitute. Any swimmer who substitutes running for swimming to improve aerobic capacity should understand that the results will be inferior to those he or she could achieve by expending the same time and effort in swim training.

Running uphill or running up stairs is not advised for swimmers under any circumstances. The only improvements swimmers can hope to achieve from running up stairs will occur in the leg muscles used for running. No improvement will occur in the muscles of their upper bodies. At the same time, leg muscles that are more active in swimming than in running will not receive the same training benefit that would result from swim training. I believe that swimmers could more profitably spend the time they devote to running uphill and up stairs to doing kicking drills to improve the speed and endurance of their leg muscles. As far as land activities are concerned, exercises that increase leg extension power, such as plyometric jumps, vertical jumps, and power leg extension exercises with weights, should provide greater improvement in leg power for starting and turning than running uphill or running up stairs could produce.

Finally, running uphill and up stairs can be dangerous. Falling injuries are common. Some of these may require the athlete to take a few days off for healing, but others can be so serious that they curtail training for a good portion of the season. Injuries to the ankles, knees, and hip joints may occur because of the tremendous effort required to lift one's body weight explosively with one leg.

Although members of both sexes are susceptible to leg injuries from uphill running and, especially, from running stairs, the incidence of such injuries is likely to be greater among females than among males. Women, on average, have looser joints and smaller ligaments and tendons. In addition, fat makes up a greater percentage of their body weight, and muscle a smaller percentage. These differences between the sexes cause females to be more susceptible to injuries from activities in which they have to support their body weight. In addition, females generally have wider hips than males, which increases the angle between the long bone of the upper leg, the femur, and one of the two long bones of the lower leg, the tibia. When a female flexes her leg, that larger angle between the bones of the upper and lower leg permits the kneecap, or patella, to move laterally farther than it would in a male. Females are thus more susceptible to knee injuries, particularly dislocations of the patella (Wells 1985). I do not recommend including stair running in the training programs of swimmers, particularly female swimmers.

14

Sprint, Race-Pace, and Recovery Training

New in this edition:

- A description of race-pace swimming as a separate category of training
- A section on recovery training

Coaches and scientists have been concerned with endurance training over the years, and rightly so. Increased aerobic endurance probably contributes more to improved swimming performance in all events of 100 yd or m and longer than any other physiological adaptation. But I must also note that too little attention has been given to sprint and power training. Adaptations in these areas contribute to improved performances in all events, not only in sprints but also in middle distance and even distance swimming. Improvements in speed and power provide long sprint and middle distance swimmers with what is known as *easy speed,* the ability to take races out faster with less effort. They also provide middle distance and distance swimmers with what is termed a *finishing kick,* the ability to sprint faster during the final portion of their races.

Race-pace swimming is another part of the training regimen that swimmers and coaches sometimes neglect. Swimming at competition speed in training simulates actual competition better than any other form of training. Through its use, athletes train the aerobic and anaerobic metabolic processes to interact in the most economical and effective way for each race distance. They also train their bodies to counteract the debilitating effects of fatigue, principally acidosis, more effectively during races. Finally, race-pace training allows athletes the opportunity to discover what combinations of stroke rate and stroke length work best for each race distance.

Recovery training increases both the rate and extent of adaptation to all forms of training. Because it speeds the removal of toxins from the muscles and the delivery of nutrients to them, recovery training performs an important function. This type of workout does not simply produce "garbage yards," as some people contend.

Purposes of Sprint Training

The two main purposes for sprint training are to increase maximum sprinting speed so that swimmers can take races out faster and to improve buffering capacity so that sprinters can maintain a speed in races closer to their maximum sprinting speed. The topics for this section will be the elements of energy metabolism that can increase sprint speed and improve buffering capacity. Of course, swimmers can also increase speed by improving stroke mechanics and minimizing body drag. Stroke mechanics and drag were covered in part I of this book, so further discussion here is unnecessary. The important aspects of increasing sprint speed that this chapter will cover concern the rate of anaerobic metabolism, improving muscular power, and increasing buffering capacity. As explained in chapter 10, anaerobic metabolism refers to the first 11 steps in the breakdown of muscle glycogen and the release of energy and phosphate to recycle ATP. I will refer to it here as anaerobic power. The process of improving muscular power is complicated, involving increasing muscular strength, improving the pattern of recruitment of muscle fibers by the central nervous system, and increasing the rate of anaerobic metabolism. Athletes improve buffering capacity by creating the need for more buffers to be stored in muscles by subjecting the body to large accumulations of lactic acid, the product of anaerobic metabolism.

Improving Anaerobic Power

Although measurements of oxygen consumption are the recognized standard for expressing aerobic capacity, no method is universally accepted for quantifying anaerobic power. Some scientists have tried to equate anaerobic power with the oxygen deficit so it could also be expressed in milliliters of oxygen per kilogram of body weight per minute (ml O_2/kg/min). Other tests that have been suggested include the vertical jump, sprint running tests on the level and uphill, rapid stair climbing, and rapid cycling tests. All have been quantified in different ways. Some are expressed in foot-pounds of work per second, others in watts, and still others in newtons. Peak blood lactates after sprint efforts have also been used for this purpose.

Unfortunately, none of these tests provides an accurate measurement of the maximal rate of anaerobic metabolism, although some reflect it better than others do. Measures of oxygen deficit have shown a reasonable correlation with running speed (Nummela et al. 1996), and 100 m swimming speed (Takahashi et al. 1992) and for that reason may be useful in evaluating anaerobic power. Some studies have also found a significant relationship between peak blood lactates after sprints and running speed (Berg and Keul 1985; Jacobs et al. 1987; LaCour, Bouvat, and Barthelemy 1990), but others have reported no change (Cheetham and Williams 1987; Medbo and Burgers 1990). The bulk of evidence suggests that this measure has value for use with swimmers, despite reports to the contrary. Some suggestions for constructing tests to measure anaerobic power with peak blood lactate values will be provided in a later chapter on monitoring training.

Let me comment on the other tests. The vertical jump test is really too short to reflect anaerobic power; it is more a test of muscle power. The running and cycling tests are probably not well suited for testing swimmers. They measure rapid work output by the leg muscles. Swimming, with the exception of breaststroke, is an arms-dominated activity. The chapter on monitoring training will suggest some in-water tests that might better reflect the anaerobic power of swimmers. Those tests include complex procedures such as measuring power output on land and blood lactate concentrations during swimming. Perhaps the best procedure for evaluating anaerobic power is the most direct—by testing swimmers for speed over 25 and 50 yd or m.

Researchers have not extensively studied how much improvement athletes can expect to achieve in anaerobic power. The literature has reported improvements in sprint running speed in the range of 3% to 10% (Cadefau et al. 1990; Medbo and Burgers 1990; Nevill et al. 1989; Nummela, Mero, and Rusko 1996). In one of these studies (Nummela, Mero, and Rusko 1996) the average improvement in sprinting speed was 3.4% over a 10-week training period but only 1.2% when the training was extended to 1 yr. This result suggested to the authors that athletes could maintain high levels of performance only for short periods during the year and that therefore it was better to cycle the emphasis on sprint training throughout each season instead of maintaining an equal, high emphasis on sprint training throughout each season.

Improvements of 3% to 10% may seem insignificant until one considers how important each 1/10 second improvement can be to sprinters. For example, a 3% improvement for a female swimming a long-course 50 m freestyle with a best time of 25.00 would lower that time to 24.25.

Improving Anaerobic Muscular Endurance

The second purpose of sprint training is to improve the percentage of maximum anaerobic power that an athlete can maintain for the length of a sprint race. I refer to this as *anaerobic muscular endurance*. The relationship between anaerobic power and anaerobic muscular endurance is illustrated by the graph in figure 14.1.

Distinguishing between aerobic and anaerobic muscular endurance is difficult. One could argue, quite accurately, that they are really the same because both involve oxygen delivery, oxygen utilization, lactate removal rates, and improvement of buffering capacity. I believe, however, that the two forms of endurance differ in a subtle but important way as far as training for certain events. Athletes in middle distance events need to perform their anaerobic training so that it emphasizes improving oxygen consumption and lactate removal first and buffering capacity second. For them, the repeat sets should be reasonably long to provide time for most of those mechanisms to be stimulated to a high level of function. On the other hand, sprinters need to emphasize improvement in buffering capacity first with their training. Increases of oxygen consumption and lactate removal are welcome, but their effect is secondary to that of improved buffering capacity because sprinters generally complete their events in 1 min or less. For this reason I have chosen to identify anaerobic muscular endurance separately from aerobic muscular endurance. The distinction emphasizes the importance of improving buffering

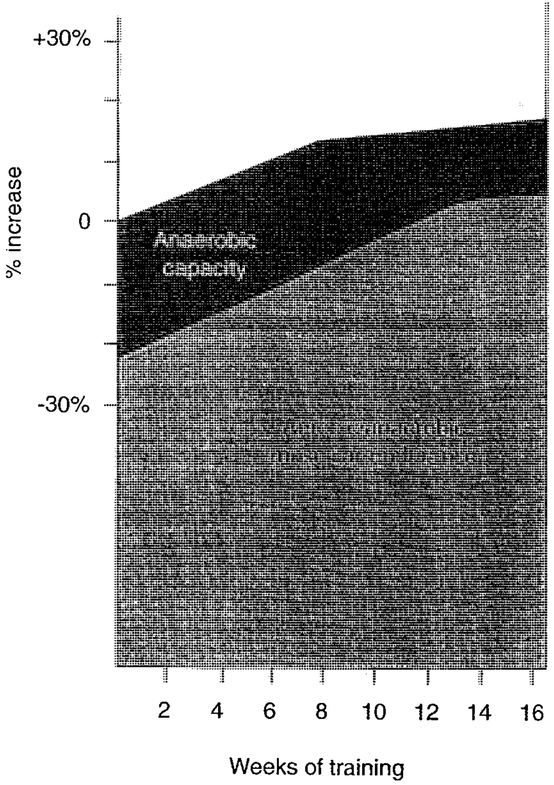


Figure 14.1 The relationship between anaerobic capacity and anaerobic muscular endurance. Training increases anaerobic capacity rapidly during the first 8 to 10 weeks, after which the rate of improvement slows. The athlete is able to swim at only 80% of that maximum at first. With proper training, however, the athlete can swim at 90% of maximum anaerobic capacity for the length of sprint races.

capacity for sprinters, a goal best accomplished by short, intense sets rather than the longer anaerobic sets that swimmers use to improve aerobic muscular endurance.

The term *anaerobic muscular endurance* as used in this textbook is synonymous with the term *anaerobic capacity* as it is defined in the bulk of physiological literature on training. As mentioned earlier, buffering capacity is a major contributor to anaerobic muscular endurance, particularly in sprint races, although there is evidence that lactate removal may also play a significant role. Nevill and associates (1989) found that an increase in anaerobic ATP recycling after sprint training resulted in a reduction in blood pH but no reduction in muscle pH during a 30 sec sprint. They reasoned, therefore, that a sizable portion of the hydrogen ions produced in the muscles must have been transported out of the muscles and into the blood during the 30 sec sprint. I believe that improved buffering capacity and an increase in the rate of lactate removal are also principal reasons for improved endurance in 100 and 200 events, although an increase in the rate of oxygen consumption becomes more important in the 200 than it was in the shorter sprints.

Like anaerobic power, anaerobic muscular endurance is not measured by any universally accepted method. Attempts at quantification have included tests that measure the drop-off in maximum power output or speed during the course of an all-out effort lasting 1 to 2 min. In these tests, subjects begin at maximum effort, do not attempt to pace, and continue until they are exhausted or have completed a predetermined span of work that would produce severe acidosis. Their anaerobic muscular endurance is then determined from the amount of drop-off in power or velocity over the length of the test. The problem with such tests is that motivation or the lack of it has a significant influence. Measures of the oxygen deficit have been used for this purpose with reasonable success. A procedure in which the velocity that produces a blood lactate concentration of 10 mmol/L during a progressive series of 100 or 200 m sprints has also been used to measure changes in anaerobic muscular endurance in swimming. This method, however, probably reflects a combination of aerobic and anaerobic muscular endurance more than it does improved buffering capacity. A later chapter will describe some procedures for measuring anaerobic muscular endurance.

The amount of improvement that athletes can expect to make in anaerobic muscular endurance is difficult to estimate because so few studies have evaluated the issue. In one of the few studies to examine the effects of sprint training on muscle buffering capacity, Sharp and associates (1986) produced an average improvement of 37% in buffering capacity for a group of untrained subjects after 8 weeks of sprint cycling. The range of improvements was 12% to 50% for the subjects in the study, which resulted in an average increase of 27% in the work performed during a maximal 45 sec cycling test. The subjects trained 4 days per week, performing eight 30 sec maximum cycling efforts with 4 min of rest after each effort.

Three Types of Sprint Training

Given that sprint training involves improving two processes, anaerobic power and anaerobic muscular endurance, sprint athletes should use three types of training. I call the first level *lactate tolerance (Sp-1)* training. The purpose of this type of training is to increase buffering capacity and anaerobic muscular endurance. The second type is *lactate production (Sp-2)* training. Its purpose is to improve the rate of anaerobic glycolysis. Increasing muscular force and power is the purpose of the third type, *power (Sp-3)* training.

Types of Sprint Training

1. **Lactate tolerance (Sp-1):** The purpose is to improve buffering capacity and anaerobic muscular endurance.
2. **Lactate production (Sp-2):** The purpose is to increase the rate of anaerobic metabolism.
3. **Power training (Sp-3):** The purpose is to increase muscular force and power.

Lactate Tolerance Training

Lactate tolerance training involves swimming long sprints with medium to long rest periods or short sprints with short rest periods. The goal is to produce acidosis in the working muscle fibers and thus stimulate an increase in muscle buffering capacity.

Training Effects

The primary effects of lactate tolerance training are (1) to increase muscle buffering capacity, (2) to improve the ability of athletes to maintain stroke integrity and swimming speed in spite of severe acidosis, and (3) to improve the ability of athletes to tolerate the pain of acidosis.

Secondary adaptations include increases in muscle concentrations of glycogen, ATP, and CP and an increase in the rate of lactate removal from muscles and blood. Lactate tolerance training will also increase $\dot{V}O_2$max somewhat, probably because it stimulates the oxygen consumption mechanisms of FTb muscle fibers. This effect is probably minimal. Sharp and his associates (1986) reported an 8% increase in $\dot{V}O_2$max for a group of subjects after sprint training that fits in the lactate tolerance category.

Lactate tolerance training will also increase the rate of anaerobic metabolism. Medbo and Burgers (1990) found that experienced sprint runners who trained with fast 2 min runs increased their rates of anaerobic metabolism just as much as another group of sprint runners who trained by doing 20 sec sprints. Apparently, training adaptations resulting from lactate tolerance training overlap considerably with those that occur with lactate production training. Nevertheless, I feel that the effects differ just enough to warrant the design of specific repeat sets for each purpose.

Effects of Lactate Tolerance Training

Primary

- Increase in muscle buffering capacity
- Improvement in the ability of swimmers to maintain good technique in spite of severe acidosis
- Improvement in the ability of swimmers to tolerate the pain of severe acidosis

Secondary

- Increase in the amounts of glycogen, ATP, and CP stored in trained muscle fibers
- Increase in the rate of lactate removal from the muscles and blood
- Increase in $\dot{V}O_2$max
- Increase in the rate of anaerobic metabolism

Season Planning

Swimming is the best form of lactate tolerance training because of its specific effects. The training effects that improve muscle buffering capacity occur only in and around the fibers used in training. Swimming, particularly when athletes use the stroke or strokes they plan to use in competition, is the best way to be certain those fibers are being trained.

Adaptations to lactate tolerance training take place rapidly. Significant improvements in muscle buffering capacity can occur within 4 to 6 weeks. Therefore, a major emphasis on lactate tolerance training need not occur until 4 to 6 weeks before the taper for an important competition. Until then, occasional time trials, competitions, and overload endurance training will serve to improve buffering capacity and pain tolerance. I recommend this emphasis on lactate tolerance training late in the season only for swimmers in sprint events. Middle distance and distance swimmers have no need to engage in lactate tolerance training. They can use time trials, overload endurance training, and race-pace training throughout the entire season to improve buffering capacity and pain tolerance.

Land training devices such as medicine balls, weights, calisthenics, surgical tubing, swim benches, and the Vasa trainer are alternative ways to improve muscle buffering capacity. Land training used for this purpose must be planned carefully to include the desired muscle groups. These methods should serve only as a supplement, never as a substitute, for lactate tolerance training in the water.

Lactate tolerance training must be administered judiciously. Although it can improve certain aspects of metabolism, it also has the potential to cause serious side effects that could impair performance. The acidosis that results from lactate tolerance training will be quite severe. Structural damage has the potential to become so pervasive over time that athletes can lose endurance and power. Additionally, if performed too often, lactate tolerance training can weaken the responses from the endocrine and immune systems. A reduction in the function of these systems could result in a reduced rate of recovery, a loss of motivation for training and competing, and an increased incidence of viral infections and muscle and joint injuries.

Another reason that athletes should not do lactate tolerance training too frequently is that overload and threshold endurance training also produce many of its potentially damaging effects. Consequently, lactate tolerance training should not be used too often when these two forms of endurance training are being emphasized, nor should overload and threshold training be scheduled too often when lactate tolerance training is the focus of a particular training cycle.

One might wonder why athletes should use lactate tolerance training if threshold and overload endurance training can produce the same training effects. The rationale is that lactate tolerance training is one of the best methods for improving the buffering capacity of sprinters. The sets are shorter, faster, and require higher rates of anaerobic metabolism. Therefore, they simulate the nature of sprint races more effectively than either overload or threshold endurance sets do. At the same time, they are less likely to reduce the rate of anaerobic metabolism to the extent that endurance training does. Consequently, lactate tolerance training is a better form of buffer training for sprinters during the later stages of the season when increasing sprinting speed should be a major consideration in training programs.

Sprinters should limit their lactate tolerance training to one small set each week in the early season and to one or two short sets in the middle of the season when they emphasize increasing speed and anaerobic capacity. Lactate tolerance sets could be scheduled perhaps twice per week during this time but only for 4 to 6 weeks. Sprinters can increase buffering capacity considerably in this short period, and keeping the lactate tolerance work to moderate levels will reduce the possibility of saturation and overtraining.

The rate of glycogen use is rapid during lactate tolerance training, and the amount lost from muscle fibers, particularly fast-twitch muscle fibers, will be considerable. Some fast-twitch muscle fibers may become depleted of glycogen during long lactate tolerance sets, but this is not likely when the sets are short and infrequent, when they are not scheduled back to back, and when they are not performed in combination with threshold and overload endurance sets.

As mentioned, muscle damage from acidosis from lactate tolerance sets can be considerable. Consequently, athletes should have 2 to 3 days of recovery after performing a set. Threshold endurance, overload endurance, and race-pace training should not be scheduled during this time, but swimmers can do basic endurance and lactate production training.

Guidelines for Constructing Lactate Tolerance Repeat Sets

The goal of lactate tolerance training is to produce severe acidosis in the working muscle fibers so that those fibers will store more buffers and become more effective at buffering lactic acid. At the same time, swimmers should also concentrate on maintaining a high level of effort and efficient stroke mechanics in spite of acidosis. This training, which may be more mental than physical, will help them in at least two ways. First, they may become less sensitive to the pain of acidosis, and second, they can condition themselves *not* to commit some of the common technique errors that accompany severe acidosis, such as allowing their arms to slip through the water, losing their stroke timing, sacrificing too much distance per stroke, or sacrificing turnover rate to maintain distance per stroke.

Factors such as repeat distances and rest intervals are not critical in the design of lactate tolerance repeat sets. Any group of repeats that produces acidosis can produce the training effect. Consequently, the intensity and number of repeats are the most important ingredients for sets of this type. Athletes can use three general methods to stimulate severe acidosis in training. The first is to swim repeats of 100 yd or m and longer at very fast speeds with long rest periods after each repeat. I have termed this type of repeat set *long sprints with long rest*, for obvious reasons. The second is to swim repeats of 25 yd or m and longer with medium rest intervals that do not permit recovery from acidosis after each swim. The term for this type of set is *sprints with medium rest*. The third method involves broken swims, that is, swimming small series of repeats with very short rest intervals. I call this method *sprints on short rest*. The graphs in figure 14.2 illustrate the probable effects of each type of repeat on muscle pH. The next several paragraphs will describe those effects.

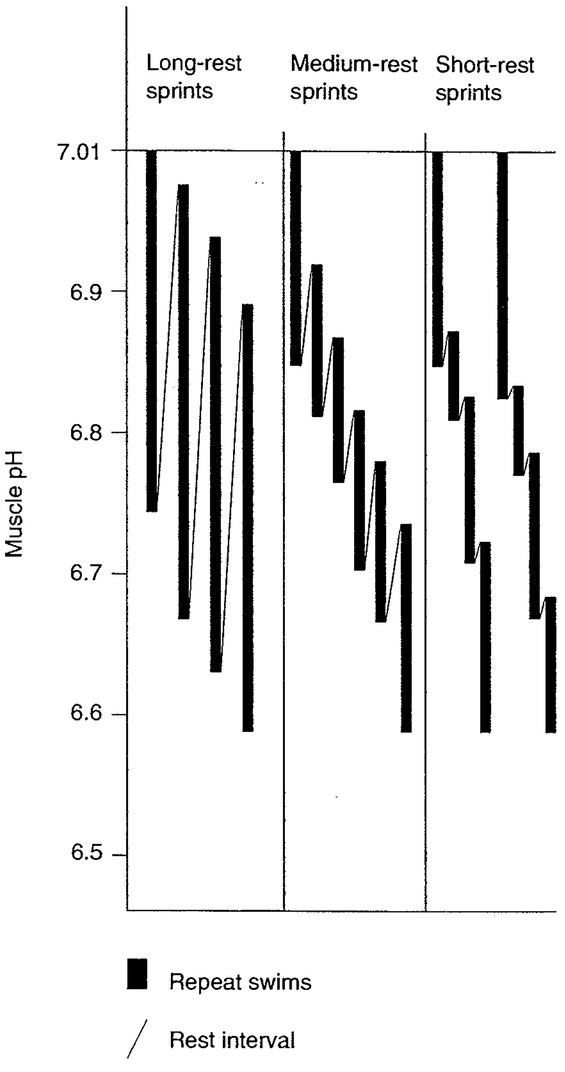


Figure 14.2 Three methods of swimming lactate tolerance repeats. The first method involves swimming long sprints with long rest intervals. This method produces severe acidosis with each swim and allows nearly complete return of muscle pH to normal between repeats. The second method involves swimming sprints on medium rest intervals. This method results in a gradual reduction in muscle pH. The rest interval is too short to permit removal of a large amount of lactic acid from the working muscle fibers between repeats, so a *stacking effect* occurs that produces a low muscle pH at the end of the set. The third method involves swimming several short sets of sprints with very short rest intervals. These intervals are so short that they allow the removal of only a small amount of lactic acid from muscles between swims. As a result, a stacking effect occurs that reduces muscle pH considerably by the end of a few swims.

Long Sprints With Long Rest Swimming long sprints on long rest intervals improves buffering because each repeat produces severe acidosis. Swimmers should rest for at least 5 to 10 min to provide time to remove a significant amount of the lactic acid from their muscles and restore muscle pH somewhat before attempting another swim (Krukau, Volker, and Liesen 1987; Troup, Metzger, and Fitts 1985). Otherwise, they will not be able to swim fast enough on subsequent repeats to stimulate further acidosis.

Swimming lactate tolerance repeats in this manner has several advantages. The set will produce severe acidosis several times, thus providing multiple periods of stimulation for increasing buffering capacity. Because the speed of the repeats will be near race speed, athletes will also be able to concentrate on using racelike breathing patterns, executing good turns, maintaining stroke integrity, and fighting off the effects of painful acidosis.

The best distances for these repeats are 100 and 200 yd or m because they are the minimum distances that will produce the desired training effect. These distances are long enough to cause severe acidosis yet short enough that athletes can swim several repeats during a particular training session.

The optimum length of repeat sets of this type is somewhere between 300 and 800 yd or m. The work of Gollnick and associates (1973) supports this recommendation. They showed that fast-twitch muscle fibers become depleted of their glycogen after four to six all-out rides on a bicycle ergometer.

Swimming speeds should be faster than threshold speeds so that lactic acid accumulates in the muscles. I am tempted to say that athletes should swim these repeats as fast as possible, but no scientific evidence supports that advice. Swimming these repeats as fast as possible may indeed improve the training effect. On the other hand, simply lowering muscle pH a substantial amount with fast but not maximum swimming speeds may provide a stimulus for improving muscle buffering capacity that is just as effective as swimming at faster speeds.

A good rule of thumb is that repeat speeds should be at least 85% of best times for 100 and 200 races or within 6 sec of an athlete's best 100 time and within 12 sec of the swimmer's best 200 time. Distance swimmers should be able to swim these repeats closer to their best times than sprinters can because swimmers in the former category generally have greater aerobic capacity and endurance and therefore do not produce as much lactic acid during their repeat swims.

Sprints With Medium Rest Intervals In the second method, in which athletes swim a series of repeats with a moderate rest interval, the rest interval should be long enough to allow them to swim faster than threshold speeds but not so long that it permits more than a modest recovery from acidosis between repeats. The major advantage of this set over the previous one is that it allows athletes to swim more repeats in a designated period of time or the same number of repeats in less time. Sprints with medium rest intervals provide the same opportunities to stimulate increases in muscle buffers and to practice race techniques under conditions of severe acidosis.

Any repeat distance can be used for medium-rest sprints, but I suggest repeat distances that are half the race distance or less because repeat speeds will be closer to race pace. Generally, sprinters will swim repeat distances of 25, 50, 75, and 100 yd or m for these sets.

Summary of Guidelines for Constructing Lactate Tolerance Repeat Sets

- Set length: 300 to 1,200 yd or m. The optimum set distance for sprinters is 400 to 800 yd or m. Middle distance and distance swimmers can swim longer sets.
- Repeat distances: Distances of 100 to 200 yd or m are optimum for repeats on long rest. Distances of 25 to 100 yd or m are optimum for sprinters on sets with medium and short rest intervals. Middle distance and distance swimmers can increase repeat lengths to between 200 and 500 yd or m, although it is not necessary to do so.
- Rest intervals: Rest intervals should be 3 to 10 min on sets in which the goal is to produce severe acidosis with each repeat, between 15 sec and 2 min when swimmers do repeats on a moderate send-off time, and very short, between 5 and 30 sec, for sets done as multiples of the race distance.
- Speed: Training speed should be faster than threshold speed and sufficient to push muscle pH down to the point that causes severe acidosis.

Some examples of lactate tolerance repeat sets are provided in table 14.1.

The optimum length of these sets is anywhere from 600 to 1,200 yd or m. Sprinters who specialize in short events should generally keep the length of their sets at 800 yd or m or less, whereas those who compete in 200 events can move up to the longer set distance on occasion.

Send-off times should allow approximately 15 sec of rest for 25 repeats, 15 to 30 sec of rest for 50 repeats, 30 to 40 sec of rest for 75 repeats, and 45 to 60 sec of rest for 100 repeats. Training speeds should be faster than threshold speeds to ensure that athletes are accumulating lactic acid in their muscles.

Sprints With Short Rest Intervals Acidosis is produced by keeping the recovery time very short in the third method of lactate tolerance training, sprinting with short rest intervals. Swimmers do this type of set as broken swims, in which they complete the set distance as a series of underdistance swims with very short rest periods. The improvement in buffering capacity results from the stacking effect of lactic acid in the muscles, which leads to severe acidosis after several repeats.

Broken swims and other sprints completed on short rest intervals are motivating and require

Table 14.1 Examples of Lactate Tolerance Repeat Sets

Long sprints with long rest periods
- 6 × 100 on 7 min
- 3 × 200 on 10 min

Sprints with medium rest intervals
- 12 × 25 on 30 sec
- 12 × 50 on 1 min
- 8 × 100 on 2 min
- 6 × 200 on 3 or 4 min

Sprints with short rest intervals
- 3 sets of 4 × 25 on 20 to 30 sec
- 3 sets of 4 × 50 with a rest interval of 10 to 15 sec
- 15 × 100 on 1:30

only a short amount of practice time to accomplish the purpose of improving buffering capacity. They provide the same opportunities to practice fighting off the stress of acidosis while maintaining good racing techniques.

Any repeat distance that produces acidosis can be used for this purpose, but repeats that are one-fourth of the athlete's race distance or less encourage training near race speeds. These sets can be extremely motivating.

The length of each set can be any distance that produces acidosis. Sets that are race distance, slightly shorter than race distance, or slightly longer than race distance are optimum. Sets slightly shorter than race distance encourage faster speeds. Sets slightly longer than race distance condition athletes to maintain good technique longer than the length of the race. Athletes can complete two to four such sets in one training session provided they have time to restore muscle pH to near normal between each set.

Rest periods should be quite short, 5 to 15 sec, so that little recovery occurs between repeats. The speed of the repeats should approximate race speed at the maximum and should certainly be faster than threshold speeds at the minimum.

Active Versus Passive Recovery

Athletes should always swim easy between lactate tolerance repeats unless the send-off time is too short to allow them to do so. When that happens they should organize longer sets of repeats into shorter sets with a recovery swim after each short set. Several studies have shown that swimmers can remove more lactic acid from their muscles in a shorter time when they continue to exercise moderately during the rest period between efforts as compared with being inactive during the recovery period (Belcastro and Bonen 1975; Bond et al. 1987; Davies, Knibbs, and Musgrove 1970; Hermansen 1981; Hermansen and Stensvold 1972). Moving about at a moderate pace during the recovery period has been termed an *active recovery* procedure, and remaining inactive is known as *passive recovery*. Belcastro and Bonen (1975) compared a group of runners who jogged during the recovery period with a group who simply lay down or sat beside the track during the same period. The recovery rate among those who used the active recovery procedure was 100% greater at 5 min and 400% greater at 20 min.

In another study contrasting active and passive methods (Hermansen 1981), the subjects in the passive recovery group sat quietly after a series of exercise bouts to exhaustion. Members of the active recovery group continued to run easily at a rate requiring 50% to 60% effort. The passive recovery group required approximately twice as long to remove the same amount of lactate from their blood as the active recovery group did.

Light exercise is superior to simply resting during recovery periods because it maintains a faster rate of blood flow, which removes more lactic acid from muscles in less time. The effort during recovery should be moderate. At very low levels of effort, the rate of removal will be slower than optimum, thus impeding recovery. On the other hand, a recovery effort that is too strenuous will produce additional lactic acid and delay the recovery process.

Several studies have attempted to identify the best mode of exercise to use during recovery and the proper intensity of effort for active recovery. Regarding the mode of exercise, one study clearly showed that swimmers recover faster by swimming during recovery rather than performing some other nonspecific exercise (Krukau, Volker, and Leisen 1987). Easy swimming during the recovery period brought blood lactate back to half its resting level in approximately 6 min after a fast 200 time trial. The time needed to produce the same response was 13 min when the swimmers used easy cycling as their mode of active recovery.

As far as intensity is concerned, Hermansen and Stensvold (1972), among others, have shown that work performed at efforts between 50% and 70% of $\dot{V}O_2max$ results in more rapid recovery than exercise that was less or more strenuous. Of course, swimmers do not gain much from learning that optimum rates of effort for active recovery are a particular percentages of maximum oxygen consumption. For this reason, Cazorla and coworkers (1983) identified the rates in more practical terms. They reported that swimmers recovered more than twice as fast by swimming at 60% to 75% of their maximum speed for 100 m. Another interesting aspect of this study was that the swimmers recovered just as quickly when they chose their own pace for recovery swimming. Apparently, athletes can intuitively identify the proper recovery effort. Left to their own devices, they select speeds adequate for this purpose.

Training Speeds for Lactate Tolerance Repeats

Training speeds should be sufficient to produce maximum heart rates during lactate tolerance swimming. Perceived efforts should be in the range of 18 to 20 on a scale of 20, and blood lactate concentrations should be near maximum. But coaches really have no need to use any of these methods to monitor lactate tolerance training speeds. The times of the repeats and the fatigued reactions of the swimmers provide the most objective evidence that they are or are not training properly. The only reason for coaches to use other monitoring procedures is when they suspect subpar efforts and want to validate their suspicion.

Progressive Overload

Any of the common methods for increasing the overload—increasing repeat speed, reducing the length of rest intervals, or increasing volume—can be used effectively with lactate tolerance swimming. An increase in the average repeat speed for a set is a good indication that anaerobic muscular endurance is improving.

A gradual reduction in the length of the rest interval can be used effectively with sprints done on a medium or short rest interval. I do not recommend this method for sprints done with long rest, however, because the training effect occurs within each repeat. If slowing of repeat speed occurs when rest intervals are reduced, swimmers should attempt to overload by working toward restoring the repeat speed to its previous level.

Increasing the number of lactate tolerance repeats per set or increasing the number of sets per week, within reason, is another way to continue stimulating improvements from this type of training. Swimmers should do this procedure only for a short time, perhaps 4 to 6 weeks, to avoid the detrimental effects of producing acidosis too frequently, and they should do it in the latter part of the season after they have increased their aerobic capacity.

Other Types of Lactate Tolerance Training

Repeat sets can take several other forms for lactate tolerance training. Specific forms of land training can also be used for this purpose.

Shortest Send-Off Repeat Sets An ideal way to construct repeat sets for improving buffering capacity is to use shortest send-off repeats. Table 14.2 provides two examples of such sets.

Mixed-Distance, Mixed-Rest, and Mixed-Style Repeat Sets Some examples of mixed-distance, mixed-rest, and mixed-style repeat sets designed to improve buffering capacity are provided in table 14.2. Set designs of this type are well suited for this purpose because long periods of active rest can occur between the fast swims.

Lactate Tolerance Training on Land Any of the three methods for lactate tolerance training just described can be adapted to land training. Land training designed to im-

Table 14.2 Additional Types of Lactate Tolerance Training

SHORTEST SEND-OFF REPEAT SETS	MIXED-DISTANCE, MIXED-REST, AND MIXED-STYLE REPEAT SETS	LACTATE TOLERANCE TRAINING ON LAND
Example #1 Swim 4 sets of 3 × 25 m on a send-off time of 20 sec. Pull 225 m of some stroke drill between each set. It is assumed that the athlete will swim the 25 m sprints at 14 to 17 sec on the designated send-off time.	*Example #1* Mixed-distance repeat set Swim 200 m fast on a 3 min send-off time. Swim 4 × 100 m easy on a 2 min send-off time. Repeat this set four times.	*Example #1* 4 sets of 1 min pulls on a swim bench, Vasa trainer, or with surgical tubing. Take 5 to 10 min rest between each set or perform a similar set for some other muscle group. Try to improve scores if device offers some method for quantifying the effort expended during one min.
Example #2 Swim 4 sets of 6 × 50 m on a send-off time of 45 sec. Kick 200 m easy between each set. It is assumed that the athlete will swim the 50 m sprints at times of 33 to 38 sec on the designated send-off time.	*Example #2* Mixed-rest repeat set Swim 100 yd fast on a 2 min send-off time. Swim 4 × 100 yd easy on a 1:40 send-off time. Repeat this set four times.	*Example #2* 10 × 20 reps of medicine ball throws or some calisthenic exercise. Rest 5 to 30 sec between each set of 20 reps.
	Example #3 Mixed-style repeat set Swim 100 m butterfly on a 2 min send-off time. Swim 100 m, kick 100 m, and pull 100 m of freestyle easy on 6 min.	

prove muscle buffering capacity should include intense efforts that last 45 sec to 2 min with long periods of active rest after each effort. Four to six such efforts should be adequate.

Lactate tolerance training on land can also consist of several shorter efforts with short rest periods that ultimately produce acidosis. Any method that quantifies the work done during lactate tolerance training on land will improve the motivation of the athletes and perhaps, the training effect they receive as well. Table 14.2 lists some examples of land training that will improve buffering capacity.

Lactate Production Training

Lactate production training consists of short sprints at near-maximum speeds for improving anaerobic power.

Training Effects

A training period of 4 to 8 weeks can produce significant improvements in the rate of anaerobic metabolism. Research suggests that improvements can continue for 1 to 2 yr with long-term, continuous training (Olbrecht 2000). In one study (Nevill et al. 1989) the amount of ATP that was recycled anaerobically increased by 20% after 8 weeks of sprint training. The authors suggested that an increase in the enzyme phosphofructokinase (PFK) made a large contribution to this increase in the rate of anaerobic metabolism. Surprisingly, the amount of energy supplied by creatine phosphate did not change.

The subjects in this study were eight active but nonathletic males and females. They trained by running two 30 sec all-out sprints with 10 min of rest after each sprint. They did this training twice per week. They also completed 6 to 10 sprints of 6 sec with 54 sec of rest after each, once per week. According to the authors, their study suggests "that the supply of energy from anaerobic glycolysis was limiting to performance before training." In other words, the rate of anaerobic glycolysis became faster with training, resulting in improvements in sprint performance.

Secondary adaptations that can result from lactate production training are (1) an increase in the quantities of ATP and CP stored in trained muscle fibers, (2) an increase in the rate of energy released from ATP and an increase in the rate at which ATP can be recycled by creatine phosphate, (3) an increase in muscular power, and (4) improved neuromuscular coordination at fast swimming speeds. Lactate production training can also produce some improvements in buffering capacity because of the rapid rate of lactic acid accumulation in working muscle fibers and the moderate reduction in muscle pH resulting from it.

The desired result of all of these physiological adaptations is that athletes will increase their maximum sprinting speed over short distances. Remember also that any increase in maximum speed will provide athletes with *easy speed.* In other words, they will be able to take longer races out faster with less effort.

Effects of Lactate Production Training

Primary

- Increase in the rate of anaerobic metabolism
- Increase in maximum sprinting speed

Secondary

- Increase in the quantities of ATP and CP stored in trained muscle fibers
- Increase in the rate of energy release from ATP
- Increase in the recycling rate of ATP with CP
- Increase in muscular power
- Increase in neuromuscular coordination at fast swimming speeds
- Increase in buffering capacity

Season Planning

Swimming is by far the best method for lactate production training. Further, swimmers should perform the bulk of this training in the stroke or strokes for which they are training. The rate of anaerobic metabolism will increase only in the muscle fibers that athletes use. Therefore, athletes must contract the same muscle fibers in training that they will use when racing.

Although swimmers should do adequate amounts of lactate production swimming during all phases of the season, they should emphasize this form of sprint training during the early season to increase the rate of anaerobic metabolism. Swimmers should be able to improve that rate even while they are also performing a large volume of basic endurance training. The fast-twitch muscle fibers will not be used significantly during basic endurance training, so their contraction speed should decrease. On the other hand, during lactate production training the fast-twitch fibers will be greatly involved in a way that should increase their contraction speed and power.

A considerable amount of lactate production training should also occur during the middle of the season to reduce the decrease in the rate of anaerobic metabolism that can occur when athletes are doing a lot of threshold and overload endurance training. These intense types of endurance training tend to reduce muscle contraction speed, and lactate production training may counteract that tendency. Finally, lactate production training should be an important part of the training day in the last portion of the season when athletes are trying to increase their sprinting speed.

Because lactate production training causes rapid anaerobic metabolism, the rate of glycogen use is high. Despite this, the amount of glycogen lost from working muscle fibers will be small because the length of each repeat and the distance of the sets are relatively short. Consequently, athletes do not need time for muscle glycogen replacement between sets of this type. Muscle damage should be minor as well; therefore, recovery time is not an issue. In other words, athletes can do some lactate production sets every day. The major considerations for scheduling lactate production sets are available training time and motivation of the swimmers, not recovery. Swimmers can lose motivation when they must sprint fast in workout after workout. Consequently, a coach may get better efforts by cutting back on or eliminating lactate production training during some of the training sessions each week. Certainly, swimmers can and probably should do some sprinting each day, but they should probably not schedule major lactate production sets for more than three or four training sessions each week. This recommendation means that athletes who are training once per day should be doing some major sprint sets during nearly every workout. Those who are training twice per day should probably schedule major lactate production sets during one of those workouts on most days.

Guidelines for Constructing Lactate Production Repeat Sets

The following are suggested set and repeat distances, rest intervals, and training speeds for lactate production repeat sets.

Repeat Distances Swimmers can best increase the rate of anaerobic metabolism by swimming repeats that are long enough to engage this system fully yet short enough that acidosis does not cause a reduction in the rate of energy release before they complete the repeat. This means that the best distances for lactate production repeats are 25 and 50 yd or m. Repeats of these distances require between 9 and 30 sec for most swimmers, a period ideal for the purpose of stimulating anaerobic metabolism without causing severe acidosis (Hellwig et al. 1988; Song et al. 1988). Anaerobic metabolism becomes the principal source of energy for recycling ATP after the first 4 to 6 sec of exercise, and extreme acidosis will not slow the rate of anaerobic metabolism noticeably until sometime between 20 and 40 sec after work has begun.

Rest Intervals The recovery time between repeats should be considerably longer than the time required to swim each repeat. The long rest provides time to transport most of the lactic acid produced during the swim out of the muscles so that stacking of this byproduct of anaerobic metabolism will not occur from one repeat to the next. Such stacking can result in acidosis before swimmers complete the set. Acidosis will slow the rate of anaerobic metabolism and defeat the purpose of lactate production training, which is to improve the rate of anaerobic glycolysis.

The recovery period should also be long enough to allow replacement of most of the CP used in the preceding sprint so that this source of energy is available at the beginning of each repeat. The replacement of creatine phosphate in muscles proceeds in two stages, a fast stage and a slow stage. Research has shown that approximately half of the creatine phosphate used during exercise will be replaced within 90 sec of recovery. An additional 4 to 8 min may be necessary to replace the remaining amount (Nevill et al. 1996). Consequently, swimmers should probably rest at least 90 sec after each sprint. They can rest longer if they like, and doing so will not reduce the training effect. The most important point is to ensure that the rest interval is not too short.

Rest periods of 1 1/2 to 3 min should be sufficient for 25 repeats, and 3 to 5 min of rest is probably needed after each 50 repeat simply because more lactic acid will have accumulated in the swimmers' muscles because of the additional time required to complete the longer distance.

Rest periods of 30 to 60 sec are definitely too short to prevent acidosis during lactate production sprints. Wootton and Williams (1983) reported that the average blood lactate concentrations for a group of subjects reached near maximum levels of 15.5 mmol/L after running only five 6 sec sprints with a 30 sec recovery period after each sprint. Blood lactate still increased considerably, to 10.3 mmol/L, during those 6 sec sprints when the recovery period was 60 sec. Athletes should swim easily during recovery periods to encourage the removal of lactate from their muscles and blood.

Set Length Allowing 4 or more min of rest after each sprint of a lactate production set is probably not feasible if swimmers are to have sufficient time for all of the other types of training that should be included in a training session. For this reason, lactate production sets swum with send-off times of 1 1/2 to 3 min should be no longer than 300 to 600 yd or m. Set distances in this range are long enough to produce a training effect without being so long that acidosis becomes severe.

Swimmers should be able to perform multiple lactate production sets of 300 to 600 yd or m during one training period. Subsequent sets should not begin, however, until swimmers have 5 to 15 min of recovery time. No research is available to guide us about how many yards or meters of daily lactate production training will produce the best results. The best rule of thumb is that athletes can continue these sets as long as they are able to swim the repeats in approximately the same times. They should discontinue them when fatigue causes them to slow down.

One of the most difficult concepts for swimmers to comprehend is that they should avoid the pain of acidosis during lactate production repeats. Because acidosis actually slows the rate of anaerobic metabolism, it defeats the purpose of lactate production training. When acidosis becomes severe, lactate production training becomes lactate tolerance training. When this happens the training effect shifts toward improving buffering capacity and away from increasing the rate of anaerobic glycolysis. This seems a reasonable assumption, although available research does not support it. The few studies about this issue show that sprints of 30 sec and longer will increase the rate of anaerobic glycolysis as effectively as shorter sprints do.

Training Speeds Training speeds should be very fast to encourage high rates of anaerobic metabolism. The literature provides no indication of minimum or optimum training speeds that will produce the desired training effects. In one study, however, 20 sec sprint runs performed at 76% of maximum speed for a 30 sec sprint produced an increase of 10% in oxygen deficit and improvements of 6% to 8% in performance on a 30 sec maximal effort (Medbo and Burgers 1990).

Regardless of this result, personal experience suggests that swimmers should complete their sprint repeats at a speed greater than 80% of their maximum speed for 50 yd or m and greater than 85% of their maximum speed for 25 yd or m. Another way to express the swimming speed for lactate production training is that athletes should swim their sprints within 1 to 2 sec of their best time for 25 yd or m sprints and within 2 to 3 sec of their best time for 50 yd or m sprints.

Summary of Guidelines for Constructing Lactate Production Repeat Sets

- Set length: 300 to 600 yd or m is the optimum range for these sets. Swimmers can perform several such sets in one training session.
- Repeat distances: 25 to 50 yd or m is the best repeat distance.
- Rest intervals: 1 to 3 min for 25 repeats and 3 to 5 min for 50 repeats.
- Speed: Training speeds should be near maximum. Times should probably be within 1 to 2 sec of the swimmer's best time for 25 repeats and within 2 to 3 sec of the best time for 50 repeats.

Examples of lactate production repeat sets are provided in table 14.3.

Counting exercise heart rates and estimating perceived efforts are not useful for monitoring the optimum speeds for lactate production training. Heart rates will not have time to reach maximum on the shorter repeats. Perceived efforts could be used for this purpose, although it would be superfluous to do so if the repeats are also being timed. The speed of each repeat should provide a more accurate method for evaluating its effectiveness for improving the rate of anaerobic glycolysis.

Progressive Overload

The most direct method to continue overloading anaerobic metabolism is to increase the speed of repeats as the season progresses. Increasing the volume of lactate production repeats is also a good overloading procedure.

Decreasing the rest interval is not a usable overloading procedure with lactate production repeats because shortening the recovery time will simply cause acidosis to occur sooner and reduce the length and effectiveness of the set.

Other Types of Lactate Production Training

Other types of lactate production training include mixed-distance, mixed-rest, and mixed-style repeat sets, as well as land training.

Mixed-Distance, Mixed-Rest, and Mixed-Style Repeat Sets Any of the mixed set types—mixed-distance, mixed-rest, or mixed-style repeat sets—are feasible for lactate production training. They can be particularly well suited for this purpose if the sets are designed so that they have only a few sprint segments interspersed with much longer periods of easy swimming, kicking, or pulling. The recommendations discussed in the guidelines for constructing lactate production repeat sets should be followed when planning these sets. The sprint segments should be no longer than 25 or 50 m with long rest periods after each repeat. Table 14.4 offers examples of mixed-distance, mixed-rest, and mixed-style repeat sets designed to improve the rate of anaerobic metabolism.

Table 14.3 Examples of Lactate Production Sets

Water training
- 8 × 25 on 2 min
- 6 × 50 on 5 min
- 6 sets of 4 × 25 on 30 sec. The first 25 of each set is sprinted. The remaining three may be swum, kicked, or pulled easy as stroke drills.
- 4 × 25 on 2 min followed by 4 × 50 stroke drills on 1 min. Then 4 x 50 on 4 min, followed by 8 × 25 stroke drills on 30 sec.
- Pull 4 × 25 on 2 min followed by kicking 4 × 25 on 2 min. Swim 200 stroke drill. Repeat set one or two more times.

Lactate Production Training on Land Lactate production training can also be conducted effectively on land. In some ways, lactate production training on land has advantages over the same type of training in the water. Still, land forms of sprint training cannot and should not replace sprint training in the water.

The principal disadvantage of land training is that it is not possible to involve all the muscle fibers used in actual sprint swimming, even with stroke-simulating exercises. Swimming is a total-body sport that also requires efficient stroke rhythm and smooth body rotation in some strokes and smooth undulation in others. No device in current use can duplicate all these stroke elements on land. Simulation of a stroke on land may not involve all the muscle fibers involved in swimming that stroke, and none of the elements of rhythm, rotation, and undulation can be effectively simulated. For this reason, land training can supplement, but not replace, water forms of lactate production training.

Having said this, I should also say that land resistance training may be more effective than training in water for overloading many of the muscle groups that swimmers use. The primary advantage of land training is the precision with which the overload can be applied and monitored. For example, pulling against the resistance of a biokinetic swim bench, a Vasa™ trainer, or even surgical tubing provides immediate feedback and solid resistance on every pull. Using swimming muscles during the performance of nonspecific weight training exercises can have a similar effect. In contrast, water yields when swimmers push against it, and swimmers learn the result of their efforts only when they hear their time at the end of a swim.

Another advantage of land training is that the lactate production training effects can be restricted to selected groups of muscles that may be limiting swimming performance. Some swimmers may use faulty mechanics because certain muscle groups lack the power to participate fully in stroking efforts. If this is the case, training that targets the weak muscle groups may increase their power, enabling them to participate more fully during actual swimming. This sort of training may eliminate the weak link and improve the swimmers' mechanics and speed.

Land training can include movements that simulate stroke mechanics as well as traditional, nonspecific strength training exercises that involve the major swimming muscle groups. The nonspecific exercises should be planned carefully to include as many of the major muscle groups involved in swimming as possible.

Land training exercises designed to increase the rate of anaerobic metabolism should probably consist of multiple 10 to 20 sec efforts, or 15 to 30 repetitions against resistance. Weight devices such as dumbbells, weight machines, and medicine balls can supply the resistance. Friction devices such as biokinetic swim benches can provide resistance in a stroke-simulating fashion, or the swimmer can use his or her body weight with Vasa trainers or calisthenics. To achieve maximum effect, the athlete can perform the timed efforts or repetitions in groups of three to six sets. The rest period between sets should be 2 to 5 min.

As mentioned earlier, devices that in some way quantify the effort expended can be effective because they provide motivation to improve one's scores. Some swim benches have digital readouts that simplify quantification. Land training devices that provide a pull-by-pull readout of force production can motivate athletes to work at considerably higher rates of effort. In the absence of digital technology, it is possible to devise other methods. For example, quantification can be provided according to (1) the average or total amount of resistance moved for the specified number of repetitions (for example, an average resistance of 20 lb for 30 reps) or (2) the time required to complete the repetitions (for example, 30 reps in 30 sec). Some examples of land training that will improve the rate of anaerobic glycolysis are listed in table 14.4.

Power Training

Power training consists of ultrashort sprints designed to stress both the force and speed of contraction of muscle fibers involved in competitive swimming. The purpose of power

Table 14.4 Additional Types of Lactate Production Training

MIXED-DISTANCE, MIXED-REST, AND MIXED-STYLE REPEAT SETS	LACTATE PRODUCTION TRAINING ON LAND
Example #1 Mixed-distance repeat set: Swim 8 × 100 yd on a 2 min send-off time. Swim 25 yd fast and 75 yd easy during each 100 swim.	*Example #1* 6 × 20 pulls against the resistance of a swim bench, Vasa trainer, or surgical tubing. Rest 3 min between sets.
Example #2 Mixed-rest repeat set: Swim 50 m fast on a 1 min send-off time. Swim 100 m easy on a 2 min send-off time. Repeat this set eight times.	*Example #2* 6 sets of medicine ball exercises, each lasting 15 sec. Take 3 min rest between each set.
Example #3 Mixed-style repeat set: Swim 25 butterfly fast on a 1 min send-off time. Pull 125 yd freestyle on a 2 min send-off time. Repeat this set eight times.	*Example #3* 4 sets of 15 vertical jumps with 3 min rest between each set, or alternating each set with a set of upper body exercises.

training is to increase stroking power. Stroking power is a result of the muscular force applied by the swimmer and the speed of application of that force. The adage "power is speed" is true. Johnson, Sharp, and Hedrick (1993) reported highly significant correlations of 0.84 to 0.87 between swimming power and sprint performance. They assessed swimming power by having athletes sprint for 5 to 6 sec on a Power Rack, shown in figure 14.3. A study by Dopsaj and associates (1998) produced results that are even more revealing. The researchers suggested that it was not muscular power per se but the rate at which that power could be developed that was most important to swimming speed. In that study, a group of experienced competitive swimmers were tested for muscular strength and for various measures of power in several muscle groups of the legs, trunk, arms, shoulders, and back. The tests of muscular power included maximum power output during a short sprint and the rate of force development, which was a measure of how quickly a large amount of muscular power could be developed. The rate of force development was the only parameter that reached statistical significance when related to sprint speed.

Training Effects The rate of force development that athletes can attain has to do with

1. muscular strength,
2. the speed with which the nervous system can stimulate muscle fibers to contract, and
3. the speed of that contraction once those fibers are stimulated.

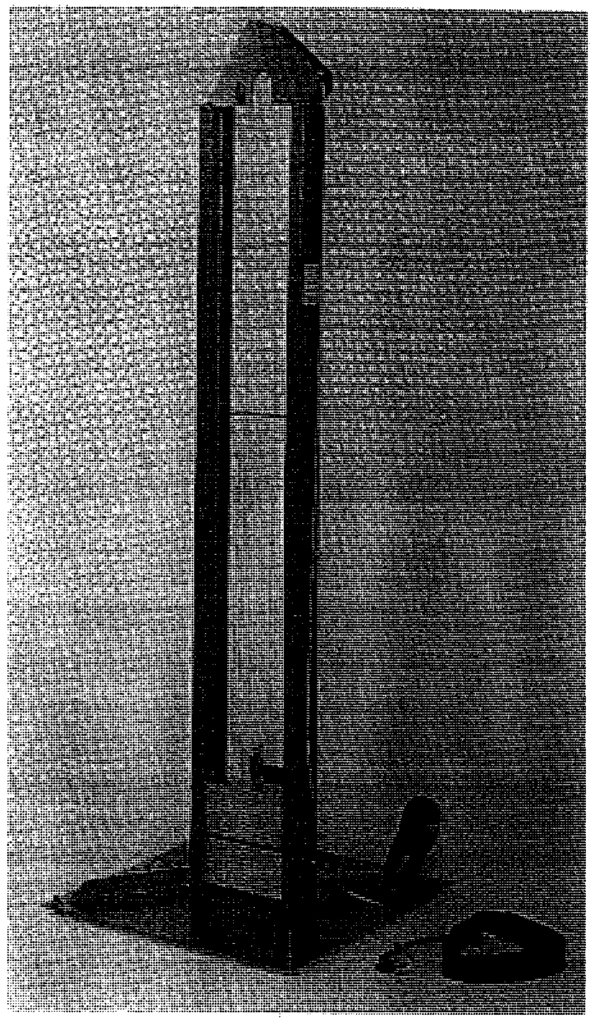


Figure 14.3 A photo of a Power Rack.

This device is marketed by Total Performance, Inc., P.O. Box 268, 592 South Illinois Avenue, Mansfield, Ohio.

Swimmers can improve these mechanisms with power training on land or in the water. Traditional techniques for improving stroking power have centered on land training, particularly weight training. That method, although effective for improving the rate of force development in trained muscle fibers, has limitations regarding the transfer of that improved rate to competitive swimming. Complete transference does not occur because stroking power results not only from the rate of force development in muscle fibers but also from the ability of the central nervous system to recruit those fibers in the correct sequence for performing a swimming stroke. Sprint swimming is the only way to improve that recruitment pattern. Sprint swimming is the bridge that swimmers must build between the muscular strength and power they gain with land resistance training and the expression of those qualities in competitive races.

I should mention that lactate production and power training have considerable overlap. The 25 and 50 sprints that athletes swim during lactate production training will certainly improve the rate and magnitude of swimming power. One could make a strong argument that lactate production training can improve this ability as well as power training can. Lactate production training involves all of the fast-twitch and slow-twitch fibers in muscles. The speeds used in lactate production training may be as effective as shorter, faster sprints are in increasing the rate and magnitude of power that these fibers can develop. Having said that, I believe that the shorter repeat distances and faster speeds used in power training can increase the expression of muscular power even more in at least two ways.

First, very short sprints allow swimmers to stroke faster and apply more force against the water than they do in even their shortest races. This sort of work may provide a greater stimulus for increases in both the rate of force development and the maximum power that swimmers can exert. Second, the ultrashort sprints of power training involve anaerobic metabolism less than the longer sprints used in lactate production training do. If you remember, Greenhaff and Timmons (1998) demonstrated that the rate of work declined slightly after 4 to 6 sec, when anaerobic metabolism took over from creatine phosphate to become the major contributor of energy for ATP recycling. Therefore, the rate of muscular contraction can be maintained at the highest possible rate only by restricting the effort to a time period (4 to 6 sec) during which creatine phosphate is the major source of energy for ATP recycling. Additionally, anaerobic metabolism can cause muscle pH to decline because of the accumulation of lactic acid in muscles over the course of several longer sprints. That accumulation, and its effect on muscle contractile rate, can be avoided when the amount of energy provided by anaerobic metabolism is kept to a minimum by shortening the sprint distance.

Effects of Power Training

Primary

Stroking power increases because of several adaptations:

- An increase of muscular strength
- An increase in the rate and pattern of muscle fiber stimulation by the central nervous system
- An increase in the rate of force development within muscles

Secondary

Increases in the ATP and CP content of trained muscle fibers

Season Planning

Adequate amounts of power training in the water should be part of the training plan during all phases of the season. Power training does not require much time, so it fits easily into the weekly plan without sacrificing other types of training. Swimmers should emphasize it during the early season so that they can increase swimming power before the emphasis on lactate tolerance training begins. Maintenance of swimming power should be the goal during the middle of the season. Increasing power should again become a primary goal during the latter portion of the season.

Power repeats will not substantially deplete muscle glycogen because they are so short. Additionally, they should not cause significant amounts of muscle damage from acidosis or overstraining. Consequently, power training on land should probably be performed only 2 or 3 days each week.

Guidelines for Constructing Power Repeat Sets

The following guidelines can be used when creating power repeat sets.

Repeat Distances Repeats of 10 to 12 1/2 yd or m are the best distances for increasing muscular power. Another method is to count stroke cycles. Efforts involving five to eight stroke cycles would be ideal. Swimmers should exert more force against the water during these repeats than they do at any other time in training.

Rest Intervals The rest interval between power swimming repeats should be 45 sec to 2 min, a period long enough to permit replacement of most of the creatine phosphate used during the short sprints.

Set Length Swimmers should probably not do more than 4 to 10 such repeats at a time. Athletes tend to swim somewhat slower when the number of repeats is much beyond that range. They can swim several sets of repeats per training session, however, if they have a rest period of 3 to 10 min or longer after each set to recover from progressive acidosis that may have taken place. They should swim easy during the rest periods to encourage the removal of lactate from their muscles.

Unlike lactate tolerance training, power training should not cause pain or loss of speed. Both signal that acidosis is interfering with the effort. When that happens, the set is not achieving the desired purpose, and it should end.

Training Speeds Swimmers should swim as fast as possible when they perform power repeats. As mentioned earlier, the goal is to overload the mechanisms involved in applying stroking force, so swimmers must apply more force against the water at faster rates of turnover than they will use in competition. Timing these sprints is one method to monitor the effort. Velocities should be faster than a swimmer's usual velocity for 25 yd or m. Another method to ensure strong effort is to time stroke rates, which should be at least as rapid as those used in 50 races.

Swimmers must not thrash when they sprint. Certainly, their stroking rates should be at least as fast as those they intend to use in 50 sprints, but they should also attempt to maintain a reasonable stroke length. I will discuss the relationship between stroke rate and stroke length in a later chapter.

Summary of Guidelines for Constructing Power Training Repeat Sets

- Set length: 50 to 300 yd or m. Three to six sets can be completed in a training session devoted to power training.
- Repeat distances: 10 to 12 1/2 yd or m. Efforts involving sprinting for four to eight stroke cycles can also be used for this purpose. Stroke-simulated land efforts on swim benches, the Vasa trainer, or weight machines are also effective. For those methods, 4 to 12 repetitions are optimum in sets of three to six.
- Rest intervals: 45 sec to 2 min between repeats in the water. Exercises on land can be done continuously for the prescribed number of repetitions. Athletes should take rest periods of 2 to 3 min between sets.
- Training speeds: Training speeds should be maximum or near maximum. Stroke rates should be as fast or faster than those used in 50 races. Swimmers should maintain distance per stroke at a reasonable length so that they do not thrash indiscriminately.

Table 14.5 provides examples of power training repeat sets.

Progressive Overload

The best way to motivate athletes to continue striving for greater speed during power training is to time their repeats. Swimmers should therefore apply progressive overload by trying to improve their times for power repeats as the season progresses. Timing these repeats accurately is difficult, however, because they are short and usually end in midpool. The difficulty of achieving accurate timing is compounded when these sprints begin with a block start or wall push-off. For example, a push-off that is not streamlined or one that is held too long can result in a slow sprint time even when the athlete is swimming extremely fast during the swimming portion of the repeat. Timing accuracy may be improved by starting the watch as the swimmer's head passes under the flags following the dive or push from the wall and stopping it when the head passes the marker that indicates that the swimmer has covered the prescribed distance.

Table 14.5 Examples of Power Training Sets

Water training

4 sets of 8 × 12.5 on 1:15. Swim easy for 3 min between sets.

6 stroke cycles sprinted 10 times on a send-off of 1 min.

3 sets of 8 × 25 on 1:30. Sprint for 10 m; then swim the remainder of the distance easy. Swim easy for 5 min between sets.

Administratively, it may be easier to find another way to motivate swimmers to provide maximum effort.

Other Types of Power Training

Many other types of swimming sets can be used for power training. As mentioned earlier, land training can improve some aspects of stroking power . Finally, two special types of sprint training can be used for this purpose—*sprint-resisted* swimming and *sprint-assisted* swimming. Let me describe each of these training procedures beginning with some special types of repeat sets.

Mixed-Distance and Mixed-Style Repeat Sets Because they allow athletes to complete the pool length after completing their short sprints, mixed-distance and mixed-style repeat sets can lend themselves nicely to improving swimming power. Using full-pool repeats makes power sets much easier to administer. Examples of mixed-distance and mixed-style repeat sets are provided in table 14.6.

Power Training on Land Power training on land can consist of stroke-simulated exercises using swim benches, Vasa trainers, or surgical tubing, to name a few methods. They can also be performed as nonspecific resistance exercises involving such activities as weight training, calisthenics, medicine ball exercises, and plyometrics.

Land exercises designed to increase swimming power should consist of 4 to 12 repetitions, performed rapidly and continuously. These repetitions should be done in sets of three to six with rest periods of 2 to 3 min between sets.

Power training efforts are much easier to quantify on land than in the water. Obviously, swim benches that have digital readouts of the work done are motivating and provide an available and reasonably accurate method for quantifying effort. When weight machines are used, the amount of weight lifted for the specified number of repetitions provides an excellent means of quantification. When using devices that do not allow the resistance to be quantified, such as the Vasa trainer and surgical tubing, the time required to complete a specified number of repetitions should be recorded. Swimmers should then try to improve on that time during later exercise sessions. Table 14.6 offers some examples for power training on land.

Sprint-Resisted Training The most popular forms of sprint-resisted training are tethered swimming and swimming against surgical tubing. Sprinting with hand paddles, swimming with shoes and clothes that add resistance, and towing objects down the pool are other popular methods of sprint-resisted training. Two devices that allow swimmers to work against resistance in the water in a manner similar to weightlifting are the *Power Rack* and the *swim wheel.* A photo of a Power Rack was shown in figure 14.3. A swim wheel is shown in figure 14.4.

The major advantage of sprint-resisted training is that athletes must work against more resistance than that supplied by water during free swimming, or even tethered swimming. But all methods of sprint-resisted training have one serious drawback. They

Table 14.6 Additional Types of Power Training

MIXED-DISTANCE AND MIXED-STYLE REPEAT SETS	POWER TRAINING ON LAND
Example #1 Mixed-distance repeat set: Swim 10 × 50 m on a 2 min send-off time. Sprint out for 6 stroke cycles; then complete the remainder of the pool length swimming easy.	3 sets of 6 stroke-simulated pulls against resistance. 4 sets of 8 stroke-simulated pulls against resistance, timed. Try to reduce the time it takes to complete 8 strokes. 3 sets of 10 vertical jumps.
Example #2 Mixed-style repeat set: Swim 16 × 25 m on a 1 min send-off time. Sprint 12.5 m using your primary stroke. Then complete the pool length using any style you choose.	

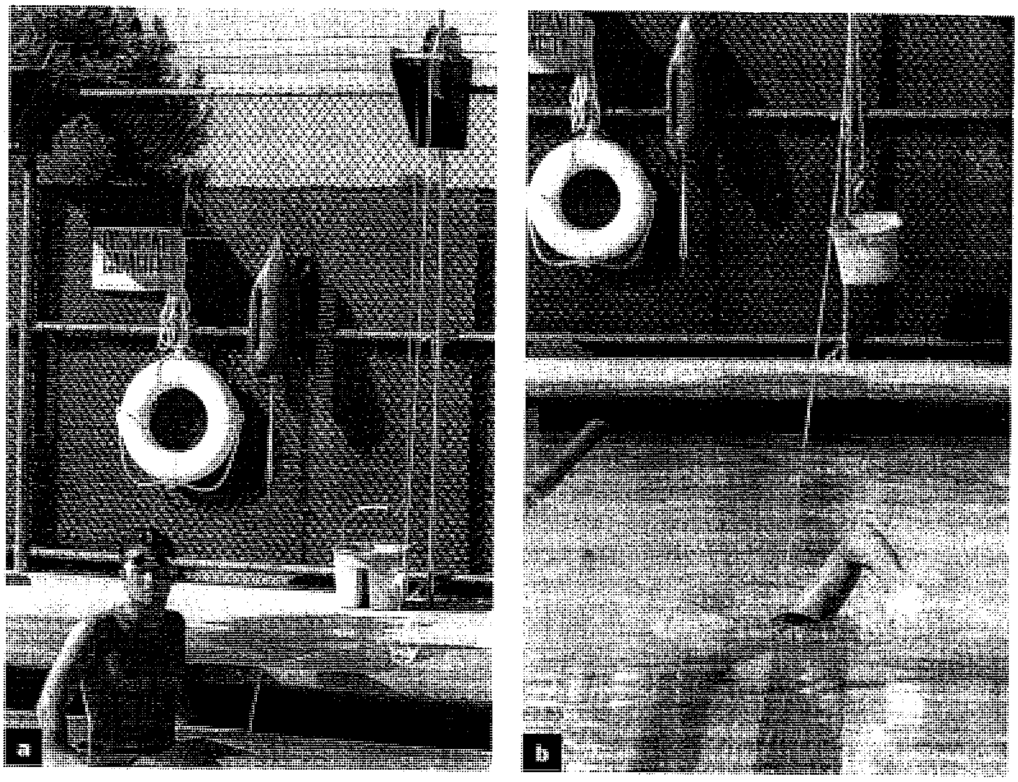


Figure 14.4 Photos of a swim wheel. Bob Mertz and Kennon Heard invented this device while they were students and competitive swimmers at California State University, Bakersfield. Photo *(a)* shows Derek Robinson preparing to swim down the pool. The wheel is mounted on the fence behind him with a bucket of diving bricks sitting on the deck. Photo *(b)* shows him swimming down the pool while lifting the bucket. The swim wheel can be built inexpensively according to the description given in this textbook.

cause athletes to stroke in ways that would be inefficient during free swimming. Swimmers take slower and shorter strokes, kick deeper, and tend to thrash and swing their bodies from side to side when they swim against added resistance (Maglischo et al. 1984). Not surprisingly, research studies have reported no improvement in speed from the effects of these and other methods of sprint-resisted training (Good 1973; Hutinger 1970; Ross 1973).

Despite opinions to the contrary, I believe that certain types of sprint-resisted training can be beneficial if athletes pay close attention to their stroke rates and stroke lengths while performing them. If stroke rates remain near competition levels and athletes attempt to maintain reasonable stroke lengths, they should be able to improve their stroking power without causing damage to their stroke mechanics. When swimmers take these precautions, sprint-resisted training has greater potential to increase stroking power than any other method. Even inadvertent changes in mechanics during sprint-resisted training should not cause a change in the stroke mechanics of experienced swimmers. They will have grooved their strokes by the large amounts of free swimming they have done during their careers, so small amounts of sprint-resisted training are not likely to change their strokes. Inexperienced swimmers are another matter. They are more prone to carry over to free sprinting some of the counterproductive efforts they used in sprint-resisted training. Consequently, coaches who choose to use sprint-resisted training with inexperienced swimmers must balance that training with an equal or greater amount of free sprinting, giving careful attention to correct stroking.

Swimmers concerned about changes in stroke mechanics should know that just 4 to 8 weeks of sprint-resisted training should produce noticeable increases in stroking power. Consequently, using this kind of training throughout the season is not necessary.

Moreover, short sets of sprint-resisted training three times per week should produce good results.

Tethered Swimming, Partially Tethered Swimming, Towing, and Drag Suits In tethered swimming, another swimmer or some kind of rope device usually holds the swimmer in one place to provide resistance. Surgical tubing provides the resistance for partially tethered swimming. Swimmers move through the water with that type of training, but they move slowly, against the resistance of the tubing. Some swimmers wear special belts with pockets called *drag belts,* or they wear swimsuits with pockets that are called *drag suits.* The pockets are designed to catch the water and thus increase resistance to the swimmer's forward motion. Still other swimmers sprint against resistance by towing objects like buckets up and down the pool by means of a rope attached to a belt around the waist.

All these methods can effectively increase muscular power if certain precautions are taken. First, the work periods should be very short so that athletes can swim at a higher rate of effort than they maintain in races. Second, swimmers should make every effort to maintain good stroking techniques while they are working. The work time for swims aimed at increasing muscular power should be 5 to 10 sec. One of the best drills with surgical tubing is to sprint for 5 to 10 sec while using a high stroke rate (60 to 70 strokes/min). Six to 10 such repeats in sets of one to three should be excellent for increasing stroking power. Send-off times of 1 to 2 min between repeats are ideal, and 5 to 10 min of easy swimming should follow each set.

I should mention that tethered and partially tethered swimming can also be used to improve anaerobic power by simply increasing the time for repeats to 10 to 25 sec. Four to eight repeats should be adequate. The rest interval between repeats should be 1 to 3 min. In both methods, stroke rates should be checked to make sure that swimmers are training at competition stroke rates or faster, while at the same time maintaining the greatest possible stroke lengths and streamlined body positions.

Tethered and partially tethered forms of sprint-resisted training aimed at improving power and the rate of anaerobic metabolism are no more stressful than free swimming repeats of these types. Therefore, swimmers can perform them several times each week. But as I cautioned earlier, similar or greater amounts of free sprinting that stresses good technique should balance the resisted training.

Sprinting With Hand Paddles Hand paddles increase the amount of water resistance swimmers must overcome. For this reason, some people have suggested that their use will increase muscular strength and stroking power. That assumption is doubtful. The increase of resistance will be minor indeed. Pulling with hand paddles would be akin to lifting a very light weight hundreds of times. An initial small increase in pulling force may occur with the additional resistance. After a rapid adaptation to this slight overload effect occurs, no additional improvement will take place.

Sprinting with hand paddles has probably become a popular method of sprint-resisted training because athletes can surpass their best times when they wear them. Hand paddles increase the surface area of the hand, making it possible to swim faster. But swimming faster with paddles does not mean that swimmers are improving their speed. Sprinting with hand paddles allows swimmers to produce faster times with slower stroke rates because the paddles add surface area to the hands. Improvements in free swimming speed occur when swimmers are able to maintain their stroke length while increasing stroke rate or when they can increase their stroke rate without losing stroke length. I believe that hand paddles produce an artificial increase in stroke length accompanied by a significant loss of stroke rate. This combination is not a desirable effect when attempting to improve free swimming speed, so I do not recommend this method.

Nevertheless, some swimmers and coaches favor sprinting with hand paddles for improving free swimming speed. I advise them to take several precautions. They should pay careful attention to stroke rates, keeping them very close or equal to competition rates. Training speeds should be faster than those swum without hand paddles. Otherwise, swimmers will simply be substituting surface area for turnover rate, and swimming with paddles will provide no additional benefit for increasing muscular power.

One additional warning I should mention is that sprinting with paddles may exacerbate the symptoms of shoulder tendinitis. The additional surface area and added resistance of the paddles put more strain on the shoulders and may cause more friction between the bones and soft tissues. Swimmers with a history of shoulder problems should be cautious about using this method, and they should discontinue it at the first sign of shoulder pain.

Any of the repeat sets suggested for power training with free swimming can be performed with hand paddles, provided swimmers and coaches observe the precautions I mentioned.

Power Rack and Swim Wheel As seen in figure 14.3, the Power Rack consists of a stack of weighted plates that can be wheeled to the side of the pool. The swimmer puts on a *harness belt* connected to the weight stack by a double-pulley system. The swimmer then lifts the plates over the pulley system as he or she sprints down the pool. The travel height of the plates limits the distance the swimmer can travel to approximately 12 yd.

The swim wheel, shown in figure 14.4, is made up of a large wheel with a rope that connects to the swimmer with a belt. A rope also connects to one end of the axle of the large wheel. The other end of that rope connects to a bucket of diving bricks that the athlete lifts as he or she swims down the pool. The bucket is lifted by means of the rope winding up on the axle as the athlete pulls the other rope out from the large wheel. The length of the rope on the large wheel can be adjusted so that it is long enough to permit the athlete to swim 25 yd or m or some shorter distance before the bucket reaches its maximum height of 8 ft.

The advantage that both the Power Rack and swim wheel have over tethered and partially tethered swimming methods is that they allow swimmers to apply progressive overload. The weight that swimmers lift provides the overload, and they can apply progression by increasing the weight. Power can be calculated by determining how fast the weight is lifted for a particular distance. Trying to swim repeats faster is another method of applying progressive overload.

Training sets for both of these devices should probably include 4 to 10 swims performed in one to three sets. Rest periods between repeats should be 1 to 3 min with 3 to 10 min of easy swimming between sets. Efforts should be maximum, and stroke rates should be close to competition rates.

Let me elaborate on the importance of using competition stroke rates with Power Rack and swim wheel sprints. Research has shown that force and its rate of application are closely linked (Moffroid and Whipple 1970). Lifting large amounts of resistance with slow stroke rates would be a mistake because the increased force developed by such training might not be available to improve stroking power at fast stroke rates. Therefore, athletes should establish the desired stroke rate for their shortest event and then add just enough resistance so that they cannot quite maintain that rate. They should then train with that amount of resistance until they can consistently equal or surpass their desired stroke rate. They should increase the resistance and begin a new training cycle when they can do that.

Although the added resistance of the Power Rack or swim wheel undoubtedly changes stroke mechanics, the effect should not be as great as that produced by tethered and partially tethered swimming. Swimmers can travel down the pool more smoothly when they are not being pulled back by a rope or by surgical tubing.

Swimming While Wearing Shoes, Shirts, and Pants Swimming against the resistance supplied by shoes, shirts, pants, or other articles of clothing has no place in the training program of swimmers. Training that uses these items, like other forms of sprint-resisted training, will reduce the stroke rate and stroke length of swimmers and cause a loss of streamlining. The chances of improving muscular power are minimal because the additional clothing causes athletes to swim at extremely slow stroke rates. Swimmers are often fooled into thinking that the additional clothing has produced a beneficial training effect because they feel so light and fast when they remove them and sprint. Timing those sprints, however, will show this to be a false sensation that does not translate to faster times. Swimming with additional clothing likely has no beneficial effect on sprinting speed.

Sprint-Assisted Training Sprint-assisted training methods were developed to counteract the potentially disruptive effects of sprint-resisted training, such as slow turnover rate and the changes to body position and stroke mechanics that increase resistive drag. Sprint-assisted training was first used in track and field after coaches found that sprint-resisted methods were causing runners to shorten their stride length and reduce their stride rate (Dintiman 1984). Because these changes were detrimental to running speed, coaches attempted to find other methods to overload muscular power. Some methods they have used are downhill sprinting and towing. Downhill sprinting consists of 20 to 70 yd runs down a slope of no more than 2.5 to 3.0 degrees. Towing involves using surgical tubing or a motorized device called a Sprint Master™ to pull the runner. In both methods the sprints are short, usually between 25 and 40 yd. Athletes run them at speeds approximately 0.50 sec faster than their best times for the repeat distance. Results have been impressive with both downhill running and towing, although the latter procedure seems to produce the best results. Track athletes have improved their 100 m dash times by up to 0.80 sec using sprint-assisted training (Dintiman and Ward 1988).

An increase in muscular strength is not likely to have caused the improvements in speed that result from sprint-assisted training because the assistive device reduces the resistance by helping athletes overcome it. Instead, the training effect may have to do with increases in muscle fiber contraction speeds and increases in recruitment speed by the central nervous system. Perhaps these or other undetermined adaptations from sprint-assisted training help runners stride faster without decreasing stride length.

The results of these methods were so impressive with runners that Eleanor Rowe, Don Lytle, and I (Rowe, Maglischo, and Lytle 1977) decided to examine effects of sprint-assisted training with swimmers. We conducted a study in which one group of swimmers underwent traditional sprint training while another group trained with a sprint-assisted method. The method we chose was sprinting with fins.

We matched two groups of 7 and 8 yr old male and female competitive swimmers according to their best times for the 25 yd freestyle. They then sprint trained for 8 weeks. The swimmers in both groups followed a typical program of mixed endurance and sprint training that was identical in all respects but one. The experimental group wore fins for a set of 15 × 25 yd freestyle sprints that they did three times each week. We encouraged them to swim each 25 repeat faster than their best unassisted times. The control group swam these sprints at the same time in the training session, but they swam them without fins. We encouraged the members of the control group to swim each repeat within 90% of their best competitive times. One coach trained all subjects in the same pool at the same time.

Following completion of the training period, we timed the swimmers again for 25 yd of freestyle in competition. Both groups improved significantly. This result was expected because both the control and experimental groups had sprint trained. The important finding was that the average 25 yd freestyle speed of the experimental group improved significantly more than that of the control group. The control group improved an average of 0.12 sec, whereas the average improvement of the experimental group was 0.53 sec. The 0.41 sec difference in average improvement for the two groups was significant. These results suggest that using some form of assistance to sprint faster than race speed in training will improve sprinting speed more than traditional unassisted sprint training.

Another method for sprint-assisted training that has become popular is for swimmers to sprint while being pulled by surgical tubing. The tubing is used in the opposite the way it was used for sprint-resisted training. In this method, the athlete swims with the snap-back of the stretched tubing rather than against it. The device for this training is constructed of 20 to 25 ft of thin-walled surgical tubing attached to an adjustable belt made of webbing. The other end of the tubing is tied to the end of the pool below water level so that it will not cause injury if it should break. The swimmer puts on the belt and walks or swims to the other end of the pool, stretching the tubing on the way. He or she then swims back as fast as possible. The stretched tubing will be pulling the swimmer back, helping him or her to swim faster than normal.

Like sprint-resisted training, sprint-assisted training tends to change the stroke mechanics of swimmers while they are performing it. In this case, however, the changes are generally beneficial rather than detrimental. In a study in which swimmers were videotaped while sprinting free and while being pulled by surgical tubing, we found that the stroke mechanics of several butterfly swimmers changed for the better during sprint-assisted efforts as compared to their free swimming styles (Maglischo et al. 1984). Some dropped their elbows less at the catch, and those who tended to push up during the upsweep released the water earlier. Others used a longer upsweep with less elbow extension, which was also deemed an improvement over their free swimming styles.

Another method for sprint-assisted training that athletes enjoy is swimming with the current. The swimmers set up a current in the pool by pushing the water in one direction with kickboards. Then, one by one, they push off the wall or dive into the water and sprint one length in the direction the water is traveling. The athletes can swim at phenomenal speeds with this method. The effect on stroke mechanics of swimming with the current appears to be beneficial because they increase their stroke rates while maintaining or increasing stroke length.

Sprint-assisted repeats are constructed by following the guidelines presented earlier for lactate production training sets. Distances of 25 yd or m are best, although a distance of 50 m can be used in long-course pools. The optimum number of repeats is in the neighborhood of 4 to 10, with rest intervals that are adequate to remove most of the lactic acid produced during the swim. In this case, I recommend 2 to 3 min send-off times.

Sprinters should probably do some form of sprint-assisted training two or three times per week during the early and late portions of their season when the emphasis is on improving sprint speed. One or two times per week should suffice during other parts of the season. Middle distance and distance swimmers can probably do this type of training once or twice per week all season long.

Race-Pace Training

Race-pace training consists of sets of underdistance repeats swum at present or desired race pace. The repeat distance is usually half the race distance or less. The rest intervals are usually short, but their length is a secondary concern. The major concern is that swimmers perform the repeats at race speed. The rest intervals should be the shortest length that will allow the athletes to swim at those speeds.

Race-Pace Essentials

The following sections describe the desired training effects, guidelines for creating repeat sets, and different types of race-pace training.

Effects of Race-Pace Training

Primary

- Improves the interaction of aerobic and anaerobic metabolic processes so that the energy for swimming at race pace is supplied faster and more economically
- Improves the ability to sense and maintain race pace in competition
- Improves the ability to swim with the most efficient combination of stroke rate and stroke length during competition
- Improves the motivation and confidence of athletes in their ability to maintain a particular race pace in competition

Secondary

- Increases $\dot{V}O_2max$
- Increases buffering capacity
- Increases aerobic muscular endurance
- Increases anaerobic muscular endurance

Training Effects

Race-pace training can produce physiological adaptations that are primarily aerobic or primarily anaerobic, depending on the race the athlete is training for. For middle distance and distance swimmers, race-pace training will produce the same adaptations as overload endurance training. When sprinters engage in race-pace training, the adaptations are more like those produced by lactate tolerance training.

Although race-pace training produces physiological effects similar to those produced by other types of repeats, it has unique values that warrant its inclusion as a separate category in all training programs. The most important of these is that race-pace training more closely simulates the actual metabolic conditions of competition better than any other form of training does. Consequently, it can improve the interaction between the aerobic and anaerobic metabolic processes so that the energy for muscular contraction will be supplied faster and more economically during races. Race-pace training is also valuable because of the opportunity it affords swimmers to improve their sense of pace. Another value is that experimentation at various race speeds can help swimmers discover the best combination of stroke length and stroke rate for swimming at those speeds.

Race-pace training is highly motivating because swimmers understand the connection between the times they are swimming in training and the times they want to swim in competition. They will try hard to move from repeat speeds that correspond to their present best time in a particular event toward repeat speeds that equal their goal time in that event. Finally, the confidence swimmers have in their ability to swim a goal time in competition will increase considerably when they are able to swim underdistance training repeats at their goal pace.

Season Planning

Obviously, swimmers must perform race-pace training in the stroke or strokes they are training for and at the present or desired pace of the races they will swim. Race-pace training, by its nature, is highly anaerobic. Consequently, the dangers of overuse described with regard to overload endurance and lactate tolerance training also apply to this category of training repeats. For this reason, swimmers should do race-pace training infrequently in the first half of the season. After the emphasis in training changes from improving speed and aerobic capacity to improving anaerobic metabolism, swimmers can do race-pace training more frequently. The best plan is to emphasize race-pace training for only 4 to 6 weeks during the latter half of the season.

Swimming one or two major race-pace repeat sets per week during the phase of the season when it is emphasized should be sufficient to produce the desired adaptations. More than this will probably result in diminishing returns and perhaps a loss of certain training adaptations because the muscles need recovery time to repair the damage of acidosis. Race-pace training is demanding both physically and emotionally, and athletes can easily become saturated if they do too much of it. I want to caution that race-pace, overload, and lactate tolerance training should be considered one category when planning the number of major sets in a training week. Let me explain what I mean by this statement.

The effects of overload endurance, race-pace, and lactate tolerance training overlap considerably in one area. All are highly anaerobic and produce severe acidosis. For that reason, swimmers should schedule no more than three total sets from among these three categories during each training week. Thus, if a swimmer does one race-pace set during a particular week, he or she should schedule no more than two additional overload or lactate tolerance sets in that week.

Guidelines for Constructing Race-Pace Repeat Sets

The following guidelines can be used when creating race-pace repeat sets.

Repeat Distances and Speeds The most important ingredient of a race-pace set is for the athlete to swim at present to desired race speed. For this reason, the best repeat distances are half the race distance or less. Experience shows that swimmers can swim 12.5 and 25 yd or m repeats at their competition speed for 50 yd or m races, and they can swim 25 and 50 yd or m repeats at 100 yd or m competition speed. They can also swim 50 and 100 yd or m repeats at 200 yd or m race speed. In longer races, swimmers have great difficulty swimming repeats of half the race distance at race speed. Athletes usually have to swim 50 to 200 yd or m repeats to attain race speed for distances of 400 m and longer.

Rest Intervals The rest interval between repeats should be long enough to allow athletes to repeat at race speed, but no longer. Experimentation and experience is the best way to determine rest intervals for athletes of various ages and abilities. Table 14.7 provides some suggestions based on personal experience.

Set Length The number of repeats in a set should also be determined through experimentation and experience. Table 14.7 offers suggestions for set length.

Summary of Guidelines for Constructing Race-Pace Repeat Sets

- Set distance: 200 yd or m to 1,500 m or 1,650 yd.
- Repeat distances: Any distance that will allow athletes to repeat at race speed. A distance of 1/2 to 1/4 of the race distance is usually required for events of 200 yd or m and less. Repeats that are 1/4 to 1/16 of the race distance work best for longer events.
- Rest intervals: The shortest period that will allow the swimmers to repeat at race speed. Intervals of 10 to 30 sec usually work well with repeats of 100 yd or m and less. Intervals may be 1 min for longer repeats.
- Speed: Training speed should be equivalent to present or desired race speed.

Progressive Overload

Swimmers can use three methods to continue improving with race-pace training:

1. Increase the repeat speed
2. Reduce the rest interval
3. Increase the number of repeats

To use any of the three methods, the repeat set should have a repeat distance and rest interval that allow swimmers to swim the repeats at or near their present race speed. To use the first method, over the course of several weeks swimmers should try to work the repeat times down to their desired race speed. With the second method, swimmers should reduce the rest interval gradually over several weeks until they can repeat the same speed on a decidedly shorter rest interval. To use the third method, swimmers should gradually increase the number of repeats over several weeks until they are swimming a considerably larger number of repeats at race speed.

Increasing repeat speed or reducing the rest interval are probably the best ways for swimmers to condition themselves to maintain a particular pace for the entire race distance. Trying to increase repeat speed toward certain goal times is highly motivating. This method is workable with a large group of swimmers because they can all be swimming their repeats on the same send-off and working individually toward their goal times. Reducing the rest interval is the most direct of the three methods because swimmers are training toward the ultimate goal of maintaining their desired pace with no rest between segments. This method is more difficult to administer to a large group

Table 14.7 Examples of Race-Pace Sets

REPEAT DISTANCE	NUMBER OF REPEATS	REST INTERVAL
For 50 events		
12.5	1 to 3 sets of 6–8 repeats	20–30 sec between repeats; 2–3 min between sets
25	1 to 3 sets of 4–8 repeats	30 sec to 1 min between repeats; 2–3 min between sets
For 100 events		
25	1 to 4 sets of 6–12 repeats	15–30 sec between repeats; 3–5 min between sets
50	6–16	30–45 sec between repeats
For 200 events		
25	3 to 5 sets of 12–20 repeats	5–10 sec between repeats; 3–5 min between sets
50	2 to 4 sets of 8–10 repeats	20–30 sec between repeats; 3–5 min between sets
100	8–12	45–90 sec between repeats
For 400 m/500 yd events		
50	20–40	10–20 sec between repeats
100	10–15	30–45 sec between repeats
200	4–8	1–3 min between repeats
For 1,500 m/1,650 yd events		
50	30–60	10 sec between repeats
100	15–30	10–20 sec between repeats
200	10–15	30–60 sec between repeats
400/500	2–3	2–5 min between repeats

in a crowded pool, however, because the members of the group will have so many different send-off times. Increasing the number of repeats is probably the weakest of the three methods for conditioning athletes' bodies to swim at some desired race speed because it is the least direct. It can be effective, however, if administered correctly. The number of repeats could be increased from some starting number to a predetermined goal number, from 6 to 12, for example. Then the swimmer could return to the original number of repeats, 6, and try to swim them faster or with less rest.

Other Methods for Race-Pace Training

Race-pace training can be conducted in two additional ways. The first is broken swimming, and the second involves monitoring repeat efforts by stroke rates instead of times.

Broken Swims Broken swims make excellent forms of race-pace training. Broken swims are a form of swimming repeat in which a particular race distance is separated into several segments and a short rest interval, usually 5 to 30 sec, is provided after each segment. Swimmers repeat these segments in sequence until the distance of the race has been completed. For example, four 25 m swims with a 10 sec rest after each swim is a broken 100 m repeat. The total swim time is calculated by subtracting the rest periods. That time is then compared with the swimmer's best time for the race distance. For example, if a swimmer averaged 30 sec for each of four 50 m swims, her time for a broken 200 would be 2:00.00.

Broken swimming is a motivating form of race-pace training because swimmers can readily see the connection between their elapsed times for the broken swim and their race times in competition. Broken swimming is also an excellent way to teach pacing because swimmers can check and adjust their pace after each segment of the broken swim. They can then try various pace plans to see what works best for them over the distance of a particular race.

Swimming at race speed in practice during broken swims is possible because the short rest periods between segments allows time for removal of some lactic acid from the working muscles and some replacement of creatine phosphate in those muscles. Some of the common methods coaches have used for constructing broken swim are listed in table 14.8.

Race-Pace Training With Stroke Rates Another method for race-pace training that may be even more effective than swimming at race speed is for athletes to swim repeats using the stroke rates they intend to use in races. Attempts to swim practice repeats at desired end-of-season race speed may not be realistic because swimmers will not have shaved or tapered. They must give more effort to swim at those speeds in midseason than they will when rested and shaved at the end of the season. Therefore, they may be swimming at greater than predicted race effort even though the repeat speed equals desired pace. It may be more realistic for athletes to swim their midseason repeats using stroke rates they intend to use in their races at season's end.

Table 14.8 Constructing Broken Swims

RACE DISTANCE	SEGMENTS	REST INTERVAL
50	2 × 25	5–10 sec
100	4 × 25	5–10 sec
	25–50–25	5–10 sec
	2 × 50	10–30 sec
200	4 × 50	5–10 sec
	50–100–50	5–10 sec
	8 × 25	5 sec
	50–100–25–25	5–10 sec
	100–50–50	5–10 sec
	2 × 100	10–30 sec
400 m/500 yd	4 or 5 × 100	10–20 sec
	8 or 10 × 50	5–10 sec
	200–100–100	20–30 sec
	200–50–50–50–50	10–20 sec
	100–200–100	20–30 sec
	100–200–50–50	10–20 sec
	200–100–100	20–30 sec
	200–200–50–50	20–30 sec
1,500 m/1,650 yd	15 × 100	10–20 sec
	16 × 100 + 50	10–20 sec
	30 × 50	5–10 sec

To use stroke rates for race-pace training, the repeat set should be constructed by selecting the maximum number of repeats and minimum rest interval that will allow athletes to swim the entire set with the proper stroke rates. Then, over the course of the season, they can gradually reduce the rest interval until they are swimming their repeats with considerably less rest while still maintaining the proper stroke rate. Alternatively, they can gradually increase the number of repeats while attempting to maintain their goal stroke rate.

Recovery Training

This type of training refers to easy swimming used to hasten recovery from more intense training and from competitions. Recovery swimming stimulates and enhances the rate of improvement in aerobic capacity and anaerobic power. It also increases the amount of intense swimming that athletes can perform weekly because it hastens recovery from such training.

Essentials of Recovery Training

The following sections describe the training effects, season planning, and guidelines for recovery training.

Training Effects

Swim training depletes muscle glycogen, produces acidosis, and causes damage to muscle tissue. Athletes will soon lose their training adaptations, a condition known as *failing adaptation* or *overtraining*, if they do not have sufficient recovery time to replace the glycogen, eliminate the acidosis, and repair muscle damage. Swimming at low levels of intensity can speed the recovery and rebuilding process in muscles and surrounding tissues. Easy swimming maintains a high rate of blood flow throughout the body without causing any further depletion of muscle glycogen or tissue injury due to acidosis. Enhanced blood flow will cause more glucose to reach the muscles, where it can diffuse and be stored as glycogen. It will also increase the amount of proteins, vitamins, minerals, and hormones that reach the muscles so that they can repair and rebuild more rapidly. Finally, increased blood flow will increase the rate at which lactic acid is removed from muscles so that their pH is restored more rapidly. Research indicates that with passive recovery procedures, 70% of the lactic acid produced during exercise is still in the muscles 6 min later (Nevill et al. 1996). By swimming easily during the recovery period, swimmers can cut that amount in half. I mentioned earlier in this chapter that the recovery rate after exhausting exercise was 100% greater at 5 min and 400% greater at 20 min when subjects remained active rather than passive during the recovery period (Belcastro and Bonen 1975). Consequently, it seems reasonable that scheduling recovery swimming after particularly long or intense training will hasten the recovery and repair process.

Season Planning

Recovery training should be scheduled after any training repeats that produce severe acidosis. The majority of certain weekly training sessions should also be devoted to recovery training when previous sessions may have caused severe depletion of muscle glycogen or considerable tissue injury.

Recovery sessions need not be entirely devoid of training. Training sessions devoted primarily to recovery from intense endurance and long sprint training can still serve to improve other aspects of performance, particularly sprinting. Recovery training can be mixed with small amounts of lactate production and power sprints without interfering with the recovery process. These sprints do not produce severe acidosis or use large amounts of muscle glycogen, so they should not interfere with the recovery process.

Because most of the acidosis and glycogen loss will be in fast-twitch muscle fibers, recovery training sessions can also include basic endurance training. Slow-twitch muscle fibers will perform most of the work during basic endurance training, so the fast-twitch fibers will have time to recover while swimmers continue to improve such aspects of aerobic endurance as cardiac output, blood shunting, and capillarization while also increasing mitochondria, lactate transporters, and perhaps myoglobin in slow-twitch muscle fibers.

Separate pulling and kicking drills and stroke drills can be scheduled during recovery sessions because swimmers usually perform these drills at basic endurance training speeds. Distance and middle distance swimmers can schedule kicking drills for recovery training sessions because most of them do not use their legs much during their endurance training. Similarly, backstroke and butterfly swimmers can schedule underwater kicking drills for recovery sessions because these drills are usually short and do not use much glycogen or cause severe acidosis.

Small amounts of more intense endurance training can also be conducted in secondary strokes in conjunction with recovery training. Training of this type will stimulate the respiratory and circulatory systems while allowing many of the major muscle fibers that swimmers use in their main stroke time to recover. The more dissimilar the secondary stroke is to the swimmer's main stroke the better, because different muscle fibers will be carrying the load while the depleted and injured fibers are recovering.

Swimmers should always perform sessions of recovery training after competitions. Doing some recovery swimming immediately after the competition is wise, particularly if additional competitions will occur that day or the next day. Recovery swimming should be scheduled for the day after a competition. Swimmers should always do 1 to 3 days of recovery training after a major competition that extends over several days during which swimmers have competed in several events. Recovery workouts are particularly necessary if swimmers have rested and shaved down for those competitions.

Guidelines for Recovery Training

The following guidelines can be used for creating recovery training sets.

Training Speeds Recovery training should be completed at speeds fast enough to enhance blood flow significantly without depleting muscle glycogen or greatly increasing lactic acid production. Swimming speeds that fit this category are in a range between 50% and 60% of $\dot{V}O_2$max. These speeds are fast enough to maintain an elevated cardiac output but not so fast that they cause much involvement of fast-twitch muscle fibers. Another reason for swimming in this range of speeds is that fat rather than muscle glycogen will be the principal source of energy for muscular contraction (Galbo and Stallknecht 1996). Consequently, muscle glycogen supplies will not fall further, and the production of lactic acid will be minimal. Obviously, extensive swimming at greater intensity will defeat the purpose of recovery training because the muscle glycogen supply will fall further and excess amounts of lactic acid will be produced.

For most athletes, a swimming speed that produces a rate of oxygen consumption between 50% and 60% of maximum corresponds to efforts that are perceived by them as swimming at half speed or less. Heart rates in the range of 90 to 120 bpm can also be used to indicate the proper intensity for recovery swimming, as can perceived exertions of 7 to 12 on a 20-point scale. I mentioned earlier that a study by Cazorla and coworkers (1983) suggested that athletes would intuitively choose the correct level of effort when instructed to swim at a recovery intensity. Consequently, once they understand the value of recovery training, most swimmers can select their own recovery training speed.

Repeat Distances and Set Length Recovery training is most effective when it is continuous and uses the stroke or strokes that swimmers used in competition. Swimmers can also do repeats of any distance for this purpose.

The optimum length for recovery swims and recovery repeat sets that follow races or intense repeats in training is between 10 and 20 min, but they can be the full length of the workout when they are the major focus of a training session. As mentioned earlier, recovery training can be interspersed with short sprints and training in dissimilar styles during sessions designed primarily for recovery, so swimmers can achieve some collateral training benefits.

Rest Intervals To save time, swimmers should do recovery repeats with short rest periods, although the send-off times should not be so short that athletes have to swim fast to make them.

Summary of Guidelines for Recovery Training

- Set length: 10 to 20 min minimum. Longer sets are recommended for recovery training sessions.
- Repeat distances: Any distance is acceptable, although longer continuous swims are superior to shorter repeats for this purpose.
- Rest intervals: Rest intervals should be short to save time. The length of the rest interval has little bearing on the effectiveness of recovery training.
- Speed: Swimming speeds should be easy. Athletes will generally swim at the proper speed if instructed to swim at recovery intensity. For those who need guidance, heart rates should be in the range of 90 to 120 bpm, perceived exertion should be 7 to 12 on a scale of 1 to 20, or athletes should feel that they are swimming at half speed or slower. Interspersing some short sprints can add an element of speed training to the recovery session.
- Styles: Athletes should swim their main styles in recovery training. More intense training in other styles can be part of recovery training sessions to encourage additional circulatory and respiratory adaptations.

Conflicting Effects of Endurance and Sprint Training

The existence of conflicting effects for endurance and sprint training is a topic of considerable debate among sport scientists. Some contend that neither type of training interferes with the effects of the other, whereas others believe that one type of training, endurance or sprint, definitely reduces the training effects of the other. My personal experience is that swimmers lose sprinting speed when they perform large volumes of endurance work. Less well known is the fact that swimmers can lose endurance when they perform significant amounts of sprint training. Endurance training tends to produce changes in fast-twitch muscle fibers, and sometimes in slow-twitch muscle fibers, that slow their rates of contraction and the rates of anaerobic metabolism. Similarly, sprint training causes a greater reliance on anaerobic metabolism so that more lactic acid accumulates in muscles at slower speeds and acidosis tends to develop more easily.

Recent research and years of experience have indicated to me that athletes can expect the following conflicting results from endurance and sprint training.

- *Endurance training will reduce sprinting speed.* In particular, threshold (En-2) and overload (En-3) endurance training tend to slow the rate of anaerobic metabolism (anaerobic power), perhaps because they reduce the activity of anaerobic enzymes and the size and strength of fast-twitch muscle fibers. Therefore, athletes who swim events in which sprint speed is important should reduce the amounts of threshold (En-2) and overload (En-3) endurance training in their programs so that they do not lose contractile speed in their fast-twitch muscle fibers. At the same time, they should include a reasonable amount of lactate production (Sp-2) and power (Sp-3) training in their programs to improve anaerobic power. Middle distance and distance swimmers, on the other hand, will have to risk some reduction in sprint speed to improve their aerobic and buffering capacities to maximum levels. This will not happen unless those swimmers engage in a reasonable amount of threshold (En-2) and overload endurance (En-3) training. Those types of training improve the aerobic capacity of fast-twitch muscle fibers, which should provide an important additional improvement of $\dot{V}O_2max$ and thus improve their aerobic endurance. Finally, they will improve the buffering capacity of both their slow-twitch and fast-twitch muscle fibers. Greater buffering capacity will provide an additional defense against acidosis so that these athletes can swim faster for a longer time despite the fact that high volumes of lactic acid may be accumulating in their muscles.

- *Sprint training will reduce aerobic endurance.* In particular, too much overload endurance (En-3) and lactate tolerance (Sp-1) training tends to reduce aerobic capacity, perhaps because the training increases the rate of anaerobic metabolism. This effect will be most damaging to middle distance and distance swimmers. These types of training cause higher rates of lactate production and accumulation at submaximal speeds, particularly in fast-twitch muscle fibers. If increased buffering capacity does not balance these effects, the percentage of $\dot{V}O_2$max those swimmers can tax during their longest races could decrease. Therefore, to maintain $\dot{V}O_2$max at a high level, middle distance and distance swimmers should include reasonable amounts of basic endurance and threshold endurance training in their programs to balance the effects of overload endurance and lactate tolerance training.

Lactate production (Sp-2) training may also reduce aerobic capacity for the same reasons that overload and lactate tolerance training does. Additionally, lactate production training, because the sprints are so short, does little to improve muscle buffering capacity. Consequently, even sprinters should balance this type of training with reasonable amounts of lactate tolerance training to maintain buffering capacity at a high level. Otherwise, endurance could suffer. Figure 14.5 summarizes these conflicting effects of training.

Training category	Effect		
	Aerobic endurance	Anaerobic power	Anaerobic muscular endurance
Basic endurance training	↑	↓	→
Threshold endurance training	↑	↓	→
Overload endurance & lactate tolerance training	↑	↓	↑
Lactate production training	↓	↑	→

Key

↑ Increase

↓ Decrease

→ Little or no change

Figure 14.5 Conflicting effects of endurance and sprint training.

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Training for Different Events

New in this edition:

- Sample programs for some of the most successful swimmers of the past decade
- Updated training information based on recent research

How nice it would be if the process of designing training programs were the same for all swimmers and for all competitive events. That approach will not work because it oversimplifies a complex process. Training plans must be individualized for events of varying distances and for swimmers with different physiological makeups. Each swimmer comes to the training environment with a set of physiological characteristics that differs in some way from those of every other swimmer. Thus, even athletes who compete in the same events will require individualized training programs if they are to reach their maximum potential as competitive swimmers.

Coaches need to use judgment gained from both experience and science to arrive at a balance that optimizes the contributions from endurance and sprint training for each event and for each swimmer. This is no small task. No coach, no matter how successful, can provide us with a system that guarantees success because the task of individualizing training is too complex and our knowledge too limited. Having said this, I want to offer some suggestions in this chapter that can improve the chances for success. I will provide a guide to optimizing the effects of endurance and sprint training for different events and for swimmers with differing physiological characteristics. I have also included descriptions of the training programs for some of the most successful modern-day swimmers and coaches so that you can see the various ways they have trained.

Two factors essentially determine the optimal balance of endurance training and sprint training:

1. The distance of the event or events for which the swimmer is training
2. The physiological makeup of the swimmer

Obviously, endurance training will receive greater weight as competition distance increases. Sprint training will be the emphasis for sprinters, and endurance training and sprint training will warrant nearly equal consideration in programs for athletes who swim middle distance events.

The physiological makeup of individual swimmers also plays a determining role in the planning process, particularly as it concerns the relative proportions of fast-twitch and slow-twitch fibers in the muscles. Swimmers with a large percentage of fast-twitch muscle fibers will tend to supply more energy through anaerobic metabolism and less through aerobic metabolism for any race distance. This should be a factor in selecting the relative amounts of endurance and sprint training in their programs. On the other hand, swimmers with a large proportion of slow-twitch muscle fibers will rely more on aerobic metabolism and less on anaerobic metabolism for energy at any race distance. The design of their training programs should include this consideration.

Training Distance Swimmers

Distance swimmers compete in the longest events on the competitive program, the 800 m freestyle, the 1,500 m freestyle, and the 1,650 yd freestyle. They may also compete in the 400 m and 500 yd freestyles, although those are considered middle distance events.

Physical Makeup

Distance swimmers generally have a higher innate propensity for aerobic metabolism than other swimmers do. Each swimmer's $\dot{V}O_2$max and anaerobic threshold will generally be greater than those of swimmers who compete in other events. Distance swimmers will also have greater potential for improvement in these areas. One reason for this is that many athletes who excel in distance events have a higher percentage of slow-twitch muscle fibers than those in the general population do. Most mixed muscles of distance swimmers will be composed of 60% to 70% slow-twitch muscle fibers. This does not mean that athletes with approximately equal proportions of fast-twitch and slow-twitch muscle fibers cannot excel in distance events. They can, with proper training, but it is doubtful that athletes whose muscles are composed predominantly of fast-twitch fibers can excel in distance events.

On the other side of the coin, distance swimmers will generally have a lower innate level of anaerobic power because they do not have a high percentage of fast-twitch muscle fibers. To a certain extent, this is a blessing for distance swimmers. They have fewer fibers of the type that produce lots of lactic acid during races. Therefore, they can swim for long periods at fast but submaximal speeds without incurring severe acidosis. But that advantage comes with a price. Those who have very low levels of anaerobic power may not be able to get their distance races out fast enough to be competitive, and they are unlikely to have the speed to bring them back at the end.

Distance swimmers may also have a lower potential buffering capacity, although to my knowledge scientific research has not demonstrated this proposition. Because slow-twitch fibers tend to possess less buffering capacity, it seems reasonable to assume that distance swimmers have less ability to improve in this area than swimmers who have more fast twitch-muscle fibers, which tend to have greater potential for buffering.

Distance swimmers are usually not heavily muscled. They may be thin or heavy, tall or short, but they will not have bulging muscles, nor will they have a predisposition to bulk up easily with resistance training. Slow-twitch muscle fibers tend to be smaller than their fast-twitch counterparts and less responsive to hypertrophy with resistance training.

A strong flutter kick is an advantage for any swimmer, but if there is one classification of events in which athletes can achieve success without an effective kick, it is the distance events. Many distance swimmers use a broken-rhythm kick, and they use it more for maintaining good lateral and horizontal alignment and for balancing their armstrokes than for propulsion. I should mention, however, that distance swimmers should develop a strong six-beat kick that they can use during the final sprints in their races.

The physical makeup of athletes who are genetically disposed to become distance swimmers allows them to tolerate large volumes of training at reasonably fast speeds. They will generally have faster threshold paces than swimmers of comparable ability in shorter events, and they can train at somewhat higher heart rates and percentages of their best times than other swimmers during endurance sets. Again, this ability results from their generally larger proportion of slow-twitch muscle fibers. Those fibers are naturally well equipped to provide energy through aerobic metabolism, and they produce lower amounts of lactic acid at fast speeds. Additionally, distance swimmers tend to use muscle glycogen at a slower rate because they have fewer fast-twitch muscle fibers and because their preponderance of slow-twitch muscle fibers allows greater aerobic metabolism of glucose and fat. Consequently, athletes who are physiologically equipped for distance events can swim longer before depleting their muscles of glycogen.

Training Suggestions

Distance swimmers must maximize aerobic capacity while being aware that they need to maintain buffering capacity at a reasonable level. They need to have that tool available for reducing the rate of acidosis during the final portions of their races. They must also maintain their sprinting speed at normal levels to have some easy speed for taking their races out and for bringing those races home. But they do not want to overdo lactate production training. Having a high rate of anaerobic metabolism provides no benefit if their aerobic system does not have the capacity to oxidize most of the pyruvate they produce. Stacking of excess pyruvate would result in the accumulation of more lactic acid and greater acidosis at race speeds. They should not perform any lactate tolerance training, and they should be conscious of not overdoing overload endurance and race-pace training for the same reason. Consequently, distance swimmers should work to optimize, not maximize, their buffering capacity and anaerobic power.

To summarize, the main goal for the training of distance swimmers, particularly those who specialize in the longest competitive events, is to improve aerobic capacity to a great extent while maintaining a reasonable amount of buffering capacity and anaerobic power (sprint speed).

Distance swimmers should be aware that emphasizing endurance training may slow the contraction speed of their fast-twitch muscle fibers and perhaps their rates of anaerobic metabolism. Those qualities should return to normal levels during the race-preparation and taper phases of the season if athletes have done sufficient amounts of maintenance sprint training. Without proper maintenance, their sprint speed could decrease so much that a normal taper will not return it to innate levels. For this reason, the sprint speed of distance swimmers should be monitored throughout the season to make certain that it has not slowed so far that it cannot come back to a normal level within 3 to 6 weeks. If a sudden and severe decline in sprint speed occurs during the middle of a typical season, the swimmer should increase the quantity of overload endurance, race-pace, and lactate production training while reducing the volume and intensity of basic and threshold endurance training. I recommend that distance swimmers who train with very high mileage do their largest volume of endurance training during the second half of the early season and the first half of the midseason. They should reduce the volume during the latter part of the season, when they should concentrate on bringing their buffering capacity and sprint speed back to normal.

Serious distance swimmers need to do a minimum of 2 hr of endurance training daily for 5 or 6 days of every week. Training of this type will improve the aerobic capacity of their slow-twitch fibers and, to some extent, their FTa muscle fibers. They should do much of this training at slow to moderate speeds near their individual aerobic thresholds. Training at these speeds allows greater energy delivery through fat metabolism and will not drain muscle glycogen supplies rapidly.

Basic Endurance Training

Most of the endurance training that distance swimmers do should be in the basic endurance category (En–1), but they also need to do a substantial amount of threshold endurance and overload endurance training. Basic endurance training should compose the bulk of their endurance mileage because it does not produce a significant reduction in muscle pH. Consequently, it causes little if any muscle damage. Basic endurance training also reduces the rate of muscle glycogen use because fat metabolism provides more energy. Basic endurance training should be performed in combinations of long swims and long sets of short-rest interval repeats.

Threshold Endurance Training

Distance swimmers can and should swim more of their repeats near threshold speeds (En–2) than other swimmers. This training will provide a greater stimulus for improving the oxygen consumption and lactate removal rates of the FTa muscle fibers. At the same time, training at this level minimizes acidosis and its effect on muscle damage. Research presented in chapter 9 suggests that the FTa muscle fibers of swimmers come into play at training speeds in the range between 70% and 85% of $\dot{V}O_2$max. These training speeds correspond to the anaerobic threshold for most swimmers.

Threshold sets should be scheduled within a few weeks after training begins for each new season. One or two sets per week are recommended during the early season. The number of sets should increase gradually up to the middle of the season, after which swimmers should do fewer threshold sets to make room for more overload endurance and race-pace training. Because they have more slow-twitch fibers, distance swimmers will not produce as much lactic acid at threshold speeds; consequently, they will suffer less muscle damage.

Slow-twitch fibers also use glycogen at a slower rate and replace that glycogen faster after exercise; therefore, distance swimmers can afford to swim at threshold endurance speed longer and more frequently than sprinters can during each training week. Nevertheless, one long threshold endurance repeat set will deplete distance swimmers' muscle glycogen supplies by approximately one-half to two-thirds, and 24 to 36 hr will be required for them to replace that amount. Therefore, the frequency and duration of threshold endurance training must be scheduled carefully to prevent complete emptying of the muscle's glycogen supply. Athletes need to intersperse basic endurance sets with threshold sets so that they swim the latter type of repeats during no more than four sessions each week, although they can swim a few repeats near threshold speed every day. The suggested duration for most threshold sets is between 1,500 and 3,000 yd or m for junior and senior swimmers. For young age-group swimmers, older masters swimmers, and other athletes who require longer than 20 to 40 min to swim 1,500 to 3,000 yd or m, the suggested duration for threshold endurance sets is 20 to 40 min.

The aerobic capacity of slow-twitch and FTa muscle fibers improves best by constant stimulation above a certain threshold intensity over a reasonably long period. The magnitude of aerobic adaptations within the working muscles will decrease if the training stimulus is interrupted too often. For this reason, medium and long distance repeats are superior to short distance swims. The rest periods between those swims should be short for basic and threshold endurance repeat sets. The training effect will be less if a set includes too much variety. For example, alternating freestyle swimming with other strokes or with pulling or kicking will reduce the aerobic training effect. Therefore, long straight sets, descending sets, mixed-speed sets, mixed-rest sets, and shortest-rest repeat sets that include long periods of freestyle swimming with very short breaks are best suited for improving aerobic capacity.

The athlete need not train exactly at his or her individual anaerobic threshold speed to gain the benefits of this type of training. To gain the benefits of threshold training without producing tissue damage, the only consideration is to train near the highest intensity that does not produce severe acidosis.

Overload Endurance and Race-Pace Endurance Training

Large amounts of overload endurance and race-pace training (En–3) will produce severe acidosis and tissue damage. These workouts must be scheduled carefully. Both types of training are necessary because they stimulate the high-threshold FTa and the FTb muscle fibers and improve their aerobic capacity. Basic and even threshold speeds probably do not engage these fibers in a substantial way. Therefore, distance swimmers need to train occasionally with some very fast endurance swimming so that they can improve the ability of all of their muscle fibers to consume oxygen during races. I should warn that athletes can incur tissue damage, hormonal depletion, central nervous system inhibition, and other manifestations of overtraining if they perform very fast endurance training too frequently. For this reason, distance swimmers should not swim any overload or race-pace sets during the first 2 to 3 weeks of each season. They can and should descend to these speeds for a few repeats during most of these training sessions. The amount of overload endurance and race-pace training can increase during the specific preparation phase, after athletes have improved their aerobic capacity and the fat metabolism in their slow-twitch muscle fibers. The duration of these sets should be between 800 and 2,000 yd or m, or 8 to 25 min. Because of their intensity, overload endurance and race-pace repeat sets will also improve buffering capacity.

The repeat distance for most overload endurance sets should generally be between 200 yd or m and 400 m or 500 yd. Repeat distances of 50 to 150 yd or m are best suited for race-pace training of 1,500 m and 1,650 yd competitors because they will be able to swim their repeats at or near their race speeds. Athletes should have some additional rest for overload endurance and race-pace sets so that they can swim at or near race pace. The rest should not be excessive. For most short distance repeats, 20 to 30 sec is adequate. The rest can be 1 or 2 min for longer repeat distances.

Specifying optimum training speeds is unnecessary for overload endurance training. Athletes should swim these sets at the fastest possible average speed. Any sudden and continued decline in those speeds may indicate loss of aerobic capacity. In those cases, athletes should reduce the frequency and duration of threshold endurance, overload endurance, and race-pace training sets and replace them with more basic endurance and recovery mileage. After each overload endurance training set and long threshold endurance set, I suggest that swimmers do 20 to 30 min of recovery swimming to encourage faster recovery and adaptation.

Because overload endurance and race-pace sets drain muscle glycogen rapidly, they should be scheduled in place of, not in addition to, threshold endurance sets. One overload endurance set per week is sufficient during the first half of the season, and some combination of two to three overload and race-pace sets per week are recommended during the final 6 to 8 weeks before the taper. Threshold endurance, overload endurance, and race-pace repeat sets should all be considered in the same category when planning the weekly schedule. During the early season most of these should be threshold sets, with perhaps one overload or race-pace set in the weekly schedule. An additional overload or race-pace set can be added during the middle of the season, and a threshold set should be dropped. In addition, swimmers should descend their basic endurance sets down to threshold speeds and overload endurance speeds several times each week. They should also descend some of their threshold and basic endurance sets down to very fast speeds during several of the weekly sessions that do not include major overload endurance and race-pace sets. These fast repeats at the end of basic and threshold endurance sets should total between 300 and 600 yd or m. This change in training will provide additional stimulation to increase the aerobic capacity of FTb muscle fibers without causing large losses of muscle glycogen. When planning the weekly schedule, coaches and athletes should consider scheduled competitions in this combined category of threshold endurance, overload endurance, and race-pace training.

Sprint Training

As mentioned earlier, distance swimmers cannot expect to improve their rates of anaerobic metabolism or their muscular power beyond innate levels during the swim season. In fact, both will probably decrease somewhat because of the large volume of endurance training they must do. Nevertheless, distance swimmers must possess a reasonable amount of anaerobic power to take their shorter races out at competitive speeds and to sprint fast at the end of their races. The best they can hope for is to prevent large decrements in power and speed so that both can return to normal levels when they decrease the volume and intensity of their endurance training near the end of the season. Consequently, they should do some lactate production training all season long to prevent large losses of anaerobic power. The purpose of this training is to prevent large decrements in swim speed in the first two-thirds of a typical season so they can regain that speed in the latter portion of the season. Reducing losses of sprint speed and returning that speed to normal levels is a relatively simple matter of scheduling two to four lactate production sets weekly all season long.

What I have just said does not mean that distance swimmers cannot increase their innate sprinting speed during a swimming season. They can, but improvements will generally occur because of physical growth and improved stroke mechanics. They need to understand that large volumes of sprinting will not achieve this purpose because of the much greater magnitude of endurance training they must perform to optimize their aerobic capacity. Consequently, distance swimmers should focus their attempts on increasing sprinting speed, improving their stroke mechanics, and reducing resistive drag.

Distance swimmers need not include lactate tolerance training in the weekly schedule. The overload endurance training that they employ to improve the aerobic capacity of their high-threshold FTa and FTb muscle fibers will maintain and perhaps even improve the buffering capacity of those fibers and even the slow-twitch muscle fibers. Lactate tolerance training in combination with overload endurance training could even produce an overload of sprint training that could result in failing adaptation.

Table 15.1 summarizes my suggestions for training distance swimmers.

Structuring Repeat Sets for Distance Swimmers

Distance swimmers should swim most of their repeats using the freestyle stroke, although they can overdo this practice. The major drawback to performing large volumes of freestyle swimming is the possibility of creating or exacerbating shoulder tendinitis. A secondary consideration is boredom and concurrent loss of interest and motivation. The best advice is to include as much freestyle swimming in the program of distance swimmers as their joints and interest can sustain.

Mixed-style repeat sets, although popular because of their variety, are not an effective method for basic, threshold, and overload endurance training for distance swimmers because they provide too many periods of relief for some muscle fibers when the swimmers are performing styles other than freestyle. Nevertheless, sets of this type

Table 15.1 Training Suggestions for Distance Swimmers

TRAINING CATEGORY	EARLY SEASON	MID-SEASON	LATE SEASON
En-1	2 or more hr daily, 5–6 day/wk	2 or more hr daily, 4–5 day/wk	Reduce weekly quantity by 1/3
En-2	1 or 2 sets/wk	2 or 3 sets/wk	1 or 2 sets/wk
En-3	Taken care of by descending basic and threshold endurance sets	1 or 2 sets/wk plus descending work	2 sets/wk plus descending work
Lactate production	3–4 sets/wk	3–4 sets/wk	3–4 sets/wk

can improve the aerobic capacity of fast-twitch muscle fibers, particularly FTb fibers, if swimmers alternate several extended periods of very fast swimming with periods of lower intensity when they perform other swimming styles and pulling or kicking. Extended periods of fast front-crawl swimming will stimulate both the anaerobic and aerobic metabolism of the FTb muscle fibers, and they will partially recover from acidosis during the less intense periods when swimmers use other styles. Of course, distance swimmers should swim the front-crawl stroke during the periods of intense training. Those periods should be a minimum of 2 to 3 min to provide adequate aerobic stimulation.

Distance swimmers should swim more and pull less than other swimmers do so that they learn to reduce the energy cost of kicking as they swim. They should not neglect kicking in their training, however, because they need to improve the oxygen consumption and lactate removal rates in their leg muscles to delay acidosis and improve lactate removal by those muscles during races. One thousand to 1,500 yd or m or 20 to 30 min of endurance kicking during most training sessions would not be excessive. As mentioned earlier, distance swimmers must also develop a strong six-beat kick to provide added speed when they sprint at the finish of a race. They can work toward that objective by kicking 25 or 50 yd or m repeats at fast speeds. These athletes should also swim the final 50 yd or m of each training set with a six-beat kick to condition themselves to do the same in races.

Individual Differences Among Distance Swimmers

Coaches will usually have two distinct categories of distance swimmers on their teams. The first type will have inherited considerable potential to swim fast aerobically but will have poor maximum sprint speed because they possess little anaerobic power. The second type will have more anaerobic power and thus greater sprint swimming speed, although they will not have the speed of sprint swimmers of similar relative ability.

Workhorse Distance Swimmers

Swimmers in the first category will be those with an unusually large proportion of slow-twitch muscle fibers. Spotting these swimmers is not hard. They are the *workhorses* of the team. They can train with fast endurance sets day after day without showing fatigue because they can provide a greater percentage of energy through fat metabolism, thus only slowly depleting their muscle glycogen supplies. Swimmers of this type are able to swim long repeat sets and long continuous swims in training at speeds that are close to their maximum speed. They will not be able to swim very much faster during sprint sets, even with more rest. These swimmers will not be good at swimming descending sets. Their speed on the last repeats will not be much faster than their average speed for those sets.

Another indication is that these swimmers usually perform better in competition as the race distances get longer. They swim quite well over a distance of 1,500 m and 1,650 yd, not quite at the same standard for distances of 400 m and 500 yd, and their performances at distances of 100 and 200 m or yd are vastly inferior to their performances in the longer events.

These swimmers can engage in more training in the basic, threshold, overload, and race-pace categories than other swimmers can because they deplete muscle glycogen more slowly and replace it faster. They also tend to incur acidosis less easily because they have fewer fast-twitch muscle fibers, and they can tolerate a greater total volume of training. These swimmers do not need to engage in recovery training quite as often.

The solution to the problem of distance swimmers with low anaerobic power might seem to be to increase their speed as much as possible with strength and power training on land and lactate production and power training in the water. Applying that remedy, however, would be a mistake. Increasing their anaerobic power too much may reduce their aerobic endurance. They may produce more lactic acid at slower speeds, which could cause severe acidosis to occur earlier in their races. Another reason that these swimmers do not need additional strength and power training on land and in the water is that they do not have very much anaerobic power to begin with nor do they have great potential to improve it. Consequently, short lactate production sets swum three to five times weekly should reduce their loss of speed during the period of emphasis on aerobic endurance and allow them to regain what they lost during the race-pace and taper phases.

Racehorse Distance Swimmers

The second category of distance swimmers are those whose proportion of slow-twitch muscle fibers, although still dominant, is closer to 50%. These *racehorse* distance swimmers will have somewhat more anaerobic power, although they will not have the anaerobic power and speed of sprinters. Distance swimmers in this category may compete well in 1,500 and 1,650 events, but they often excel at 400 m and 500 yd. In addition, they can usually swim reasonably well in 100 and 200 yd or m races.

Unlike swimmers in the first category, these athletes will not be able to train day after day without showing signs of energy depletion because, with more fast-twitch muscle fibers, they will deplete their muscle glycogen faster and replace it at a somewhat slower rate. These swimmers will also not be quite as good as those in the first category on long sets of short-rest repeats and long, continuous swims. But they will perform better on sprint sets, although not as well as sprinters, and they will be capable of swimming fast at the end of descending sets of repeats.

Distance swimmers in the racehorse category should do even more overload endurance and race-pace training than workhorse distance swimmers. They have more fast-twitch muscle fibers, and they need to improve the aerobic capacity of those fibers so that the fibers can make their needed contribution during races.

Swimmers in this second category can do large amounts of basic endurance training, but they should engage in less threshold training. They need an adequate but not excessive amount of overload endurance training to improve the aerobic capacity of their high-threshold FTa and FTb muscle fibers. They will also need more recovery training to provide time for energy replacement and tissue repair because they tend to experience acidosis more easily and because they deplete the glycogen from their muscle fibers faster and replace it somewhat slower. Reducing the amount of threshold endurance training and replacing it with recovery and basic endurance swimming should provide this additional time they need for these purposes.

Like distance swimmers in the first category, racehorse distance swimmers do not need to do much sprint training. They can afford to lose some anaerobic power during the season because they have a greater amount to begin with. In addition, their sprinting speed should return more quickly during the part of the season that emphasizes overload endurance and race-pace training. I might go so far as to say that distance swimmers in this category should make an effort to reduce their anaerobic power somewhat if they are concentrating on races of 1,500 m and 1,650 yd. Doing so will allow them to swim faster and longer with a slower rate of lactic acid accumulation. But if they specialize in races of 400 m and 500 yd, they need to be more careful about maintaining a reasonable amount of anaerobic power. They must be even more careful if they are serious about swimming good 200 races.

Training for 400 M and 500 Yd Events

One estimate places the percentage contribution of anaerobic capacity at 14% in events lasting 15 to 20 min (Darabos, Bulbulian, and Wilcox 1984). For events of 400 m and 500 yd the anaerobic contribution is probably closer to 30% or 40%. Consequently, distance swimmers with greater anaerobic power will have an advantage in these middle distance events. The suggestions I made for training both categories of distance swimmers require no modification for the middle distance events. Improvements of aerobic capacity preclude any significant increases of buffering capacity and anaerobic power that might occur with less endurance training and more sprint training.

The major concern for distance swimmers who specialize in middle distance races is avoiding any permanent reduction in their innate buffering capacity and rate of anaerobic metabolism. They will need to monitor both carefully to be certain that they can bring them back to normal levels with a taper at the end of the season. Swimmers who specialize in the 400 m or 500 yd freestyle may need a longer and somewhat more intense period of overload and race-pace training near the end of the season to be certain that their buffering capacity and anaerobic power have returned to normal levels. They may need longer tapers for the same reason.

Training for 800 M and 1,000 Yd Events

Anaerobic metabolism contributes slightly more to the total energy requirement at 800 m and 1,000 yd distances as compared with the longer events. The contribution from anaerobic metabolism is probably only 5% to 10% greater. Consequently, the suggestions for training 1,500 and 1,650 swimmers also apply to swimmers in these events during most of a typical swimming season. The difference would be slightly greater emphasis on overload and race-pace endurance training and a somewhat longer taper during the final portion of the season.

Land Resistance Training for Distance Swimmers

The value of land resistance training for distance swimmers is controversial because they do not need a great deal of muscular power to swim their events. In addition, the scientific literature gives some indications that increasing muscle fiber size could interfere with endurance by increasing the distance that oxygen must travel from the capillaries across the muscle fibers to the mitochondria (Gollnick et al. 1972; Nelson et al. 1984; Tesch, Hakkinen, and Komi 1985). At the same time, some research indicates that simultaneous endurance and strength training may interfere with aerobic adaptations (Jacobs, Sale, and MacDougall 1987; Nelson et al. 1984; Tesch, Hakkinen, and Komi 1985), although some studies report results to the contrary (Dudley and Djamil 1985; Hickson et al. 1988; MacDougall et al. 1987). I should caution that most of the studies supporting simultaneous strength and endurance training were conducted with untrained subjects. People who have not trained are likely to improve both their strength and endurance for several weeks after commencing training because their original levels of both were low to begin with. Only after several weeks, when adaptation rates slow, would any detrimental effect that strength training might have on endurance appear.

Perhaps the best reason for distance swimmers to engage in strength training can be found in the study by Fitts, Costill, and Gardetto (1989), cited in chapter 14. Based on their research, one could argue that simultaneous strength training could reduce the loss of muscle fiber size and strength that tends to occur with endurance training. I see no need, however, to involve distance swimmers in comprehensive programs to increase strength and power. Those programs require a commitment of time and effort that could detract from their endurance training in the pool. If some form of land resistance training is desired, I suggest that it be designed simply to maintain, not increase, muscle size and strength. Land training of this type will require less time and effort, leaving more time and energy for endurance training.

Training Programs of Successful Distance Swimmers

Various sources describe the training programs of some of the most successful distance swimmers of the past decade. I have selected the training programs of Kieren Perkins, Janet Evans, and Brooke Bennett for this purpose. I have also included the program of coach Jon Urbanchek of the University of Michigan because of the great success he has enjoyed with distance swimmers.

Kieren Perkins

Kieren Perkins of Australia (Carew 1994, 1998; Johnson 1998) is the former world-record holder for the 800 m and 1,500 m freestyles with times of 7:46.00 and 14:41.66, respectively. John Carew, from Brisbane, Australia, is his coach. Perkins has set numerous world records and has won several World Championship titles in the 400, 800, and 1,500 m events. He was also the gold medal winner for the 1,500 m freestyle at the 1992 and 1996 Olympic Games.

Kieren spent 5 yr preparing for the 1992 Olympic Games, where he set his record in the 1,500 m freestyle. His average weekly mileage progressed over the 4 yr before the 1992 Olympic Games. He did 55 km weekly in the 1st y.r, 66 in the 2nd, 77 in the 3rd, and 88 during the year before the 1992 Games. He took only 3 weeks off from training during that 4 yr period.

Kieren typically trained for 11 sessions each week, swimming twice each day on Monday through Friday and once on Saturday morning. He took Saturday afternoon and all day Sunday off during each week. Each training session was typically between 7,000 and 8,000 m. He trained in a long-course pool in the morning and in a 20 m pool in the afternoon. He trained at altitude at certain times each year.

Heart rates were used to monitor his endurance training. His maximum heart rate was 181, but he seldom trained at that rate. The speed of his training repeats was established according to a certain number of heartbeats below maximum.

His yearly training plan was made up of two 26-week seasons. The typical plan was to use the first 6 weeks of each season as an aerobic build-up phase. This period included mixed training and a lot of individual medley training. The intensity was moderate. Perkins swam most repeats at heart rates 30 to 40 beats below his maximum rate.

Major endurance sets were introduced after the first 6 weeks and continued throughout the remainder of each season. Those sets were generally between 1,200 and 3,000 m in length, and the requested intensity was equivalent to Kieren's maximum heart rate minus 20 to 40 bpm. The weekly program usually included three to five such sets. His coach, John Carew, prefers that his distance athletes swim endurance sets of approximately 3,000 m. Almost all of Kieren's sets were structured as interval training. He swam continuous distances of 1,500 to 2,000 m once every week or two but always at submaximal speeds. The repeats I just described would be classified as basic endurance training in the scheme I presented in chapter 13.

Besides his basic endurance training, Kieren would complete two and sometimes three very intense heart-rate sets each week at speeds that produced heart rates between maximum and maximum minus 10 bpm. My training scheme would consider these heart-rate sets overload endurance sets. Some examples of his heart-rate sets were 30 × 100 on a send-off time of 1:40, and 6 × (200, 150, 100, 50) on a base send-off of 1:30 per 100.

One or two sets of sprint training were usually scheduled each week. An example of one of his sprint sets was 30 × 50 m on a send-off time of 1:30. During some weeks, broken swims replaced these race-pace sets. He did two or three recovery sessions each week, and these always followed sessions in which he swam intense heart-rate and sprint sets. Perkins also kicked about 1,000 m per training session. In addition, he did some pulling during every training session, usually at a very low level of effort.

A typical training session for Kieren would begin with 1,500 to 2,000 m of easy aerobic training, followed by a main set, which could be an intense heart-rate set, a sprint set, or race-pace training. That was followed by 1,000 m of kicking, and the session would end with some pulling or recovery swimming and, in some cases, some sprinting. Table 15.2 shows two typical weekly plans. Some of the main sets Perkins used in training are included in this table. I have also indicated in parentheses my best guess about where these sets fall in my training classification scheme.

Table 15.2 Sample Training Cycles for Kieren Perkins

CYCLE 1	**AM**	**PM**
Monday	Heart-rate set (En-2 to En-3) 3 × (400, 300, 200, 100)	Recovery 10 × 100 1.M on 1:40
Tuesday	Aerobic (En-1 to En-2) 2 × (5 × 400) on 5 min	Aerobic (En-1)
Wednesday	Heart rate set (En-2 to En-3) 6 × (20, 150, 100, 50)	Recovery 10 × 200 on 2:30
Thursday	Aerobic (En-1 to En-2) 20 × 100 5 × 300	Broken swims (R-P)
Friday	Aerobic (En-1 to En-2) Long 4 × 800	Aerobic (En-1)
Saturday	Sprints (En-3) 30 × 50 on a send-off of 1:30	
CYCLE 2	**AM**	**PM**
Monday	Heart-rate set (En-2 to En-3) 30 × 100 on 1:40	Aerobic long (En-1 to En-2)
Tuesday	Sprints (En-3) 6 × (4 × 50 on 1:30 plus 2 × 25 on :50)	Recovery
Wednesday	Heart-rate set (En-2 to En-3)	Aerobic long (En-1 to En-2)
Thursday	Sprints (En-3)	Recovery
Friday	Aerobic (En-1)	Aerobic long (En-1 to En-2)
Saturday	Aerobic quality (En-3) 6 × 400 on 4:30	

Adapted from Carew 1994.

Perkins did no weight training, but he did pull on stretch cords for 15 to 20 min each day. In addition, he did 20 to 30 min of stretching each day. He did sit-ups to exhaustion three times weekly and calisthenic exercise, including considerable abdominal work, for 30 min daily on the other 3 days of the week. The calisthenic exercises included chin-ups, dips, hanging sit-ups, crunches, and standing vertical jumps. He also pedaled an exercise bicycle for 30 min daily, 3 days of each week.

Janet Evans

Janet Evans (Schubert, 1994) is one of the greatest distance swimmers in our sport. Her records of 4:03.85 for 400 m freestyle, 8:16.22 for 800 m freestyle, and 15:52.10 for 1,500 m freestyle still stand over a decade after she established them. At various times she was coached by Bud McAllister, Don Watson, and most recently by Mark Schubert, coach of the Trojan Swim Club and the University of Southern California. The training program detailed here was conducted by Mark Schubert and resulted in an Olympic gold medal in the 800 m freestyle at the 1992 Olympic Games.

Her training year was divided into two seasons, each of approximately 26 weeks. She spent 3 weeks in a buildup phase, gradually increasing training mileage from 4,000 m per session to between 6,000 and 7,000 m per session. She trained for nine sessions each week during that phase. After that came an aerobic phase that lasted approximately 6 weeks, during which she trained 10 times per week. Nine weeks of high-volume training followed, during which she trained 11 times per week. During this phase, she trained twice per day on Monday, Tuesday, Thursday, Friday, and Saturday and once on Wednesday. She did not train on Wednesday morning or on Sunday. Her training mileage was generally 8,000 m per session, although it would be 9,000 or 10,000 m on some days and 6,000 or 7,000 m on others. This high-volume phase included a large amount of mixed training in which she used all competitive styles and a variety of kicks. Many of the sets were of the mixed-style type.

The predominantly freestyle sets were done as long, straight sets and mixed-distance sets. Some examples of her long sets were 9 × 400, 3 × 1,500, and 20 × 200. An example of a mixed-distance set was to swim 100, 200, 300, 400, 500, 500, 400, 300, 200, 100. She generally did all these sets in a descending fashion on short rest, and most sets were 3,000 to 6,000 m in length. Her goal was to swim three sets of 5,000 to 6,000 m per week. On occasion, she swam continuously for 20 to 60 min. She also did some short, fast sets such as 5 × 100, 2 × 400, and 4 × 100.

The next 6 weeks was termed a specific quality phase. Her training was similar to that of the previous phase during most sessions. The one difference was that three or four sessions of each week were devoted to fast endurance training with short rest intervals. Repeat distances for these fast endurance sets varied between 100 and 400 m, and the sets were 3,000 to 4,000 m in length. Times on these sets were supposed to be near race pace. Janet also swam challenge sets on the shortest possible send-off twice per week.

Schubert tried to include 800 to 1,000 m of sprint training each day throughout the season to maintain Janet's speed. Those sprints were generally at distances of 25, 50, 75, and 100 yd or m.

Janet did lots of pulling with and without oversized paddles. Most often, she used a pull buoy for flotation during pulling, but occasionally she pulled with a tube for added resistance. She performed kicking with a variety of fins and in the form of drills, such as side kicking. She did not kick during every practice session.

Land training included running for 40 min before the morning practice, four or five times per week. She did 20 min of exercise on a Stairmaster™ or exercise bicycle 3 days per week. Sometimes she used an arm ergometer (an exercise bicycle modified so that athletes push the pedals with their arms) during these sessions. She also did 300 to 400 sit-ups daily.

Her weight-training program consisted of a variety of swimming-specific exercises performed with light weights for 12 to 20 repetitions. She did these exercises on 3 days each week. On the other 3 days, she exercised with stretch cords, the biokinetic swim bench, the Vasa trainer, or medicine balls, although she did not use all of these pieces of equipment in the same training session.

Her race-pace training included a unique feature. Three times each week, she tried to swim some short, underdistance repeat sets faster than her desired race pace.

Janet did some training at altitude in preparation for the Olympic Games. During these periods she lived at 8,000 feet above sea level and trained at 5,500 feet. Schubert felt that swimming at a slightly lower altitude helped her train more intensely and that living at a higher altitude encouraged greater adaptation.

Brooke Bennett

Brooke Bennett (Banks 1997, 1998) won the gold medal in the women's 800 m freestyle at the 1996 Olympics and won gold medals in both the 400 and 800 m freestyles at the 2000 Olympic Games. She swam for the Blue Wave Swim Club in Bradenton, Florida. Peter Banks, a native of Ireland, is her coach. Her training programs for the Olympic Games and for the first few years afterward will be detailed here.

Brooke has trained continuously for several years. Her weekly training mileage increased from 65,000 m to 86,000 m in the 4 yr period before her gold medal performance in 1996. Her training year had two seasons, one lasting from September to April and the other from April to September. She took short breaks of 1 to 1 1/2 weeks between those seasons. She trained 10 times weekly, swimming twice per day on Monday, Tuesday, Thursday, and Friday and once per day on Wednesday and Saturday. She rested on Saturday afternoon and all day Sunday. Her usual mileage per training session was between 8,000 and 9,000 m, although she generally swam 12,000 m on Saturday morning.

Brooke's training cycles were generally 6 weeks long. She used a repeat set of 10 × 300 m freestyle with 20 sec rest between swims to monitor her training progress and to select training speeds. Her goal was to improve the average time for this set with each training cycle.

Brooke's training program was constructed around training at her anaerobic threshold, and her average time for the set of 10 × 300 was used to designate her threshold training speed. Her threshold sets were 3,000 to 4,500 m in length, and she tried to swim one-third to one-half of her weekly training mileage at threshold speeds.

Brooke's weekly training cycle included two sessions in which threshold training was the major emphasis and one challenge session in which she used race-pace or a shortest-rest repeat set. My classification would consider this latter set overload endurance training. She also did one additional race-pace session during some weeks. Brooke did most of her training in freestyle, but two of her weekly basic endurance sessions were devoted to individual medley swimming. Table 15.3 shows an example of her weekly training cycle.

Banks frequently challenged Brooke with shortest-rest repeat sets. She has swum 800 m repeats on 9:30, 400 m repeats on 4:40, 200 m repeats on 2:15, and 100 m repeats on 1:05 in these sets. Two of Brooke's training sessions for 1996 are listed in table 15.4.

Jon Urbanchek: University of Michigan and Club Wolverine

Jon Urbanchek coaches the Club Wolverine and the University of Michigan in Ann Arbor, Michigan. Over the years he has had remarkable success training distance swimmers. One of his best distance performers was Tom Dolan, who swam to two remarkable NCAA and American record times for short-course yards. Those swims were in the 500 yd freestyle, in which his time was 4:08.75, and in the 1,650 yd freestyle, in which he posted a 14:29.31. Jon also coached Chris Thompson to one of the best times in the world for the 1,500 m freestyle in 2000. Chris's time was 14:56.81, which was a bronze medal performance at the 2000 Olympic Games.

Jon uses a unique system in which he color codes training intensity. The program includes three endurance levels: basic endurance swimming, threshold swimming, and

Table 15.3 Sample of Brooke Bennett's Weekly Training Cycle

DAY	AM	PM
Monday	En-1 Total = 8,000 m	En-2 200–400 m repeats Total = 8,000 m
Tuesday	En-1 drills and kicking with fins Total = 7,500 m	En-1 IM swimming Total = 8,000 m
Wednesday	En-1 Total = 8,500 m	En-3 50, 100 and 200 m repeats Total = 8,000 m
Thursday	Recovery Kicking with fins Total = 7,500 m	En-2 3,000–6,000 m set Total = 8,000 m
Friday	En-1 Total = 8,500 m	En-1 Drills and IM repeats Total = 7,500 m
Saturday	En-3 Challenge set such as 100 on a send-off time of 1:05 Total = 12,000 m	

Adapted from Banks 1995.

$\dot{V}O_2$max swimming (which corresponds to overload endurance and race-pace training in my system). Each of these major endurance training categories contains two subcategories. Basic endurance training includes white and pink subcategories, threshold training has red and blue subcategories, and $\dot{V}O_2$max training has purple and green subcategories. In addition, he recognizes three sprint categories: lactate tolerance training, lactate production training, and alactic training (which corresponds to power training in my classification). These categories and subcategories of training are listed in table 15.5. The levels of training intensity corresponding to each are also listed, as are some suggested parameters for constructing repeat sets.

Jon uses a 3,000 swim to monitor improvements in aerobic capacity and to establish threshold training speeds. He uses a test set of 6 × 100 on a send-off time of 8:00 to monitor improvements in anaerobic power and buffering capacity. Both types of test sets are done approximately once every month during the training year.

His teams train 10 sessions each week, and they swim between 7,000 and 8,000 yd or m per session so that their weekly total is approximately 85,000 yd or m. They train twice per day on Monday, Tuesday, Thursday, and Friday. They train only once on Wednesday and Saturday, and they rest Saturday afternoon and all day Sunday. They usually train at altitude twice each year for 3 weeks.

A sample of Jon's weekly training cycle is shown in table 15.6 on page 501. His teams swim at threshold speeds for two sessions each week, and they do combinations of $\dot{V}O_2$max and sprint training during two sessions each week. Two of the remaining six training sessions consist primarily of basic endurance training. Two others are composed of combinations of recovery and sprint training, and the swimmers devote two sessions each week to recovery swimming.

Jon's threshold repeat sets were generally 50 to 60 min in length, and swimmers performed them at heart rates between 150 and 180 bpm. $\dot{V}O_2$max repeat sets were generally 2,000 to 3,000 yd or m in length and were swum at maximum heart rates. Race-pace sets, often conducted as broken swims, were generally 800 to 1,600 yd or m

Table 15.4 Two Training Sessions for Brooke Bennett

Training Session #1
Feb. 13, 1996

REPEAT SET	SEND-OFF	TRAINING LEVEL
Swim 12 × 100 freestyle	1:30	Recovery
Swim 1 × 800 freestyle	10:00	En-1
Swim 1 × 600 freestyle	7:30	En-1
Swim 1 × 400 freestyle	5:00	En-1
Swim 1 × 200 freestyle	2:30	En-1
Kick 16 × 50 with fins	:50	Recovery
Swim 16 × 200 freestyle	2:40	En-2
Descend 1–4, 5–8, 9–12, 13–16		
Swim 4 times		
1 × 400 IM	6:00	En-1
4 × 100 butterfly	1:30	En-2
Swim 40 × 50 freestyle	:40	En-2
Total = 12,400 m		

Training Session #2
June 25, 1996

REPEAT SET	SEND-OFF	TRAINING LEVEL
Swim 1 × 1000	15:00	En-1
(600 IM + 400 freestyle)		
Swim 12 × 50 freestyle	:45	En-1
Repeat following set 2 times		
Swim 1 × 800 freestyle	10:00	En-1
Swim 1 × 600 freestyle	7:30	En-2
Swim 1 × 400 freestyle	4:40	En-2
Swim 1 × 200 freestyle	2:20	En-2
Pull 40 × 50 freestyle	:40	En-1
16 × 100	1:30	En-1
(alternate 2 repeats swimming freestyle with 2 kicking repeats with fins)		
Total = 9,200 m		

Adapted from Banks 1997.

Table 15.5 The Color-Coded Training Intensities Used by Jon Urbanchek

TRAINING CATEGORIES	SUB-CATEGORIES (COLOR)	INTENSITY	SET LENGTH	REST INTERVAL
En-1	White	Low. Heart rates of 120–140 and blood lactates of 1–2 mmol/L.	Variable	5–15 sec
	Pink	Moderate. Heart rates of 140–150 and blood lactates of 2–3 mmol/L.	Variable	20–40 sec
En-2	Red	Hard but tolerable. Heart rates of 150–170 and blood lactates of 3–5 mmol/L.	30–45 min	10–15 sec
	Blue	Hard and uncomfortable. Heart rates of 160–180 and blood lactates of 4–6 mmol/L.	25–35 min	30–40 sec
Max $\dot{V}O_2$	Purple	Hard and uncomfortable. Heart rates of 180–190 and blood lactates of 6–10 mmol/L. Used for distance swimmers.	2,000–3,000 m	Variable
	Green	For sprinters. Hard and uncomfortable. Heart rates of 180–190 and blood lactates of 6–10 mmol/L.	800–1,600 m	Variable
Lactate tolerance	Green	Heart rates of 190–200 and blood lactates of 8–15 mmol/L.	1,600 m for distance swimmers and 400–800 m for sprinters	Long
Lactate production	Green	Very fast and difficult. Heart rates of 190–200 and blood lactates of 8–15 mmol/L.	1,200 m for distance swimmers and 300–600 m for sprinters	Long 8 min
Alactic	N/A	Very fast	100–200 m	Long

Adapted from Urbanchek 1985.

in length. The athletes also swam some anaerobic sets of 1,200 yd or m. The repeats were swum very fast with long rest periods (that is, 6 × 200 on a send-off of 8:00). Finally, they swam some sprint repeat sets that were generally only 200 to 300 yd or m in length, such as 8 × 25 on a 1 min send-off. Table 15.7 on pags 502–503 provides two examples of Jon's daily training sessions.

Training Sprinters

I define a sprinter as a swimmer who competes at distances of 50 yd or m, 100 yd or m, and 200 yd or m. Many sprinters who excel at the 200 distances, however, are more similar in physical makeup to middle distance swimmers than they are to other sprinters.

Table 15.6 A Typical Weekly Training Cycle for Jon Urbanchek's University of Michigan Swim Team

DAY	AM	PM
Monday	En-1. Pulling and kicking at white and pink intensities. Total = 7,000 m	En-2. 60 min set at red and blue intensities. Total = 10,000 m
Tuesday	Recovery swimming. Kicking and pulling at low intensities. Total = 7,500 m	Active rest. Slow endurance training and fast sprinting at white and pink intensities. Total = 8,000 m
Wednesday	Off	Max $\dot{V}O_2$ training and sprinting at purple and green intensities. Total = 8,000 m
Thursday	Recovery training at low intensities. Fin kicking and stroke drills. Total = 7,500 m	En-2 at red and blue intensities. Long sets, 50–60 min in length. Total = 8,000 m
Friday	En–1 training at white and pink intensities. Pulling , kicking, and stroke drills. Total = 7,000 m	Active rest at white and red intensities. Total = 8,000 m
Saturday	Max $\dot{V}O_2$ and sprint training at purple and green intensities. Total = 8,000 m	Off

Adapted from Urbanchek 1985.

Physical Makeup

Sprinters fall into three categories. One group will tend to perform relatively better in the 50. Their performance will fall off to some extent at the 100 distance and to a great extent in 200 races. These swimmers are commonly referred to as *drop-dead* sprinters. I feel that a more positive label should replace this derogatory term, so I will refer to this type as *fleet* sprinters, for want of a better term. Fleet sprinters have a high level of anaerobic power, but their aerobic capacity is very weak, probably because they have an unusually high percentage of fast-twitch muscle fibers.

The second group of sprinters tends to perform best at the 100, although they can swim a good 50 and a good 200 as well. They also have a high level of anaerobic power, although not as high as that of fleet sprinters. Their percentages of fast-twitch and slow-twitch muscle fibers are probably close to 50-50. I will refer to them as *normal* sprinters.

The final category includes swimmers who compete much better at distances of 200 yd or m than they do at distances of 50 and 100 yd or m. Ideally, 200 swimmers should have the aerobic capacity of distance swimmers and the anaerobic power of sprinters. This happy combination is not possible in an athlete, however, because the proportion of fast-twitch and slow-twitch muscle fibers that would make one of these possible precludes the other. Those who specialize in the 200 generally have a greater percentage of slow-twitch muscle fibers than do sprinters in the other two categories. Their physiology is really better suited for middle distance swimming even though they compete at distances that are considered sprints. For this reason, freestylers in this category may also swim events of 400 m and 500 yd. Unfortunately, 200 yd or m is the longest distance for backstroke, butterfly, and breaststroke swimmers; therefore, athletes with excellent skills in one of these strokes will specialize at this distance even though they may be better suited physiologically for longer distances. Because of their physiological

Table 15.7 Examples of Four Training Sessions for Jon Urbanchek's University of Michigan Swim Team

Wed. Jan. 26 A.M. **Purpose: Basic endurance**

REPEAT SET	SEND-OFF	PURPOSE
4 × 300 (each 300 is 100 drill, 100 kick, and 100 swim)	:30	Warm-up
Kick 8 × 25 (2 each stroke)	:30	
Swim 8 × 25 (2 each stroke)	:30	
Swim 8 × 100 (2 of each stroke in IM order)	1:15	En-1
Swim 800 IM (as 400 IM and 2 × 200 IM)	9:00	En-1
Swim 8 × 100 freestyle	1:10	En-1
Swim 800 free (descend by 200)	8:30	En-1
Swim 16 × 50 freestyle	:35	En-1
Swim 4 × 200 IM (descend 1–4)	2:15	En-2
Swim 100 maximum effort		Lactate tolerance
Total = 7,500 yd		

Wed. Jan. 26 P.M. **Purpose: Race-pace and $\dot{V}O_2max$**

REPEAT SET	SEND-OFF	PURPOSE
Warm up as you please for 1,500		
Swim 4 × 500 broken as follows:		
200 from dive	3:00	
100 from push-off	1:30	
100 from push-off	1:30	
50 from push-off	1:00	
50 from dive	1:00	En-3
Swim 150 easy between each 500	3:00	Recovery
Kick 300 easy		Recovery
Kick 6 × 50	1:00	En-1
Pull 400 no freestyle		
Pull 300 freestyle		
Pull 200 no freestyle		
Pull 100 freestyle		Recovery
Total = 5,700 yd		

(continued)

makeup, these athletes should train like middle distance swimmers rather than sprinters. Therefore, I will provide some suggestions for them in a later section.

The $\dot{V}O_2max$ in L/min of fleet and normal sprinters may be equal to or greater than that of middle distance and distance swimmers of similar ability. When expressed relative to body size, however, the amount of oxygen they can consume per kilogram of body weight will generally be somewhat lower than that of middle distance and distance swimmers.

Sprinters in the fleet and normal categories compensate for this deficiency of aerobic capacity with greater muscular power and enhanced capacity to replace ATP anaerobically. Both qualities provide them with potential for greater sprint speed compared

Table 15.7 *(continued)*

Mon. Oct. 4 A.M. Purpose: Active rest

REPEAT SET	SEND-OFF	PURPOSE
Swim 400		
Swim 4 × 100 freestyle (descend 1–4)	1:15	
Swim 8 × 50 (2 of each stroke, easy then fast)	:45	Warm-up
Swim 6 × 100 with fins and paddles (swim second 25 head-up and 4th 25 fast)	1:20	Lactate production
Swim 3 × 200 hypoxic with fins and paddles	2:20	En-1
Kick 8 × 100	1:40	En-1
Swim 4 × 300 with fins, each 300 a different stroke with last 100 of each 300 fast	:15	En-1 and lactate tolerance
Pull 8 × 50 butterfly	:40	En-1
Swim 2 × 800 freestyle, negative split	8:30	En-1 and max $\dot{V}O_2$
Swim 4 × 500 (100 fly, 100 back, 100 breast, and 200 free) (descend 1–4)	5:30	En-1 and max $\dot{V}O_2$
Total = 8,400 yd		

Mon. Oct. 4 P.M. Purpose: Threshold

REPEAT SET	SEND-OFF	PURPOSE
Swim 400 easy, kick 400 easy		
Swim 8 × 50 (fly/free)	:50	
Swim 8 × 50 freestyle	:50	Warm-up
Kick/swim 6 × 150 (50 kick, 50 drill, 50 swim)	2:30	En-1
Kick/swim 10 × 50 (25 kick, 25 swim)	:45	En-1
Pull 400, 300, 200, 100 (use all four strokes in any order)		En-1
Swim 2 × 400 white pace	5:00	En-1
Swim 4 × 400 red pace	4:55	En-2
Swim 4 × 400 blue pace	4:55	En-2
Swim 200		Recovery
Total = 8,200 yd		

Adapted from Urbanchek 1985.

with middle distance and distance swimmers. They tend to be more muscular than distance swimmers, and they have a greater potential to improve muscle size, strength, and power because they possess more fast-twitch muscle fibers.

Large, powerful sprinters in the fleet and normal categories can sometimes swim 50 yd or m exceptionally fast even with serious stroke defects by maintaining a very fast stroke rate. They must have reasonably good stroke mechanics, however, to maintain fast average speeds for 100 and 200 yd or m. They cannot maintain the energy cost of a rapid stroke rate for the time required to swim the longer events without suffering early acidosis. In addition, because these sprinters are generally larger and more heavily muscled, they must overcome more resistive drag when they swim, and the effort to do so adds up over longer distances. For these reasons, fleet and normal sprinters, perhaps more than any other category of swimmer, must have efficient stroke mechanics if they want to extend their performances beyond 50 yd or m.

A strong flutter kick is a huge advantage to a freestyle sprinter. Swimmers in these events generally use a six-beat kick. That kick contributes relatively more to their speed than it does to the speed of swimmers in middle distance and distance events. Of course, the kicks of sprinters in the other three competitive strokes must also be strong.

The physical makeup of the fleet and normal sprinters causes them to be well suited to swim very fast for short distances and short durations in training. They will not be able to train fast for long distances or during long sets of repeats on short rest. This statement is more accurate for fleet than it is for normal sprinters, although the latter group will also have noticeable difficulty maintaining a good pace during long endurance repeat sets. At any submaximal training speed, swimmers in both groups will be recruiting more fast-twitch muscle fibers than middle distance and distance swimmers do. Therefore, they will experience greater acidosis and more rapidly deplete their muscles of glycogen on longer sets.

The result of all these factors is that fleet and normal sprinters will, and should, swim much slower on basic and threshold endurance repeat sets than distance sprinters, middle distance swimmers, and distance swimmers of similar relative ability. They will probably repeat between 3 and 5 sec slower per 100 than middle distance and distance swimmers on endurance sets when swimming at the same relative intensity. Fleet and normal sprinters will not be able to tolerate the same weekly volume of endurance training as middle distance and distance swimmers do, and they will need to do more recovery swimming each week to provide time to replace their muscle glycogen and repair muscle tissue damaged by acidosis.

Fleet and normal sprinters will generally have higher submaximal heart rates than middle distance and distance swimmers at the same submaximal speeds because those speeds represent a greater physiological effort for the sprinters. For that reason, they will probably have to swim their basic endurance and threshold endurance sets at somewhat lower heart rates than their teammates who swim longer events if they are to avoid acidosis.

The same phenomenon holds true when athletes swim at certain percentages of maximum speed in training. Fleet and normal sprinters will generally be producing and accumulating more lactic acid than middle distance and distance swimmers do when they swim at the same percentage of their maximum speeds for particular race distances. Consequently, the sprinters will need to swim at lower percentages of their maximum speeds during basic and threshold endurance events so that they can delay acidosis.

Although they may have greater difficulty swimming basic and threshold endurance repeat sets, normal sprinters need not take a backseat to middle distance and distance swimmers when they swim overload endurance repeat sets. These athletes should be able to swim similar or even faster times than many middle distance and distance freestyle swimmers on those sets if the total distance is not too long (less than 2,000 yd or m). Fleet sprinters will probably find it difficult to maintain fast speeds on overload endurance repeat sets unless the total distance of those sets is very short, that is, less than 600 yd or m.

Despite their problems with endurance training, the greater power and speed of sprinters should allow them to excel during sprint training. They should definitely be able to swim faster on lactate tolerance and lactate production repeat sets than athletes of similar ability who compete in longer events. Sprinters should be able to swim high-speed 50 repeats 8 to 12 sec faster than the speeds they maintain for the same distance in basic endurance sets. Times in fast 100 repeats may be 12 to 16 sec faster than their basic endurance speeds.

Training Suggestions

Physiologically, sprinters must possess a high rate of anaerobic metabolism and an enhanced ability to buffer lactic acid to be successful in their short events. Still, they need a high level of aerobic capacity. Research suggests that successful sprinters who specialize in the 100 and 200 yd or m events have a maximal ability to consume oxygen that is much greater than that of less successful sprinters (Olbrecht 2000). This condition is true whether that ability is expressed in liters of oxygen consumed per minute (LO_2/min) or expressed relative to body size, in milliliters of oxygen consumed per kilogram of body weight per minute (ml/O_2/kg). This circumstance is advantageous because recent research suggests that aerobic metabolism contributes a minor but substantial amount of energy for muscular contraction during sprint events. For example, estimates are that aerobic metabolism contributes between 18% and 29% of the total energy for 50 sprints (Ring et al. 1996), between 25% and 35% of the energy for 100 events, and between 35% and 45% of the energy for 200 events (Trappe 1996). Obviously, aerobic metabolism makes substantial contributions to sprint events. Sprinters with above average ability to consume oxygen as well as above average anaerobic power and muscular power are certainly blessed.

Lactate Production and Power Training

Sprinters need to spend a good portion of their time performing lactate production and power repeats to increase their stroking force and efficiency. In addition, they need to engage in some lactate tolerance and race-pace training to increase the buffering capacity of their muscles. These types of training will increase the contractile speed and buffering capacity of both slow-twitch and fast-twitch muscle fibers (Troup, Metzger, and Fitts 1986; Sharp et al. 1986). Sprinters also need to increase their muscular strength and power with heavy resistance training on land and then learn to use that additional strength and power when they race by performing free swimming short sprints, sprint-resisted repeats, and sprint-assisted repeats.

Sprinters should perform some combination of three to five major lactate production and power repeat sets each week. They should also include small amounts of one or the other of these types of repeats in most of their other training sessions throughout the week. They should begin swimming these sprint sets within a few weeks after the beginning of each season, after completing their adjustment period, and they should continue swimming them for the remainder of the season. The purpose, at first, will be to maintain speed and power during the early season endurance training. Later, the purpose will be to increase speed and power. Sprinters should perform their sprint sets in the stroke or strokes they will swim in competition. The training effects that improve speed take place in the muscle fibers, so swimmers must be certain they are training the muscle fibers they will use in competition.

Athletes should develop some plan for progressive overload that does not involve simply trying to swim faster each time they perform sets of lactate production and power repeats. Relying on increases of intensity for progressive overload is too haphazard and usually works for only a short time. That method generally causes a small but rapid improvement in speed that soon reaches a plateau. A better system is to use a combination of volume and intensity for progressive overload. For example, swimmers could initially add to the number of repeats in a set until they have doubled the total distance of that set with no significant reduction in their repeat speed. After accomplishing that, they can return to the original number of repeats and try to swim them at a faster average speed. Let me describe an example of training in this manner.

Swimmers could begin by being tested for a set of 6 × 50 sprints on a send-off time of 3 min. The results of this test will yield an average time for these repeats, for example, 27.00. The swimmer should then try to maintain that speed while adding two repeats to the set every third or fourth time he or she performs it. This procedure should continue until the swimmer can swim 12 × 50s at the criterion average speed. The swimmer should then reduce the number of repeats to the original number of 6, establish a new criterion speed, and begin the process again.

Lactate Tolerance and Race-Pace Training

Sprinters can improve their buffering capacity with overload endurance training, race-pace training, or lactate tolerance training. As I mentioned earlier, distance swimmers do not need lactate tolerance repeats for this purpose. Sprinters, however, will find that lactate tolerance training is in some ways superior to overload endurance training for improving buffering capacity, simply because the former type of repeat set puts more emphasis on swimming fast and in some cases provides longer rest periods to do so. Race-pace repeats should be substituted for lactate tolerance repeats at certain times of the season because the former type of training emphasizes swimming at race speed.

Sprinters should probably swim one major lactate tolerance set per week early in the season and on occasion one race-pace set of repeats. The length of these sets should be 5 to 15 times the race distance. For example, race-pace training and lactate tolerance training for the 50 could include as many as 30 × 25 or 60 × 12.5 yd or m sprints in multiple sets. For 100 races they could include as many as 20 × 50 or 60 × 25 in multiple sets. Lactate tolerance sets for 200 races should probably be approximately 800 to 1,200 yd or m, that is, 10 × 100 on a send-off of 2 min. Obviously, swimmers should do most of these repeats in their main stroke or strokes. Besides swimming major lactate tolerance and race-pace sets, swimmers should also finish many of their endurance sets with some lactate tolerance training by descending those sets down to maximum or near-maximum speeds during the last repeat or two. These sets will also help improve their buffering capacity.

The combined number of lactate tolerance and race-pace repeat sets should increase to two per week during the middle of the season. Race-pace repeats should almost entirely replace lactate tolerance repeats during the final 4 to 6 weeks before the taper phase of the season to simulate race conditions more closely.

Recovery swimming should always immediately follow lactate tolerance and race-pace sets. Additionally, because they suffer severe acidosis more often in training, sprinters should have a few training sessions each week devoted primarily to recovery swimming.

The stroke rates and stroke lengths of sprinters should be monitored carefully during their lactate tolerance and race-pace repeats to see that they are using stroke rates similar to those they use in competition.

An overdose of lactate tolerance and race-pace training should be suspected any time a sprinter's performance in competition or training declines over a period of several days. This is particularly true if the athlete is in the phase of the season when the volume and intensity of distance training has decreased while the volume and intensity of sprint training has increased. The solution to this problem is to decrease the volume and intensity of sprint training for several days and add additional recovery training to the schedule.

I should make it clear that swimmers need not restrict their training entirely to recovery swimming when failing adaptation may be occurring. Very short sets of lactate tolerance training can also be scheduled to gauge when the swimmer's sprint speed has returned. The athlete can do short power and lactate production sets to return their anaerobic power to its previous level.

Basic Endurance Training

I mentioned earlier that sprinters should train to increase their aerobic capacities, but not at the expense of their anaerobic power and aerobic or anaerobic muscular endurance. The best way to achieve this goal is to use basic endurance training. If performed near the aerobic threshold, basic endurance swimming will increase the aerobic capacity of sprinters' slow-twitch muscle fibers without involving their fast-twitch muscle fibers much. Reasonable amounts of basic endurance training should increase the aerobic capacity of their slow-twitch muscle fibers without slowing their contraction speed (Fitts, Costill, and Gardetto 1989; Troup, Metzger, and Fitts 1986).

One of the most important benefits of basic endurance training conducted early in the season is that it will allow sprinters to train more intensely later on. Basic endurance training will increase the quantity of glycogen stored in the muscles and the amount of fat that swimmers use for energy at slow to moderate training speeds. These changes will reduce dependence on muscle glycogen so that more will be available for use during intense swimming. Basic endurance training, because of its effects on the cardiovascular system, will shorten the recovery time required between intense training periods so that swimmers can accomplish a greater amount of quality swimming per session and per week. Additionally, basic endurance training can increase the amount of oxygen sprinters consume in their slow-twitch muscle fibers during races and thus reduce their rate of lactic acid production somewhat. More basic endurance training should be scheduled for the first half of the season, and the amount of that training should decrease to maintenance levels (one-third to one-half the usual early season volume) during the second half of the season as a safeguard against the detrimental effect it could have on sprint speed.

Sprinters should do a portion of their basic endurance training as pulling and kicking repeats and as off-stroke swimming. Off-stroke swimming, kicking, and pulling will be just as effective as swimming the main stroke or strokes in improving the ability of the respiratory and circulatory systems to deliver oxygen. To produce the desired adaptations in slow-twitch muscle fibers, however, swimmers must do some basic endurance training in their main stroke or strokes.

Threshold and Overload Endurance Training

Faster endurance training, at threshold and overload endurance speeds, will increase the oxygen consumption of fast-twitch muscle fibers while also increasing the amount of lactic acid that can be removed from those muscle fibers during races. But I must reiterate that too much fast endurance training may reduce a swimmer's maximum speed.

Threshold and overload training sets should be used sparingly with sprinters. They must be careful not to overdo threshold and overload endurance training. They do not want to increase the endurance of their fast-twitch muscle fibers at the expense of the strength, anaerobic power, and contraction speed of those fibers. They should be careful about maintaining a proper balance between the various categories of sprint and endurance training. They want to improve the endurance of their fast-twitch muscle fibers as much as possible without interfering with adaptations that will improve their contractile speed and force. The balance between endurance and sprint training will be quite different from the one suggested for distance swimmers because sprinters want to increase muscular power and the rate of anaerobic metabolism in all their muscle fibers, not simply maintain them. Another complicating factor is that too much sprint training, particularly training that produces severe and prolonged acidosis and muscle damage, can be just as detrimental to sprint speed as too much endurance training.

Repeat distances should be between 50 and 300 yd or m for most of the endurance sets for sprinters. They are able to maintain better stroke integrity with shorter distance repeats, whereas they tend to drop their elbows and shorten their upsweeps when they use long repeat distances for endurance training.

Mileage for Sprinters

The question of how much endurance mileage is too much for sprinters has no definite answer. A reasonable view is that, as with distance swimmers, 2 hr per day or more of this type of training, conducted over several months, might be needed to increase their aerobic capacity. Whether sprinters can engage in such a large volume of endurance training without reducing their speed is another matter. The best advice at this time is that sprinters should engage in as much basic endurance training as they can handle without seriously retarding their sprint speed and aerobic and anaerobic muscular endurance. For this reason, their speed in lactate production, lactate tolerance, and race-pace sets should be monitored closely. In addition, a close watch should be kept on their muscle glycogen levels so that they do not end up trying to swim sprint sets when that substance is depleted or nearly depleted. Scheduling additional recovery training sessions for sprinters each week should prevent this from happening, provided the athletes do not often attempt to swim their basic endurance sets too near their anaerobic threshold speed.

Maintaining a balance between endurance and sprint training is no simple task with sprinters. Coaches and athletes should probably err on the side of speed. Consequently, the most important question one must ask to determine the volume of endurance training for sprinters is, "Will the beneficial effects of that endurance training outweigh the potential reduction in sprinting speed it may cause?"

Where training for 50 sprints is concerned, the answer to this question is a resounding no. Swimmers take only two or three breaths during these short races; consequently, any increase in their maximum ability to consume oxygen would go unused. In addition, the small additional amount of lactic acid they could remove from their muscles after endurance training, perhaps 1 to 3 mmol within 20 to 30 sec, is probably negligible as far as improving their performance is concerned. Metabolically, athletes who specialize in 50 races should focus on improving sprint speed and muscle buffering capacity. The role of endurance training in their performance is inconsequential.

Sprinters do consume a substantial amount of oxygen, and they can remove a large amount of lactic acid from their muscles during 100 and particularly 200 events. Therefore, they must do more endurance training than sprinters who specialize in 50 events. Assuming an improvement in $\dot{V}O_2$max between 20% and 30%, which is the typical range of improvement with training, one could expect an increased consumption of 6 to 10 ml of oxygen per kg of body weight during the time it takes to swim a 100 event and an increase of perhaps 20 to 30 ml per kg during a 200 event. Estimated increases in the additional amount of lactate that could be removed from their muscles during 100 and 200 events are 3 to 5 mmol in the shorter event and 7 to 12 mmol in the longer event.

These increases in oxygen consumption and lactate removal may certainly improve a swimmer's time by the few 10ths of a second that could make the difference between winning and losing 100 races, provided it is not gained at the expense of a significant reduction in their sprint speed. The point I am trying to make is that although an increase in aerobic capacity is important for improving the performance of sprinters in 100 races, training for that purpose is secondary to maintaining and, if possible, improving their sprint speed. Consequently, 100 sprinters need to make sprinting speed the top priority in their training. Endurance training is important only to the extent that it improves their ability to increase aerobic capacity without interfering with their efforts in sprint training. Sprinters should try to improve their aerobic capacity without maximizing it because that attempt may lead to a loss of sprint speed and buffering capacity.

The increases in oxygen consumed and lactate removed are much more substantial in 200 races. Therefore, endurance training assumes a position of nearly equal importance to sprint training in these events. Sprinters should probably concentrate on improving their endurance during the early stages of the season. Then, during the latter portions of the season, they should maintain those gains and work to improve their sprinting speed and buffering capacity. Athletes who compete in 200 events need a delicate balance of sprint speed and endurance for 200 events. In the first half of the season, coaches must walk a fine line between increasing the aerobic capacity of these swimmers and maintaining their sprint speed. Later in the season, they must continue the balancing act by helping their swimmers maintain their endurance while increasing their sprint speed and buffering capacity.

Descending Sets

Descending sets are an effective way for sprinters to do endurance training. Sprinters should not do long basic or threshold endurance sets at constant speeds. Those methods of training may cause some glycogen depletion in their slow-twitch muscle fibers, forcing them to perform more of the work with energy from fast-twitch muscle fibers, even at slow speeds.

Descending endurance training down to fast speeds for short periods should be continued throughout the season. The goal at first is to increase the aerobic capacity of fast-twitch muscle fibers, in conjunction with basic endurance repeat sets. Later, descending endurance sets can help maintain the aerobic capacity of those fibers while swimmers concentrate on increasing anaerobic power and contractile speed.

Table 15.8 summarizes many of the suggestions that I have made in this section for training sprinters. The following sections will cover several other aspects of training sprinters.

Kicking

Sprinters need to do a good deal of endurance kicking because they need a strong six-beat kick in their races. They should do a sizable portion of that kicking in the form of basic endurance and threshold repeats. Sprinters, like middle distance and distance swimmers, tend to minimize their kicks during endurance swimming. Unlike middle distance and distance swimmers, however, they will not be minimizing their kicks during their races. Therefore, they need to develop the aerobic capacity of both the fast-twitch and slow-twitch muscle fibers in their legs. They should do 20 to 30 min of endurance kicking during most training sessions. Endurance kicking will also help increase the delivery of oxygen to their muscles and the removal of lactate from them by their respiratory and circulatory systems.

Table 15.8 Training Suggestions for Sprinters

TRAINING CATEGORY	EARLY SEASON	MID-SEASON	LATE SEASON
En-1	1–2 hr daily or more, 5–6 days/wk.	1–2 hr daily or more, 4–5 days/wk.	1 hr daily, 4–5 days/wk.
En-2	2 sets/wk.	2 sets/wk.	1 set/wk.
	plus descending down to threshold speeds and faster several times/week during basic endurance sets.		
En-3	1 or 2 sets/wk for 200 swimmers only.	Accomplished with race-pace training for the remainder of the season for all sprinters. Perhaps 2–3 sets/wk.	
Lactate production (Sp-1) and power (P)	3–5 sets/wk all year long, plus some short sprinting sets during most other training sessions.		
Lactate tolerance (Sp-2) and race-pace	1 set/wk for 50 and 100 swimmers.	1 major lactate tolerance set/wk for 50 and 100 swimmers, plus some short race-pace sets.	2–3 sets of race-pace swimming/wk for 50 and 100 swimmers.

Sprinters should also kick some lactate tolerance repeats to improve the buffering capacity of their leg muscles. The lactate tolerance swimming they do will help in this respect, but some additional fast kicking will be beneficial, particularly for those with weak kicks.

Sprinters can do some sprint kicking repeats of the lactate production type to improve their kicking mechanics and the rate of anaerobic metabolism in their leg muscles. They do not need to do many sets of this type, however, because they must kick fast when they swim their sprint sets. Those swimming repeats will contribute greatly toward improving the rate of anaerobic metabolism in their leg muscles.

Hypoxic Training

The programs of front-crawl, backstroke, and butterfly sprinters should include hypoxic training. This kind of training will allow front-crawl swimmers to take fewer breaths during their sprint races, and it will help backstroke and butterfly swimmers kick underwater for a longer distance after each turn. Swimmers do not need to do this kind of training often or for very long to obtain the desired effect. Athletes can improve their ability to tolerate the buildup of carbon dioxide with only 2 to 3 weeks of hypoxic training.

Athletes should begin swimming hypoxic repeats early in the season so that they can achieve the desired result before they begin major competitions. Once they begin swimming races in competition, they should use their improved tolerance to carbon dioxide buildup to condition themselves to take fewer breaths and spend more time kicking underwater. When freestyle sprinters can swim their races with the desired number of breaths and when backstroke and butterfly swimmers can kick underwater for the desired distance of each pool length, they no longer need to do hypoxic training.

Training Frequency

Swimmers who compete in sprint events should train as often as middle distance swimmers, but with less volume. Sprinters can profit from swimming twice daily if time and space is available for training. They should include more recovery swimming in their weekly schedules, however, because with a greater percentage of fast-twitch muscle fibers, they tend to deplete muscle glycogen faster and replace it more slowly. In addition, they incur acidosis more easily, which can lead to muscle damage. If sprinters include sufficient recovery training in their weekly programs, they will profit greatly from swimming twice daily. But they will lose speed and may become overtrained if the double training sessions heap on large volumes of endurance training.

Land Resistance Training

Heavy resistance training is more important to sprinters than it is to any other category of swimmers. That training must accomplish more than simply maintain innate muscular strength. Sprinters need to increase their muscular force because that will help them increase their swimming speed. Consequently, they need to engage in heavy resistance programs designed to improve muscular size and strength in all the muscle groups they use when swimming their main stroke or strokes. Sprinters should emphasize this training early in the season so that they have plenty of time to train their nervous systems to recruit those muscle groups before their major competitions take place.

Training for 50 Events

The training suggestions provided in the previous section apply primarily to swimmers who specialize in 100 yd or m events. Those who specialize in events of 50 yd or m or 200 yd or m need to make some modifications to those suggestions to maximize their performance. This section will describe those modifications for swimmers who compete in events of 50 yd or m. The section on middle distance training will discuss modifications for swimmers who specialize in events of 200 yd or m.

Good stroking, starting, and turning skills are necessary for 50 sprinters, as they are for all swimmers. Part I of this book covered those skills. This section is concerned with the physiological functions that are important to sprint swimmers who specialize in 50 events. From a physiological point of view, the principal goals for those sprinters should be the following:

- To increase muscular force so that they can apply more propulsive force
- To increase the rate of anaerobic metabolism so that they can apply that force at a faster rate and thus generate a greater average amount of power over the length of the race
- To increase muscle-buffering capacity so that the effect of declining muscle pH on the rate of anaerobic metabolism will decrease
- To increase tolerance to the buildup of carbon dioxide in tissues so that they can take fewer breaths during their races

Increasing aerobic metabolism plays only a minor role in improving performance in 50 races. Endurance training may improve the ability of swimmers to perform more sprint training with less fatigue. It may also improve their recovery from sprint training. But these effects, although important, should not compromise the goal of improving sprint speed.

For this reason, 50 sprinters should swim only small amounts of basic endurance training, most of it in the form of stroke drills, kicking, and pulling. The sprinters should swim at low to moderate speeds that approximate their aerobic thresholds, not their anaerobic thresholds. Basic endurance training will reduce the time they need for recovery without running the risk of slowing their sprint speed. They do not need to descend their basic endurance sets down to fast speeds because they have no need to improve the oxygen consumption of their fast-twitch muscle fibers. After all, they will be breathing only once or twice during their races. Therefore, basic endurance training should be the minimum necessary to improve stroke mechanics, other skills, and the recovery rate. That minimum has not been quantified, but my best guess is that 1 hr or less of daily basic endurance training would be adequate.

Swimmers who specialize in 50 events do not need to do any threshold or overload endurance training. They do not need to improve the aerobic capacity of their fast-twitch muscle fibers, and they certainly do not want to risk losing strength and contractile speed in those fibers.

Fifty sprinters do need to swim an adequate volume of lactate production and power repeat sets. The amounts of such swimming need not be greater in volume or frequency than the recommendations I made earlier in this section. The quality of their sprint training is much more important than its quantity.

Swimmers who specialize in 50 races should swim two to four lactate tolerance sets each week, but these should be much shorter than those I recommended for sprinters who compete in longer events. Short sets prevent the occurrence of an overdose of acidosis. Sets of 200 to 400 yd or m are adequate for this purpose. The purposes of this lactate tolerance training are to increase buffering capacity and to provide additional stimulation for improving muscular power.

Sprinters who specialize in 50 events should engage in some hypoxic training, and they should do some fast breath-holding sprints. Their goal should be to take no more than one or two breaths during a 50 yd or m sprint without feeling great distress.

Athletes who swim these short events do not need to train twice daily, but they can do so without detrimental effects. Training longer each day at a more leisurely pace may be preferable to trying to jam too much training into one practice session. For example, 50 specialists must take an adequate amount of rest between their resistance training exercises so that they can perform them with maximum force. They also need to make sure that the rest periods between their lactate production and power swimming repeats are sufficient to replace most of their creatine phosphate and eliminate much of the lactic acid from their muscles so that they can swim subsequent repeats faster. Only by swimming fast can they stimulate their rate of anaerobic metabolism to maximum levels. These suggestions for training 50 sprinters are summarized in table 15.9.

Training Programs of Successful Sprinters

The training programs of some of the most successful present sprinters have been described in various swimming periodicals, such as *Swimming Technique* and the *World Clinic Yearbooks* of the American Swimming Coaches Association. Drawing on these, I will describe the programs of Alexander Popov and Penny Heyns. I will also describe the training program of David Marsh, coach of Auburn University, because of the remarkable success he has had with sprinters.

Alexander Popov

Alexander Popov (Touretski 1994, 1997, 1998) of Russia is the current world-record holder for the 50 m freestyle at 21.64. He won both the 50 and 100 m freestyle at the 1992 and 1996 Olympic Games and was a finalist in both events at the 2000 Olympic Games. He won numerous World Championships in the 50 and 100 m freestyle, and many consider him one of the greatest sprint swimmers in the history of competitive swimming. Gennadi Touretski was his coach throughout his remarkable career of international victories.

Touretski uses seven levels of training. Table 15.10 lists those levels, the percentage race speed they represent, recommended training heart rates, and the blood lactates they produce.

Alexander has trained year-round for several years. His typical training year consisted of four cycles. Each of those cycles was 8 to 12 weeks in length and included four phases. An example of one training cycle is shown in table 15.11. The first phase was for general conditioning and lasted 1 to 3 weeks. Alexander swam approximately 8,000 m per day during this phase, or 40 to 50 km each week.

Next came an endurance phase of 3 to 4 weeks. He trained three times daily during this period covering between 80,000 and 100,000 m per week. He did this training in minicycles, each lasting 3 days, and he trained three times per day. He covered as much as 15,000 m daily for 2 days of each minicycle, followed by a day during which he trained twice and covered approximately 8,000 m.

Table 15.9 Training Suggestions for Sprinters Who Specialize in 50 Events

TRAINING CATEGORY	EARLY SEASON	MID-SEASON	LATE SEASON
En-1	1 hr daily, 5–6 days/wk.	1 or more hr daily, 4–5 days/wk.	1 hr daily, 4–5 days/wk.
En-2 and En-3	Not needed at any time during the season.		
Lactate production (Sp-1) and power (P)	3–5 sets/wk all year long, plus some short sprinting sets during most other training sessions.		
Lactate tolerance (Sp-2) and race-pace (R-P) training	1 or 2 short sets/wk throughout the season.		
Land resistance training	Increase muscular strength.	Increase muscular strength.	Increase muscular strength.

Table 15.10 Training Categories for Alexander Popov

TRAINING CATEGORY	SYMBOL	% RACE SPEED	HEART RATE*	BLOOD LACTATE MMOL/L
Low-intensity aerobic	A1	Up to 75%	120–140	1–3
Moderate aerobic	A2	75%–85%	140–160	1–3
Anaerobic threshold	AT	85%–95%	160–170	3–5
Maximal oxygen uptake	$M\dot{V}O_2$	85%–105%	180–190	5–10
Lactate tolerance	LT	90%–110%	190–200	8–15
Lactate production	LP	95%–110%	190–200	8–12
Alactic anaerobic (speed)	SP	110%–120%	160–170	3–6

*Heart-rate recommendations are based on a maximum heart rate of 200 bpm.
Adapted from Touretski 1997.

On the days he trained three times, the early session consisted of low- and moderate-intensity endurance training, the middle session contained a major anaerobic threshold set, and the final session was a $\dot{V}O_2$max set. Sprint training was also part of the daily schedule. Alexander did a large amount of threshold training compared with what most other sprinters in the world did. An example of one of his endurance training cycles is shown in table 15.12.

The endurance period was followed by 3 to 4 weeks of race-specific training. This period was composed of several 4-day cycles, during which he trained twice per day for 3 days and then had a recovery day. He covered approximately 12,000 m per day during the major training days and 4,000 m on the recovery days. Alexandre did little lactate tolerance training during this time, less than one set per week.

The typical pattern for these 4-day minicycles included morning sessions devoted to anaerobic threshold training on days #1 and #3. The morning session on day #2 was composed of low-and moderate-intensity aerobic training. The afternoon session was geared toward lactate production or lactate tolerance training on days #1 and #3, and the afternoon session of day #2 was used for recovery training. The single training session on day #4 was devoted to low- and moderate-intensity endurance training. Table 15.13 shows an example of one of his 4-day race-specific training cycles.

A taper phase of approximately 3 weeks followed the race-specific period, during which Alexander gradually reduced the volume of his work from 50 to 70 km per week to between 20 and 30 km weekly. Alexander engaged in altitude training two or three times during each year.

Touretski used a 2,000 swim for time to test for improvements in aerobic capacity and to establish times for threshold training. In addition, he used a swimming step test that included blood lactate testing to evaluate the balance between Alexander's aerobic and anaerobic training. The protocol for one such test was to swim 3 × 100 m, with 30 sec rest between swims, at low intensity (A1). A blood lactate reading was taken during a 3 min rest period following the third swim. Following that, Alexander swam 2 × 100 at threshold speed (AT) with 45 sec rest between swims. Another blood lactate reading was taken during a 3 min rest period after the second swim. Then he swam 1 × 100 at $\dot{V}O_2$max speed followed by another blood lactate sample. Alexander's stroke rates and heart rates were recorded for these swims, and the data on blood lactates and heart rate were plotted opposite his swimming velocity.

Some of the typical repeat sets that Alexandre swam at anaerobic threshold pace were 4 × 4 × 400 m on a send-off time of 5:30, alternating freestyle and backstroke, and

Table 15.11 Typical Training Cycle for Alexander Popov (Cycle Length is 8 to 12 Weeks)

		TRAINING SESSIONS		
CYCLE PHASE	DAILY CYCLE	MORNING	AFTERNOON	EVENING
General conditioning 1–3 wk	Daily	Low-intensity & moderate-intensity aerobic training; some sprinting. 4,000 m	Same as morning. 4,000 m	
Endurance phase 2–4 wk	Days 1 & 2	Low-intensity & moderate-intensity aerobic training; some sprinting. 4,000 m	An. threshold set. 6,000 m	Max $\dot{V}O_2$ set; some sprinting. 5,000 m
	Day 3	Low-intensity & moderate-intensity aerobic training; some sprinting. 4,000 m	Same as morning. 4,000 m	Off
Race-specific phase 2–4 wk	Days 1 & 3	An. threshold set. 5,000 m	Max $\dot{V}O_2$ set. 4,000 m	Sprinting. 3,000 m
	Day 2	Low-intensity & moderate-intensity aerobic training. 5,000 m	Sprinting. 3,000 m	Recovery. 4,000 m
	Day 4	Low-intensity & moderate-intensity aerobic training. 4,000 m	Off	Off
Taper & competition 1–3 wk		3,000–4,000 m	3,000–4,000 m	Off

Adapted from Touretski 1994.

8 × 400 m on the same send-off, alternating freestyle and backstroke. Some typical repeat sets for $\dot{V}O_2$max training were 2 × 8 × 100 m freestyle on a send-off time of 2:00 and 4 × (800 m at anaerobic threshold speed + 200 m at $\dot{V}O_2$max speed). A typical sprint set was 6 to 8 × 50 m on a send-off time of 2:00. Alexander swam the first four at speeds of 23+ to 24+ sec, and he performed the last two by kicking only. Alexander has been able to kick 50 m in 28.20. Another sprint set he swam frequently was 8 to 12 × 25 m with a send-off time of 30 sec. He was able to swim approximately 11:00 on each repeat with a stroke rate of 47 stroke cycles per min.

Alexander's land training consisted of 40 min of calisthenics and rowing machine exercises. He did not lift heavy weights.

Penny Heyns

Penny Heyns (Bidrman 1997, 1998, 2000) is a native of South Africa. She won the gold medal in both the 100 and 200 m breaststrokes at the 1996 Olympic Games. Her time for the 50 m LC breaststroke was 30.83, for the 100 m LC race, 1:06.52, and for the 200 m LC

Table 15.12 Three-Day Endurance Training Cycle for Alexander Popov

DAY	MORNING			AFTERNOON			EVENING		
1	Rowing machine			600 warm-up			400 warm-up		
	S	1,200 fr/bk	A1	S	6 × 100/1:30	A2	S	4 × 50/60	$M\dot{V}O_2$
		1,200 kick	A1	S	6 × 15 m/1:15	SP	S	100 easy	Rec
	S	1,200 free	A1	2,000 swim		AT	S	2 × 50/1:30	$M\dot{V}O_2$
	Land train—40 min			S	10 × 100/1:45	AT	P	1,200	Rec
				S	5 × 25/2	SP	S	6 × 50/:45 (30 m fast)	$M\dot{V}O_2$
				Swim-down 500		Rec	S	4 × 50/:50 (25 m fast)	$M\dot{V}O_2$
				Stretching—30 min			S	2 × 50/:60 (20 m fast)	$M\dot{V}O_2$
							Swim-down 600		Rec
2	Rowing machine			600 warm-up			400 warm-up		
		1,000 fr/bk	A1	S	12 × 50/:50	A2	K	4 × 100/1:45	A2
	K	1,000	A1	S	4 × 25/1:15	SP	P	4 × 150/2	A2
	S	1,000	A1	S	3 × 200/2:30	A2	S	400 free	A2
	Land train—40 min			S	3 × 200/2:45	AT	Repeat set twice		
				S	3 × 200/3:00	$M\dot{V}O_2$	S	300 fr/bk	$M\dot{V}O_2$
				S	1 × 200	LT	S	8 × 100/2 (15 fast + 70 easy + 15 fast)	SP
				Stretching—30 min			300 swim-down		Rec
3	Rowing machine			600 warm-up			Sauna		
	S	5 × 600/1	A2	S	5 × 400/5	AT			
	S	5 × 50/3	LP	S	5 × 400/5:30	$M\dot{V}O_2$			
	Stretching—30 min			Massage					

Adapted from Touretski 1998.

breaststroke, 2:23.64. Jan Bidrman, a native of Czechoslovakia, who is working in Calgary, Canada, at the time of this writing, has been her coach.

Penny's yearly training plan for the 1995–96 season included a short-course season that lasted from September to April and a long-course season that began in early April and ended with the Olympic Games. Each season had four phases: an aerobic period, an anaerobic period, a pretaper period, and a taper period. Table 15.14 outlines Penny's yearly training program. She did some altitude training each year when she returned to her home in Johannesburg, South Africa.

The aerobic period lasted 12 weeks during the short-course season and 6 weeks during the long-course season. She trained 9 sessions each week with morning workouts on Monday, Wednesday, Friday, and Saturday and afternoon workouts on Monday through Friday. Her weekly mileage was between 55,000 and 65,000 yd or m per week. Basic endurance swimming made up most of her training mileage, but she swam three threshold sets, one overload endurance set, one lactate tolerance set, and two lactate production or power sets each week. An example of her weekly plan during the aerobic period is shown in table 15.15.

Table 15.13 Four-Day Race-Specific Training Cycle for Alexander Popov

DAY	MORNING		AFTERNOON		EVENING	
1	Swim 2,000 (300 fr/bk 200 IM)	A1	600 warm-up		1,200 warm-up	
	Pull 1,500	A1	S 4 × 100/1:30	AT	Swim 4 × 50/3	LP
	Kick 10 × 100/2	A2	S 200 drill	Rec		
	Swim 4 × 25	SP	Swim 2 × 50	SP		
			S 2 × 400/5:30	AT		
			S 2 × 100/1:30	M$\dot{V}O_2$		
			Repeat set			
			S 10 × 50/:50	Rec		
2	600 warm-up		600 warm-up		600 warm-up	fr/bk
	#1, 3, 5 fr/bk		S 2 × (400 AT + 100 M$\dot{V}O_2$)		S 8 × 25 IM	Rec
	#2, 4 kick	A2	1,200 k/pull	Rec	S 2,000 w/fins	Rec
	S 20 × 100/1:45	AT	S 4 × 25	SP	Massage	
	S 2 × 50 DPS	SP				
3	Technique 90 min	Rec	200 warm-up		Warm-up	
			S 8 × 25	SP	S 6 × 50/2	LP
			8 × 100 kick	A2	600 swim-down	Rec
			8 × 100 pull	A2		
			8 × 100 fr/bk	A2		
			S 8 × 25	SP		
			200 swim-down	Rec		
4	Swim 1,200	Rec	Massage		Sauna	
	Kick 800	Rec				
	Pull 1,000	Rec				
	30 min of land training					

S = Swim

Adapted from Touretski 1994.

Table 15.14 Yearly Training Program for Penny Heyns

SEASON PHASE	SHORT-COURSE SEASON	LONG-COURSE SEASON
Aerobic	12 weeks	6 weeks
Anaerobic	6 weeks	5 weeks
Pre-taper	2 weeks	2 weeks
Taper	3 weeks	4 weeks

Adapted from Bidrman 2000.

Most of her threshold sets were swum freestyle or with a mixture of competitive strokes. They were between 2,000 and 3,000 yd or m in length. She rarely swam breaststroke during threshold sets. Overload endurance sets were between 1,000 and 2,000 yd or m, and much of that distance was breaststroke. Lactate tolerance sets, also swum breaststroke, were generally 1,000 to 1,200 yd or m. Lactate production sets were generally 300 to 500 yd or m in length. She completed those sets in combinations of breaststroke swimming, kicking, and pulling.

The anaerobic period was 6 weeks long during the short-course season and 5 weeks long during the long-course season. She continued training for nine sessions weekly, continuing to emphasize basic endurance training. The amount of threshold training decreased, however, and the number of lactate tolerance sets increased to three per

Table 15.15 Weekly Training Plan for Penny Heyns During the Aerobic Phase of the Season

DAY	AM	PM
Monday	En-1 drills	En-2
Tuesday	Off	En-3
Wednesday	En-1 and sprints	En-1 drills
Thursday	Off	Lactate tolerance, En-2, and drills
Friday	En-1, descending sets, and drills	En-1, descending sets, and sprints
Saturday	En-1, En-2, and drills	Off

Adapted from Bidrman 1997.

week. The number of combined lactate production and power sets also increased to three per week. These included swimming on a Power Rack and performing combinations of sprint-assisted and sprint-resisted training using surgical tubing for resistance and assistance. She did several series of 12 to 24 × 25 yd or m weekly in conjunction with 10 m sprints on the Power Rack. Penny did most of these sprint sets in combinations of breaststroke swimming, kicking, and pulling. Weekly mileage was between 40,000 and 50,000 yd or m. Table 15.16 provides an example of her weekly schedule during the anaerobic period.

The pretaper period lasted 2 weeks. Her training was similar to that of the anaerobic period except that her daily mileage and the length of her anaerobic sets decreased to provide additional recovery time. The taper period lasted 3 or 4 weeks.

The following were some of her favorite overload endurance sets:

- 10 × 100 breaststroke on a 1:45 send-off time.
- 3 × 8 × 50 breaststroke on send-off times of 55, 50, and 45 sec with an easy 100 swim between sets.
- 12 × 75 breaststroke kick on a 1:40 send-off time.
- 3 × (200 on 3:20, 150 on 2:30, 100 on 1:40, and 50 on 0:50). She kicked breaststroke on set #1, pulled breaststroke with zoomers and paddles on set #2, and swam breaststroke on set #3.

Table 15.16 Weekly Training Plan for Penny Heyns During the Anaerobic Phase

DAY	AM	PM
Monday	En-1, drills, and descending sets	En-1, En-3, and lactate tolerance
Tuesday	Off	En-1 and drills
Wednesday	En-1, sprints, and drills	En-1 and lactate tolerance
Thursday	Off	En-1 and drills
Friday	En-1, sprints, descending sets, and drills	En-1 and lactate production
Saturday	En-1 and drills	

Adapted from Bidrman 1997.

The following were some of her favorite lactate tolerance sets:

- 3 × 4 × 100 breaststroke on a 2:30 send-off time. Each set was faster than the one before it, and she swam 200 yd after each set.
- 4 × 175 breaststroke on a send-off time of 4:30. She descended the set to her goal time for the 200 race.
- 2 × 10 × 50. She kicked the first set breaststroke on a send-off time of 1:30. Penny held times of 35 to 36 sec. She pulled breaststroke on the second set on a send-off time of 1:20. She held times of 29 to 30 sec using zoomers and paddles.

The following were some of her favorite lactate production sets:

- 12 × 25 breaststroke on a send-off time of 45 sec, swimming 12.5 m fast and 12.5 m easy.
- 3 × (4 Power Rack swims on a 1 min send-off time followed by 2 × 25 breaststroke sprints from a dive on a 1:00 send-off time).
- 10 × 50 breaststroke on a send-off time of 3:00, all from a dive.
- 3 × 8 × 25 on a send-off time of 1 min. She swam set #1 freestyle with zoomers and paddles. On set #2, she pulled breaststroke, again with zoomers and paddles. She swam breaststroke on set #3.

Weight training played a big role in Penny's training program. She began lifting weights during the aerobic period of each season. She lifted weights 4 days each week, emphasizing power training on Monday and Thursday. Exercises included squats, cleans, and power presses. She generally performed each exercise for three sets of 5 repetitions. She did circuit training on Tuesday and Friday using standard large-muscle exercises such as curls, lat pulls, and sit-ups. She generally performed two sets of 10 repetitions.

Her weight-training program remained the same on Monday and Thursday during the next 4 weeks, but the circuit training was less intense on Tuesday and Friday. She took more rest between exercises and lifted lighter weights.

Power continued to be the emphasis on Monday and Thursday during the next weight-training cycle, which lasted 3 weeks. She performed more squats and plyometric training on Monday and Thursday and reduced the intensity to maintenance levels on Tuesday and Friday. She stopped lifting weights 4 weeks before the Olympic Games.

Penny had fantastic performances for a year and a half following her Olympic victories. She broke world records in the 50, 100, and 200 m breaststrokes on 11 different occasions from May 1998 to August 1999. The major difference in her training between this period and her Olympic preparation had to do with her basic endurance mileage. Bidrman stated that Penny was often tired and broken down during the Olympic year because she did most of what had been labeled basic endurance mileage at or near her anaerobic threshold. She reduced her training intensity to true basic endurance speeds during the period following the Olympic Games. She was instructed to swim most of her basic endurance mileage at an intensity that produced a heart rate 50 beats below maximum. Because her maximum heart rate was 200 bpm, she did most of this swimming at a heart rate of 150 bpm or less.

Penny also included Olympic lifts in her weight-training program for the first time during her post-Olympic training period. She did hang cleans, rhythm squats, and box squats in addition to military presses, bench presses, seated rowing, squats, and lat pull-downs. She did three sets of each exercise with 5 to 10 repetitions per set.

David Marsh: Auburn University Sprint Training Program

I have chosen to describe the sprint training program of Coach David Marsh (Marsh 1997) of Auburn University because that program has produced so many outstanding sprint swimmers in recent years. At the time of this writing, Auburn has won three

NCAA National Championships, largely on the strength of their sprinters. In addition, they set NCAA records for several sprint relays, including the 200 yd freestyle relay at 1:16.63, the 400 yd freestyle relay at 2:50.90, and the 200 yd medley relay at 1:25.24.

The typical short-course swimming season was 26 weeks long at Auburn University. Power training was emphasized, both in the water and on land. In sprint training, close attention was paid to swimming at and beyond race stroke rates and race speeds. The swimmers trained for nine sessions per week, swimming twice per day on Monday, Tuesday, Thursday, and Friday, and once on Saturday. They took Wednesday and Sunday off.

Auburn University used six categories of training. Table 15.17 lists the categories, along with the heart rates and blood lactate levels they were expected to produce. During a typical midseason week, the athletes swam two anaerobic threshold sets, three lactate tolerance sets (two swimming and one kicking), and four lactate production or power sets. Table 15.18 shows a typical midseason weekly training plan for Auburn.

Heavy resistance training played a major role in the training program of Auburn sprinters. That training was cycled throughout the entire season, beginning with a general conditioning phase during the first 3 weeks when the swimmers used circuit training with light weights and many repetitions. The next phase was 6 weeks of strength training using heavy weights and few repetitions, that is, three sets of 5 to 10 reps. The next 6 weeks were devoted to power training, during which the swimmers performed Olympic lifts at fast speeds. Plyometrics were emphasized during the final 4 weeks of the season. The lifting program was reduced to maintenance levels during this time.

Training Middle Distance Swimmers

I define middle distance swimmers as those who specialize in events between 200 yd or m and 400 m or 500 yd in length. Some of these athletes may extend their range up to the distance events of 800 m, 1,000 yd, 1,500 m, or 1,650 yd, but their performance will not be at the same standard. Others may compete in 100 yd or m events, but again, their performance will not be up to the standards they achieve at race distances of 200 yd or m or 400 m or 500 yd. My definition of middle distance swimmers also includes butterfly, backstroke, and breaststroke swimmers whose best event is 200 yd or m. These swimmers may also compete in 100 yd or m events, but they are clearly superior in the longer events and cannot be considered sprinters. Athletes who swim both the 200 and 400 yd or m individual medleys also fall into the middle distance group as far as training is concerned.

Table 15.17 Training Categories for Auburn University Sprinters

TRAINING	EXPLANATION	HEART RATE BPM	BLOOD LACTATE MMOL/L
Low-aerobic	Short rest interval and continuous swimming	<130	<2
Mid-aerobic	Short rest interval swimming	130–150	1–3
Threshold	Rest interval swimming with 10–30 sec rest	150–170	3–6
Lactate tolerance	Long rest interval training	>180	6–12
Peak lactate	Very long rest interval training	Maximum	Maximum
ATP-CP	Short sprints with long rest periods	N/A	1–5

Adapted from Marsh 1997.

Table 15.18 Sample Midseason Weekly Training Cycle for Auburn University Sprinters

DAY	AM	PM
Monday	Low aerobic swim, mid-aerobic for 1 hr; 5,000 m LC	Lower body weights and plyometrics kick; short threshold set (1,000 m) with short distance repeats of 75–125 m; low aerobic pulling set, 2,000 yd in length; turns; all training SC
Tuesday	Upper body weights and plyometrics for 1 hr; 20 min of 25 and 12.5 yd sprints; all training SC	Lactate tolerance set (12 × 50/2); hypoxic pulling for 2,000 yd; relay starts and short sprints; all training SC
Wednesday	Off	Off
Thursday	Low aerobic swimming; threshold set (20 × 100/with 20–30 sec rest); 6,000 m; all LC	Lower body weights and plyometrics for 1 hr; mid-aerobic sets (12 × 200 pulling and swimming); lactate tolerance kicking set (8 × 35/3:00); all training SC
Friday	Upper body weights and plyometrics for 1 hr; 20 min of short sprints	Low aerobic drill and swim set; mid-aerobic pulling set; starts, turns and sprints; all training SC
Saturday	Mid-aerobic kick/swim set; lactate tolerance set (1 × 200, 1 × 150, 2 × 100, 4 × 50) all on a base send-off of 3:00 per 50 yd; SC training	Off

Adapted from Marsh 1997.

Physical Makeup

Swimmers who specialize in middle distance events will generally have highly developed aerobic capacity and better than average anaerobic power because of various aspects of their physiological makeup. They will probably have approximately equal percentages of fast-twitch and slow-twitch muscle fibers, or the concentration of the latter fiber type may be slightly higher. In part, this combination of aerobic and anaerobic abilities provides middle distance swimmers with the endurance to swim at a fast average pace for 2 to 5 min.

Middle distance swimmers will generally not have the explosiveness of sprinters, but their sprint speed will be adequate for taking their races out at a competitive pace and bringing them home with a strong finishing kick. In addition, they will have the potential to develop their buffering capacity to withstand the rapid accumulation of lactic acid that inevitably occurs in these races.

Middle distance swimmers can perform well in both endurance and sprint training. But they will not be able to train as distance swimmers do on a daily basis because most middle distance swimmers have a somewhat higher percentage of fast-twitch muscle fibers than most distance swimmers. As a result, they will generally deplete their muscle glycogen faster during endurance repeats, particularly those that they swim at threshold and overload training speeds, and they will require more recovery time during each training week to replace the energy in their muscles.

Athletes in middle distance freestyle events may use six-beat kicks or some reduced kicking rhythm such as a two-beat or four-beat kick. A strong kick is an advantage but not a necessity for success in these events, because freestyle swimmers relax their kick during most of the race. Nevertheless, all middle distance freestyle swimmers should train to use a strong six-beat kick over the final 50 yd or m of their races. Unlike freestylers, butterfly, backstroke, and breaststroke middle distance swimmers should have reasonably strong kicks because kicking is so important to success in their events.

Training Suggestions

Middle distance swimmers need to develop their aerobic capacity to a high level with endurance training. They should achieve this during the first two-thirds of their seasons, even if anaerobic power and anaerobic muscular endurance suffer somewhat because of the large volume of endurance training they engage in. These swimmers should train to maintain their newly developed aerobic capacity during the final one-third of their season, while concentrating on improving both their buffering capacity and their anaerobic power.

Middle distance swimmers should limit their attempts to increase swimming speed to improving their stroke techniques. The volume of endurance work they need to perform probably precludes any training-induced increase in their innate anaerobic power. The best they can hope for is to keep their rate of anaerobic metabolism near normal during the phases of the season when they emphasize endurance training and then return them to normal during the latter portion when the emphasis shifts toward lower mileage and more race-pace training.

Middle distance swimmers have no need to do lactate tolerance training unless they also compete in 100 yd or m events. The combination of overload endurance and race-pace training will be adequate for increasing their buffering capacity.

Endurance Training

Middle distance swimmers should do 2 or more hours of basic endurance training daily for 5 or 6 days of every week during the first half of the swimming season. Training at that level, because fat metabolism provides more energy, will improve the aerobic capacity of their slow-twitch and low-threshold FTa muscle fibers without depleting them of muscle glycogen. Basic endurance training will also increase the delivery of oxygen by their circulatory and respiratory systems. I recommend combinations of long swims and short-rest interval repeat sets for basic endurance training.

Athletes who specialize in middle distance events should swim some combination of three to four threshold and overload endurance sets each week during the first half of the season so that they can also improve the aerobic capacity of their high-threshold FTa and FTb muscle fibers. The frequency and duration of these repeat sets should be scheduled carefully to prevent complete emptying of muscle glycogen supplies. Threshold endurance repeat sets should be scheduled within a few weeks after training begins for each new season, and overload endurance sets should begin a few weeks after that. The volume of threshold endurance swimming should exceed the volume of overload endurance training by a considerable amount during the first half of the season. During this time, most of the training aimed at improving the aerobic capacity of FTb muscle fibers should be achieved by descending the last few repeats down to fast times on some of the basic and threshold endurance sets.

The quantity of threshold endurance training should decrease during the second half of the season, and the volume of overload endurance and race-pace training should increase. The number of overload and race-pace sets should increase to two or three weekly. The overload endurance repeat sets should be 1,000 to 2,000 yd or m in length. Most of the race-pace sets should be in the form of underdistance repeats and broken swims. The length of each set of race-pace repeats should be one to two times the race distance for which an athlete is training. The swimmer can repeat several such sets during one training session. In addition, most training sessions should include some swimming at overload endurance and race-pace by continuing to descend basic endurance sets down to fast speeds.

As I indicated earlier, swimming overload endurance and race-pace repeats will also improve muscle-buffering capacity because of the acidosis produced at those fast speeds.

Consequently, one or two recovery training sessions should be included in the weekly plan for middle distance swimmers because they will be suffering severe acidosis and possible muscle glycogen depletion more frequently. Within a particular training session, short recovery sets should also follow overload and race-pace repeat sets.

Swimmers can perform a portion of the basic endurance training with off strokes and with pulling and kicking because nonspecific basic endurance training will improve the respiratory and circulatory systems as well as specific training does. But athletes should swim some of that mileage in their main stroke or strokes. Middle distance swimmers should perform all of their overload endurance and race-pace training in their main stroke or strokes because the main purpose of that training is to improve the aerobic capacity of individual muscle fibers.

Middle distance swimmers who compete in freestyle events need to develop a strong six-beat kick for the finish of their races. Therefore, they should include some fast kicking sets in their schedule, perhaps once every week. They should make it a habit to swim the last 50 yd or m of each repeat set with a strong six-beat kick.

Butterfly, backstroke, and breaststroke swimmers who specialize at the 200 distance will need to do a high volume of endurance kicking in their main styles at both basic endurance and threshold endurance speeds each week. This training, added to the stimulus their legs will receive during overload endurance and race-pace swimming, should be adequate to improve the aerobic endurance and buffering capacity of their leg muscles. I recommend that all middle distance swimmers, both freestyle and stroke specialists, include 1,000 to 2,000 yd or m, or 20 to 30 min, of endurance kicking in most of their training sessions.

Sprint Training

Middle distance specialists should swim three to five major lactate production sets during each training week. The purpose of this training is to reduce the loss of anaerobic power throughout most of the season. Training of this type will also help them regain their normal form when they reduce their training mileage later in the season.

Table 15.19 summarizes my suggestions for training middle distance swimmers.

Land Resistance Training

Middle distance swimmers should probably do some land resistance training throughout each season. The purpose of that training is to maintain muscular strength and power, not increase them. As with distance swimmers, the volume of endurance training that middle distance swimmers must do probably precludes any significant increases in strength and endurance. Additionally, the intensity of a comprehensive weight-training program aimed at increasing muscle size and power would probably interfere with the athletes' ability to tolerate the volume and intensity of swimming training they need to be successful in their events. Consequently, land resistance training programs should probably incorporate a design that seeks only to maintain muscle size and strength.

Training for 200 Events

Athletes who specialize in 200 events need to improve their aerobic capacity to a high level. Unlike swimmers who specialize in the 50 and 100 events, they need to increase the aerobic capacity of their fast-twitch muscle fibers, even if the rate of anaerobic metabolism slows and they lose some contractile speed and force in those fibers. They also need to concentrate on improving the buffering capacity of all fibers by swimming some overload endurance and race-pace repeat sets. They do not need to swim lactate tolerance repeats because overload endurance and race-pace swimming will increase the buffering capacity of their muscle fibers adequately while also improving the aerobic capacity of their fast-twitch muscle fibers.

To strike a balance between endurance and sprint training, athletes who specialize in 200 events should emphasize improving aerobic capacity during the first half of the season and emphasize improving buffering capacity and sprinting speed during

Table 15.19 Training Suggestions for Middle Distance Swimmers

TRAINING CATEGORY	EARLY SEASON	MID-SEASON	LATE SEASON
En-1	2 or more hr daily, 5–6 days/wk.	2 or more hr daily, 3–4 days/wk.	1–2 hr daily, 3–4 days/wk.
En-2	2–3 sets/wk plus descending down to threshold speeds and faster several times per week during basic endurance sets.	1–2 sets/wk. Swimmers should continue descending down to their threshold endurance speeds near the end of their basic endurance sets.	1 set/wk.
En-3 and race-pace	1 set/wk plus descending down to these speeds several times each week during basic and threshold endurance sets.	2–3 sets/wk plus descending down to these speeds during some basic endurance repeat sets.	2–3 sets/wk. The sets should be shorter than they were during the previous phase, however.
Lactate production and power	3–4 sets/wk. all year long, plus some short sprinting sets during most other training sessions.		
Lactate tolerance	1 major set/wk only if the swimmer is also competing in 100 yd/m events.	Replaced with race-pace training for the remainder of the season.	

the second half. In addition, they should do enough sprint training in the first half of the season to prevent serious loss of buffering capacity and sprint speed, and they should do enough endurance training during the second half of the season to maintain aerobic capacity. During the first half of the season the objective is to balance the endurance and sprint training of 200 swimmers so that they will experience only a temporary reduction in anaerobic power and muscle contractile speed and be able to regain normal levels during the second half of the season. Similarly, during the second half of the season the balance between sprint and endurance training should allow for improvement in speed and buffering capacity without a significant reduction in endurance.

Sprinters who specialize in 200 events should swim a minimum of 2 hours of basic endurance training per day during the first half of the swimming season to increase their aerobic capacity. They should swim some combination of three to four threshold and overload repeat sets per week and descend their basic endurance sets down to threshold and overload speeds during most training sessions. They should swim major lactate production sets during four to five sessions of each week to maintain their swimming speed. In addition, they should swim some additional short sprint sets during most of their other training sessions.

The number of threshold sets should decrease to one or two per week during the second half of the season. These sets should be shorter in length, perhaps only 1,200 to 2,000 yd or m, and swimmers should continue to descend many of their basic endurance sets down to threshold levels so that they can maintain the improvement of aerobic capacity they made earlier. During the second half of the season, race-pace training should replace overload endurance repeats. Swimmers should perform race-pace sets two or three times per week. The goal of these sets is to maintain the aerobic capacity of fast-twitch muscle fibers and increase the buffering capacity of all muscle fiber types.

During weeks when competitions occur, races can substitute for race-pace repeats so that athletes will not overdo this type of training. The race-pace sets for 200 swimmers

Table 15.20 Training Suggestions for Sprinters Who Specialize in 200 Events

TRAINING CATEGORY	EARLY SEASON	MIDSEASON	LATE SEASON
En-1	2 or more hr daily, 5–6 days/wk.	2 or more hr daily, 4–5 days/wk.	1–2 hr daily, 4–5 days/wk.
En-2 and En-3	3–4 sets/wk plus descending down to threshold speeds and faster several times per week during basic endurance sets.	1–2 sets/wk. En-2 only. These sets should be shorter than they were during the early season. Swimmers should continue descending down to threshold endurance speeds near the end of their basic endurance sets. Overload endurance training should be replaced with race-pace training for the remainder of the season.	1 set/wk.
Lactate production and power	3–5 sets/wk all year long, plus some short sprinting sets during most other training sessions.		
Lactate tolerance	1 major set/wk.	Replaced with race-pace training for the remainder of the season.	
Race-pace training		2–3 sets weekly for the remainder of the season.	

should be five to six times longer than their races in competition. The volume of lactate production training should stay at the level recommended for the first half of the season. These suggestions for training sprinters who specialize in the 200 distance are summarized in table 15.20.

Training Programs of Successful Middle Distance Swimmers

This section describes the training programs of Susan O'Neil and Mike Barrowman. O'Neil specialized in the 200 m butterfly, and Barrowman specialized in the 200 m breaststroke, although both swimmers also competed in 100 events.

Susan O'Neill

Susan O'Neill (Volkers 1997, 1998) of Australia was the gold medal winner in the 200 m butterfly at the 1996 Olympic Games in a time of 2:07.76. She won the silver medal in this event at the 2000 Olympic Games, where she also won the gold medal in the women's 200 m freestyle. Scott Volkers of the Commercial Swim Club in Queensland, Australia, was her coach.

Susan's training mileage varied between 40,000 and 50,000 m per week, and she trained for 10 sessions each week. She trained twice daily on Monday, Tuesday, Thursday, and Friday, and once daily on Wednesday afternoon and Saturday morning. She rested on Saturday afternoon and all day on Sunday. Volkers was conscious of including several levels of training in her weekly schedule and interspersing these with adequate recovery periods.

Volkers used five levels of training intensity: aerobic recovery, aerobic, anaerobic threshold, anaerobic, and critical velocity. These training levels are defined in table 15.21, along with examples of Susan's expected times, heart rates, and blood lactate concentrations at each level.

Susan's typical weekly cycle included one threshold set, which she usually did on Monday morning. She swam heart-rate sets twice each week, during afternoon sessions. Two lactate tolerance sets were also scheduled each week, during afternoon training. Susan swam a major sprint set on Saturday morning. Two training sessions were devoted to low-intensity aerobic training and recovery each week. Table 15.22 presents an example of Susan's weekly training cycle.

Table 15.21 Training Categories for Susan O'Neill

TRAINING CATEGORIES	TRAINING PARAMETERS	
Aerobic recovery	Times/100	<1:11 freestyle
	Heart rate in bpm	<164
	Blood lactate in mmol/L	<2.0
Aerobic	Times/100	1:09–1:15 freestyle
	Heart rate in bpm	164–180
	Blood lactate in mmol/L	1.8–2.8
Anaerobic threshold	Times/100	66–68 butterfly w/fins
	Heart rate in bpm	181–185
	Blood lactate in mmol/L	2.9
Anaerobic	Times/100	>66 butterfly
	Heart rate in bpm	>185
	Blood lactate in mmol/L	>2.9
Critical velocity	Times/100	63.5 butterfly
	Heart rate in bpm	205
	Blood lactate in mmol/L	6.9

Adapted from Volkers 1997.

Table 15.22 Weekly Training Plan for Susan O'Neill

DAY	AM	PM
Monday	Anaerobic threshold training Example set: 7 × 300/5:15 This set was swum butterfly with fins. 5,000–6,000 m	Lactate tolerance training LC. Example set: 6 × 100/8, swum butterfly. Susan has averaged 61.+ on this set. Some lactate production repeats were also done. 5,000 m
Tuesday	Land training, including weights and calisthenics. Susan also runs 7 km followed by 500–700 m of easy swimming.	Heart rate set. Basic endurance training in the form of swimming, kicking, and pulling drills. 6,000 m
Wednesday	Off	Aerobic training in the form of swimming, pulling, and kicking drills. Main set at 3,000 m or more. 6,000–7,000 m
Thursday	Same as Tuesday morning.	Lactate production training. Main set is 800 m in length. 5,000 m
Friday	Recovery, drills, and fin kicking. 5,000 m	Heart rate set. Basic endurance training. 5,000–6,000 m
Saturday	Land training. Lactate production and power training. 4,000 m	Off

Adapted from Volkers 1998.

Her low-intensity aerobic training consisted of swimming, pulling, and kicking drills. She did much of her aerobic kicking with fins. A typical anaerobic threshold set was 7 × 300 butterfly on a send-off time of 5:15. She swam this set with fins.

Susan's heart-rate sets were generally 2,000 to 3,000 m long, swum in a descending manner. She swam most, if not all, of these sets with the butterfly stroke. She did the first quarter of each set at an intensity 30 beats below her maximum heart rate, the next quarter at an intensity 20 beats below maximum, the third quarter at an intensity 10 beats below maximum, and the last quarter at maximum speed. Two examples of her heart-rate sets follow:

Set 1
5 × 100/1:40 max HR—30 bpm
1 × 200/3 (first 100 at the speed of five previous 100s and the last 100 at the same speed or faster)
1 × 50 easy/1
5 × 100/1:50 max HR—20 bpm
1 × 200/3 (swum in the same manner as the previous 200)
1 × 50 easy/1
5 × 100/2:00 max HR—10 bpm
1 × 200/3 (swum in same manner as the previous 200s)
1 × 50 easy
Set 2
3 × 200/3 max HR—30 bpm
100 easy/2
6 × 100/1:50 max HR—20 bpm
100 easy/2
6 × 100/2 max HR—10 bpm
100 easy
1 × 100/2 maximum effort

Her lactate production and power sets were combinations of 12.5, 25, and 50 m sprints.

Volkers used a descending set of 7 × 200 freestyle on a send-off of 5 min to test for improvements in aerobic and anaerobic performance and to establish training times for her aerobic repeats. Volkers monitored Susan's heart rate, blood lactate concentration, stroke rate, and stroke count per 50 m on this set.

A descending set of 6 × 50 m butterfly on a 2:00 send-off was used to evaluate Susan's stroke efficiency. Volkers monitored her stroke rate, stroke count, and distance per stroke on this set and from this data determined the best combination of stroke rate and stroke count for her to use when swimming the 200 m butterfly in competition. He also had her swim a set of 4 × 50 m butterfly on a send-off time of 1:30 every day during her taper. He estimated her rate of recovery from this set by comparing her stroke rate and her distance per stroke to her previously determined ideal levels.

Susan performed her land training program in three 9-week cycles per season. Each of these 9-week cycles was divided into three 3-week minicycles. She spent the first 3 weeks of each 9-week cycle lifting heavy weights to gain muscular strength. She focused on power training during the next 3 weeks by lifting weights at fast speeds. She devoted the final 3 weeks of each cycle to circuit training aimed at improving her aerobic and anaerobic muscular endurance. She did no weight training during her taper. Susan also ran 7 km on each of two mornings during the week to improve the endurance of her leg muscles. She did her primary weight-training sessions on Tuesday and Saturday mornings. On Thursday morning she did 30 min of stretching followed by calisthenics exercises specially designed to improve the muscles of her trunk and limbs. She continued this calisthenics program until 2 days before major meets.

Mike Barrowman

Mike Barrowman (Nagy 1994) of the United States won the gold medal for the 200 m breaststroke at the 1992 Olympic Games. He holds the world record of 2:10.16 in that event. He attended the University of Michigan, where he trained under Jon Urbanchek during the school year. He competed for the Curl-Burke Swim Club during the long-course season, when Jozsef Nagy was his coach. The following section describes the training that he did under Nagy for the final 11 weeks before the 1992 Olympic Games.

Mike trained 11 sessions per week. He trained twice per day on Monday through Friday and once on Saturday morning. He did most of his training in a 25 yd pool. He completed only 10 long-course training sessions during this period and did no altitude training.

He typically swam between 6,500 and 7,500 yd per training session, most with breaststroke. In addition, he did a great deal of his remaining training yardage with breaststroke pulling and kicking drills. He frequently pulled breaststroke with small hand paddles. He did not use a pull-buoy, and Nagy permitted him to take only one dolphin kick per stroke cycle during pulling drills. Mike also did a large quantity of breaststroke kicking, much of it without using a kickboard.

A typical endurance repeat set was the following:

8 × 4 × 100/1:40

10 × 200 freestyle/2:30

3 × 300 (alternating 100 breaststroke swim, 100 breaststroke pull, and 100 breaststroke swim on each 300). The send-off was generally set to allow him 30 to 40 sec rest between repeats.

2 × 400 (alternating four breaststroke cycles on the surface and four breaststroke cycles underwater)

One of his favorite sprint sets was 8 × 50 on a send-off time of 1 min, during which he tried to hold times equivalent to the time he hoped to swim during the final 50 m of his goal 200 race. To simulate the conditions of the race, he usually did this set at the end of a training session when fatigued.

Mike's taper was 2 weeks in length, but he continued doing some very intense training up to 8 days before the Olympic Games. Table 15.23 shows examples of four different training days: an early season training day, a midseason training day, a training day at the beginning of his taper, and a training day in the middle of his taper.

Mike did 30 to 60 min of land training 6 days each week during his peak training period. He did not lift weights. Instead, he used stretch cords and an intense medicine ball circuit combined with squat jumps and stretching. The quantity and length of his land training decreased to 2 days per week and 30 min per day 3 weeks before the start of the Olympic Games. His last land training session occurred 8 days before his Olympic swim.

Additional Training Suggestions for Backstroke, Butterfly, and Breaststroke

Because so many of the training adaptations that improve endurance and speed reside in the muscle fibers, swimmers must train in their main stroke for a significant amount of time during each season. Consequently, they should do more than half their training mileage in their specialty during the second half of the swim season, carrying out that training for all energy systems. Athletes can do freestyle swimming in many, but not

Table 15.23 Sample Daily Training Sessions for Mike Barrowman

Thursday, May 14, 1992 (11 weeks prior to the start of the Olympic Games)

AM	PM
Land training—60 min 400 IM 10 × 400 free/30 sec rest 16 × 25/:35 no breath on every second 25 200 recovery Total = 5,000 yd	400 warm-up 200 breaststroke kick (alternate 25 yd kicking with right, left, and both legs and 25 yd kicking with both legs) 200 breaststroke pull (alternate 25 yd with head up and 25 yd with 4 strokes and 4 strokes underwater) 4 × 100 IM/1:30 + 100 easy 8 × 50 breaststroke/1:00 + 100 easy 4 × 75 breaststroke/1:15 (pull, kick, swim by 25) 4 × 100 breaststroke/1:40 (pull 25, kick 25, swim 50) 10 × 150 breaststroke/2:15 (pull, kick, swim by 50) 4 × 75 breaststroke/1:15 (pull, kick, swim by 25) + 100 easy 400 choice with fins + 100 easy 2 × 100 breaststroke/1:40 (25 pull, 25 kick, 50 swim) 2 × 150 breaststroke/2:15 (pull, kick, swim by 50) 3 × 300 breaststroke/4:15 (pull, kick, swim by 100) 2 × 150 breaststroke/2:15 (pull, kick, swim by 50) 2 × 100 breaststroke/1:40 (25 pull, 25 kick, 50 swim) + 100 easy 8 × 50 breaststroke/1 at 200 pace 600 recovery Total = 7,900 yd

Tuesday, June 23, 1992 (5 weeks prior to the start of the Olympic Games)

AM	PM
Land training—50 min 400 breaststroke kick (25 easy, 25 fast) 10 × 150 IM/2:00 (25 fly, 75 backstroke, 50 freestyle) + 100 easy 10 × 100 breaststroke kick/1:45 + 100 easy 8 × 50 breaststroke pull/1:00 + 100 easy	4 x 200 (50 free, 50 breaststroke kick, 50 butterfly, 50 choice) 400 choice, 200 butterfly (1-1-2) 8 x 50 backstroke/free/:45 200 breaststroke kick, 200 breaststroke pull, 100 easy

Table 15.23 *(continued)*

Tuesday, June 23, 1992 *(continued)*

AM	PM
4 × 200 IM/3:00 (25 butterfly, 25 backstroke, 125 breaststroke, and 25 freestyle) + 100 easy 3 × 400 breaststroke/5:45 (#1 & 2 are breaststroke pull, 4 strokes under and 4 strokes above water, #3 breaststroke swim) 400 recovery Total = 6,900 yd	5 × 4 × 50 (set #1 breaststroke kick on 1:00, set #2 breaststroke pull on :55, set #3 breaststroke, 3 kicks + 1 pull on :55, set #4, breaststroke, 2 kicks + 1 pull on :55, set #5 breaststroke swim on :50) 200 breaststroke swim + 50 easy 200 swim easy 200 butterfly (1-1-2) 8 × 50 kick, no breaststroke/1:00 + 100 easy 8 × 100 freestyle with fins/1:20 + 100 easy 2 × 400 breaststroke/5:45 (4 strokes under and 4 strokes above water) + 100 easy 8 × 50 breaststroke/1:00 at 200 pace + 100 easy 1 × 100 breaststroke at 100% (25 pull, 25 kick, 50 swim) 400 recovery Total = 6,200 yd

Tuesday, July 21, 1992 (8 days before Olympic race)

AM	PM
800 warm-up 800 breaststroke (alternate 100 kick and 100 pull) 4 × 50 breaststroke/1:30 (alternate 4 kicks underwater with 4 pulls on surface at 95%–100% effort) + 100 easy 2 × 200 IM/3:00 + 100 easy 4 × 25 drill/:30 + 50 easy 4 × 100 freestyle/1:30 + 100 easy 8 × 50/1:00 (25 fly no breath, 25 back + 50 easy 400 recovery Total = 3,900 yd	400 warm-up 200 butterfly (1-1-2) 400 breaststroke kick (25 right, left, both, and 25 kick with both legs) 200 backstroke/freestyle by 25 4 × 75 breaststroke/1:15 (25 pull, 25 kick, 25 swim) 4 × 100 breaststroke/1:40 (25 pull, 25 kick, 50 swim) 2 × 150 breaststroke/2:15 (50 pull, 50 kick, 50 swim) 4 × 100 breaststroke/1:40 (25 pull, 25 kick, 50 swim) 4 × 75 breaststroke/1:15 (25 pull, 25 kick, 25 swim + 100 easy 400 choice with fins 8 × 50 breaststroke/1:00 (25 kick underwater, 25 pull on surface)

(continued)

Table 15.23 *(continued)*

Tuesday, July 21, 1992 *(continued)*

AM	PM
	8 × 50 breaststroke/1:00 (25 pull underwater, 25 pull on surface) 8 × 50 breaststroke/1:00 (4 pulls underwater, 1 pull on surface) 200 easy 100 breaststroke (25 pull 4 underwater and 1 pull on surface, 25 pull on surface, 15 pull 4 underwater and 1 pull on surface, 25 swim) 600 recovery Total = 5,500 yd

Saturday, July 25, 1992 (4 days before Olympic race)

AM	PM
400 warm-up 200 IM (25 kick, 25 pull) 200 butterfly (1-1-2) 400 (swim 75 backstroke easy and 25 butterflly fast) 200 breaststroke kick 400 freestyle (75 easy, 25 fast) 8 x 25 breaststroke pulls underwater 800 recovery Total = 3,200 yd	800 warm-up 400 breaststroke kick (alternate 50 with 10 easy kicks and 5 fast kicks with 200 breaststroke kick (an easy 50 kick) 400 breaststroke pull (alternate 10 easy pulls and 5 fast pulls throughout) 200 choice 4 x 50 breaststroke/1:15 (alternate 3 breaststroke kicks underwater with 2 strokes on the surface) 400 choice 2 x 100 breaststroke/2:00 (alternate four stroke underwater with 4 strokes on the surface at 90%–95% effort) 400 recovery Total = 3,000 yd

Adapted from Nagy 1994.

all, basic endurance sets because the circulatory and respiratory adaptations resulting from that training will benefit all the other strokes. They should definitely swim most of their threshold and overload endurance repeat sets, and most of their race-pace, sprint, and power sets in their main stroke or strokes, because the adaptations they seek from these forms of training reside primarily in the muscle fibers that they use for them. In addition, nearly all of their kicking mileage should be in their specialties. The purpose of the following sections is to provide some suggestions for making the training butterfly, backstroke, and breaststroke swimmers more effective.

Training Backstrokers

Backstroke swimmers should spend a good deal of time improving both the endurance and the speed of their kicks by performing special basic endurance repeat kicking sets. The need for an effective backstroke kick is supported by the fact that nearly all world-class backstrokers use a six-beat kick in their races, rather than the two- and four-beat kicking rhythms used by many front-crawl swimmers. The kick probably contributes more to propulsion in backstroke than it does in the front crawl because the swimmer's supine position allows for a longer propulsive upbeat from the legs.

Backstrokers do not need to do a large amount of sprint kicking. The speed of full-stroke sprint swimming requires a strong kick, so training alone should be sufficient for improving the anaerobic power of the leg muscles. But backstrokers should use some sprint kicking sets to improve their technique and thus their kicking speed. One or two of these sets per week should be sufficient. Improving kicking technique, of course, is a fruitful way to improve speed.

Modern-day backstrokers also need to spend a sizable amount of their time improving the speed of their underwater dolphin kicks and their ability to kick farther underwater during each length of their races. The surgical tubing drill described in the earlier chapter on backstroke is an excellent one for improving the ability of backstrokers to spend more of each pool length kicking underwater. They should use this drill early in the season to condition themselves to stay underwater for at least half of each pool length. High-quality 50 sprints on long rest are also good for this purpose. Swimmers can perform these sprints in several ways. One method is by kicking the entire 50 underwater. Another method feasible in short-course pools is to kick 15 m of each pool length underwater, coming up only to turn and finish.

Breaststrokers should also use underwater sprint kicking drills to improve their underwater dolphin kicking technique. Timed 12.5 and 25 yd underwater sprints are excellent for this purpose. Using swim fins and monofins on some of these sprints is also a productive and interesting way to improve underwater dolphin kicking. The fins help swimmers perfect the fast *shimmey* technique that is essential to effective underwater dolphin kicking.

Training Butterflyers

A propulsive kick is equally important to swimmers in the butterfly. Consequently, the suggestions for improving the kicks of backstroke swimmers apply to the training of butterflyers. They must have good aerobic endurance in their leg muscles, which they can develop by a combination of basic endurance and threshold endurance kicking. They also need to do some sprint kicking repeats with an emphasis on good technique. Butterflyers can use the same drills mentioned for this purpose in connection with backstroke to improve their kicking speed. Of course, butterfly swimmers should use the dolphin kick for most of their kicking drills.

Butterfly swimmers who dolphin kick underwater for most of their races also need to improve their ability to maintain a powerful underwater kick for a larger portion of each pool length. They should use the drills mentioned in connection with the underwater dolphin kick for backstroke to accomplish this purpose.

Butterflyers need to do some endurance training in their main stroke because that is the only way they can be certain that they will improve the aerobic capacity of all the muscle fibers they use when they swim that stroke in races. Certainly, butterfly swimmers can afford to do a sizable portion of their basic endurance training in other strokes, particularly freestyle, because that training will create circulatory and respiratory adaptations that will increase the delivery of oxygen to their muscles as well as swimming butterfly can. Muscle fiber involvement in butterfly swimming is also so similar to that of the front crawl that swimming the latter stroke will improve the aerobic capacity of many of the fibers used in the former. Nevertheless, butterfly swimmers who specialize in the 200 event need to swim some threshold and overload endurance sets in their main stroke to be certain that they train all the muscle fibers they use in their races.

The threshold and overload endurance sets can be somewhat shorter than usual, perhaps, 800 to 1,600 yd or m for threshold endurance sets and 600 to 1,200 yd or m for overload endurance sets. They should also take slightly more rest than usual between repeats on these sets so that they can maintain good mechanics. Rest periods should be between 20 and 40 sec on shorter repeats of 50 to 100 yd or m and up to 60 sec for repeats of 200 to 400 yd or m. Athletes should probably swim one to two of these specialized butterfly sets each week during the early season and two to four each week later in the season. In most cases, race-pace butterfly training can replace overload endurance training later in the season.

Swimmers who specialize in the shorter butterfly events will not need to do as much endurance training. They should swim their main stroke during most of their lactate tolerance and race-pace repeats. All butterfly swimmers should swim most of their lactate production and power training sets in their main stroke.

Many coaches and swimmers have noticed that endurance butterfly training causes a breakdown in the mechanics of some swimmers. This failure occurs because the energy cost for swimming butterfly is greater than it is for swimming the front crawl and backstroke, at slow and fast speeds. More energy is required because fluctuations in forward velocity during each butterfly stroke cycle are greater than those in the front crawl and backstroke.

The forward velocity of even skilled butterfly swimmers decelerates markedly during each stroke cycle. They will decelerate as much as 1.0 m/sec during arm recovery and a similar amount during the interval between the end of the downbeat of the first dolphin kick and the time they begin accelerating their bodies forward with the armstroke. On the other hand, front-crawl and backstroke swimmers decelerate much less during the stroke cycle, usually no more than 0.2 to 0.3 m/sec. Butterfly swimmers must supply enough energy to provide a major forward acceleration twice during each stroke cycle, increasing the energy cost above that of front-crawl or backstroke swimmers, even at similar relative speeds. Largely for that reason, butterfly swimmers produce more lactic acid and have higher heart rates than freestyle and backstroke swimmers at speeds that represent the same level of effort in the three styles. Endurance butterfly training is thus more likely to cause overtraining than similar training in either backstroke or freestyle. Let me suggest some ways that athletes can do endurance butterfly training without experiencing a breakdown in stroke mechanics.

Swimming butterfly with fins is one method. Another is to swim a 1-1-2 drill, in which swimmers take some predetermined number of butterfly armstrokes, say two strokes, with the right arm, the same number with the left arm, and an equal number with both arms. A third is to use the kick underwater, swim-on-the-surface drill, in which swimmers take two or three dolphin kicks underwater followed by two or three strokes above water during each pool length. A fourth method is to swim descending sets, using freestyle for most of the set and then switching to butterfly on the fast swims near the end of the set. As the season progresses, the swimmer should always work toward a goal of swimming more of the total distance of these sets with the complete butterfly stroke.

No matter how well coaches and swimmers plan, a certain amount of stroke deterioration may take place during butterfly endurance sets. Principally, swimmers will tend to relax the dolphin kick, undulate less, glide for a short distance after the arms enter the water, and drop the elbows. That loss of form should not cause any serious mechanical problems if certain precautions are taken. As butterflyers become more experienced and skilled, they will be able to perform more endurance butterfly training without hurting their mechanics. An occasional breakdown in training will not permanently damage a stroke that is well grooved from seasons of good training. Swimming butterfly to the point of inefficiency may even be beneficial in some ways, particularly if swimmers concentrate on trying to maintain good mechanics as they become fatigued. Swimmers' strokes often deteriorate in the same ways during races that they do during endurance butterfly training. Chances are they will be able to maintain an efficient stroke in races if they concentrate on maintaining good stroke mechanics during training sets and become more successful at doing so. Having said this, I should warn that butterflyers who seem to be getting worse instead of better at maintaining good mechanics during their races may be overdoing butterfly endurance training. A swimmer having that problem should temporarily reduce the amount of butterfly endurance training.

Training Breaststrokers

All that I have said about how important it is for athletes to swim their main stroke in training applies to breaststrokers, perhaps even more than it applies to others, because breaststroke is the stroke most dissimilar to the other three competitive styles.

Of course, breaststrokers can swim other strokes during some of their basic endurance training for the reasons stated earlier. Basic endurance swimming in other styles can improve respiratory and circulatory function as well as breaststroke swimming can. Nevertheless, breaststrokers should swim 50% to 75% of their total mileage as breaststroke to improve the aerobic capacity and anaerobic power of all the muscle fibers involved in swimming that stroke. But breaststroke swimmers cannot and should not use full-stroke swimming for all this mileage. The magnitude of acceleration and deceleration of forward velocity are greater in breaststroke than in any other style. Forward velocity can decelerate up to 2 m/sec during leg recovery, after which breaststrokers will need to regain all that speed as they thrust their legs backward. Obviously, the effort to do so will be considerable, so breaststroke swimmers, like butterflyers, will produce more lactic acid and have higher heart rates than freestyle and backstroke swimmers at speeds that represent the same relative level of effort. Consequently, breaststrokers should not swim their full stroke too often during long basic endurance or threshold endurance sets.

The procedure that some successful coaches have used to improve the aerobic capacity of breaststroke swimmers is to separate basic endurance sets into alternating series of kicking, pulling, and swimming repeats. Velocity fluctuations are not so large during pulling, so those sets provide some relief. The description of Mike Barrowman's training program provided examples of this procedure.

Breaststrokers who specialize in the 200 event can and should swim some threshold and overload endurance sets in their specialty. Of course, they should also swim breaststroke during most of their race-pace sets. Breaststrokers who specialize in the shorter distances should avoid long straight threshold and overload endurance sets. Instead, they should descend many of their basic endurance repeat sets down to threshold and overload speeds to provide a training stimulus for their fast-twitch muscle fibers without causing them to lose speed and power.

Coaches cannot expect breaststrokers to swim as close to their best times on threshold and overload endurance sets as swimmers in other strokes do. Because of the large velocity fluctuations inherent in their stroke cycles, breaststrokers will usually have slower anaerobic threshold training speeds relative to their best times and will generally swim at lower heart rates and percentage efforts during threshold sets. Therefore, these sets should be somewhat shorter than those recommended for freestyle and backstroke swimmers, and the rest intervals should be slightly longer to delay fatigue and maintain stroke integrity at a higher level from beginning to end.

All that I said about the importance of kicking for backstroke and butterfly swimmers goes double or triple for this stroke. Breaststrokers should kick that stroke for many yards or meters each day. Although this recommendation may be sound physiologically, achieving it is often difficult because of stress on the knees. Unfortunately, the potential for injury to the soft tissues of the knees makes it necessary to administer a breaststroker's kicking mileage with the dual considerations of improving leg endurance and preventing sore knees. For this reason, these swimmers should not do a large amount of breaststroke endurance swimming and endurance kicking during the same training session. Alternating breaststroke kicking or full-stroke swimming with breaststroke pulling during long, basic endurance sets will provide a periodic rest period for the swimmer's knees and reduce the strain on them.

Breaststrokers should do most of their kicking at basic endurance speed. Breaststroke is a leg-dominated stroke as compared with the other three styles, which are arm dominated. Therefore, breaststrokers do as much or even more work with their legs as they do with their arms during full-stroke swimming. Consequently, they do not need to kick at threshold or overload endurance speeds to improve the aerobic capacity of the fast-twitch muscles in their legs. Nevertheless, they should descend their speeds to threshold and overload levels regularly near the end, when they kick basic endurance sets.

Breaststroke swimmers do not need to do a great deal of sprint kicking for the reason cited in the previous paragraph. Their legs will receive an adequate training stimulus when they swim the full stroke during sprint repeats because their kick is so pertinent to the stroke.

Kicking on a board is a good way for breaststroke swimmers to train their legs, but they should not use that as their exclusive method for leg training. They should do some kicking without a board to practice streamlining their arms, heads, and trunks underwater as they kick, just as they do when they swim the full stroke.

As I stated earlier, breaststrokers tend to favor their legs when they swim the full stroke. Therefore, they should devote a sizable portion of their endurance training mileage to pulling. Swimmers who specialize in the 200 breaststroke should do that pulling in combinations of basic endurance, threshold endurance, and overload endurance repeat sets. Breaststrokers who specialize in the 100 event want to maintain a high degree of speed and power in their arms, so they should do most of their endurance training in descending sets in which most of the mileage is at basic endurance speeds.

Sprint breaststroke swimming should provide enough stimulation for improving the anaerobic power and buffering capacity of the swimmers' pulling muscles. Nevertheless, certain breaststroke swimmers should do some sprint sets, pulling only, if they are not using their arms fully when they race.

The practice of pulling with a dolphin kick should be discouraged, except during stroke and timing drills. Swimmers should not use the dolphin kick when the purpose of a pulling set is to improve the aerobic capacity or anaerobic power of the arms. Breaststrokers with weak pulls may compensate by letting their kicks do most of the work on these swims. Accordingly, the training stimulus on the arm muscles may remain too low for optimum adaptations of either type.

Pulling breaststroke is not the only way that swimmers can improve the pull. The front half of the butterfly armstroke is similar to the propulsive phase of the breaststroke armstroke. Therefore, swimming butterfly is a good supplement to breaststroke pulling and provides variety in training.

Training for the Individual Medley Events

Individual medley swimmers should spend a great deal of time perfecting the techniques of all four competitive strokes. From a physiological standpoint, swimmers in these events must also spend considerable time swimming all four competitive strokes in their training, performing several different levels of endurance and sprint training for each stroke. They need not stress each level of training to the same extent in every stroke, however. The metabolic demands for each stroke are somewhat different because of their order in the race. Table 15.24 lists the most important types of training that should be included in the programs of 400 IM and 200 IM swimmers.

Table 15.24 Training Requirements for the Four Strokes of the Individual Medley

MOST IMPORTANT TRAINING REQUIREMENTS	BUTTERFLY	BACKSTROKE	BREASTSTROKE	FREESTYLE
400 IM	En-1 Race-pace training Lactate production training	En-1 En-2 En-3 Race-pace training	En-1 En-2 En-3 Race-pace training	En-1 En-3 Race-pace training
200 IM	Lactate production training Race-pace training	Lactate production training En-1 En-2 En-3 Race-pace training	Lactate production training En-1 En-2 En-3 Race-pace training	Lactate production training En-1 En-2 En-3 Race-pace training

Designing Repeat Sets for Individual Medley Training

Mixed-style sets are frequently used to train individual medley swimmers. The number of repeats in each set is divided equally among the four competitive strokes. This method works well for sprint and race-pace training, but it is not the best method for endurance training. Balanced training does not provide continuous stimulation of sufficient duration to improve oxygen use by the muscle fibers used in certain strokes but not others. For this reason, I advise individual medley swimmers to swim longer, straight endurance sets in each of the last three strokes of individual medley races—backstroke, breaststroke, and freestyle. Each repeat set for a particular stroke should be 800 to 2,000 m in length. Swimmers should swim most of these sets at basic endurance speed, but they should regularly descend to overload endurance speed for the last 300 to 600 m so that they can also improve the aerobic capacity of their fast-twitch muscle fibers. They should perform descending sets of this type regularly during the early season. Athletes who specialize in the 200 IM should continue to train in this way throughout the season so that they do not lose too much anaerobic power. Individual medley swimmers who specialize at the 400 distance should gradually swim more of their backstroke, breaststroke, and freestyle sets at threshold and overload endurance speed during the middle of the season to optimize their endurance in those strokes.

IM swimmers need not perform all four strokes during every training session. Instead, they should alternate days throughout the week when certain strokes are emphasized so that they can complete at least two major endurance sets for each of the final three strokes of the race by week's end.

Individual medley swimmers should concentrate on improving their endurance in their weakest stroke or strokes during the first half of the season by including more training for that stroke or strokes in their weekly plan. I recommend that 200 IM swimmers include extra lactate production training for their weakest stroke or strokes during the first half of the season to improve their speed.

Despite what I said earlier, swimming mixed-style repeats is sometimes a good idea. Those repeats help swimmers improve their ability to change from one stroke to the next without losing rhythm, and they help with pacing during IM races. Swimmers should include some sets of IM repeats in their training to help them perfect their changeover turns from one stroke to the next.

Mixed-style repeat sets are also useful for helping athletes move from one stroke to the next with an even distribution of effort. Rest intervals between these repeats should generally be short, although they can become longer during freestyle repeats to encourage faster swimming at the end of IM races. The emphasis should be on swimming the first three strokes aerobically and the final stroke anaerobically.

Athletes who specialize in these events should also do some repeat sets in which they swim a partial or complete individual medley during each repeat. When athletes swim complete individual medleys, they should do most repeat sets at overload and sprint training speeds to learn proper pacing. Many athletes tend to swim too fast in their best strokes in the mistaken notion that building up a lead there will prevent competitors from catching them in their weaker strokes. Another mistake they make is to swim too fast immediately after changing strokes, only to slow down later when they realize the pace is too fast. Individual medley swimmers must learn to swim the butterfly leg of these races fast and easy and then maintain an even distribution of effort during the backstroke and breaststroke segments so that the rate of acidosis will not accelerate too early during the race. The freestyle leg of individual medleys should be the only time when athletes try to swim as fast as they can.

Two methods of designing individual medley repeats are well suited for improving endurance in the middle two strokes while improving easy speed in the butterfly and buffering capacity in the freestyle. The first is to increase the length of the backstroke and breaststroke segments over those of the butterfly and freestyle within an individual medley repeat. This method will place a premium on endurance in the former two styles and on speed in the latter two. The second method is to swim repeats that include only a portion of a complete individual medley. For example, athletes could swim a set of 8 × 250 repeats in the following manner:

Swim 4 × 250 (50 butterfly, 100 backstroke, 100 breaststroke)
Swim 4 × 250 (100 backstroke, 100 breaststroke, 50 freestyle)

Kicking During Individual Medley Races

Individual medley swimmers need to develop a strong breaststroke kick because most are weakest in that stroke. Besides its positive effect on the breaststroke leg of the race, a good breaststroke kick will allow swimmers to rest their arms somewhat for the freestyle leg that follows. Of course, a good kick is an advantage in every stroke, but for individual medley swimmers it is more important in the breaststroke than in any other. The freestyle flutter kick is second in importance for these swimmers because they should be able to use a six-beat style during that leg of the race. IM swimmers, particularly those who specialize in the 400 event, should not kick hard during the butterfly and backstroke legs of their races so that they can conserve energy.

Training Programs of Successful Individual Medley Swimmers

The training programs for Tom Dolan and Summer Sanders, both of whom competed in the 200 and 400 IM events, are examples of successful IM training programs.

Tom Dolan

Tom Dolan (Urbanchek 1998) was the gold medal winner in the 400 IM at the 1996 and 2000 Olympic Games. He also won the silver medal in the 200 IM at the 2000 Games. His time of 4:11.76 in the 400 IM at 2000 Olympic Games was a new world record, breaking his previous record of 4:12.30. His time of 1:59.77 for the 200 IM in the 2000 Games was an American record. Tom's training program before the 1996 Olympic Games is reviewed here. Jon Urbanchek at the University of Michigan and Rick Curl of the Curl-Burke Swim Club conducted his training at various times during the year.

Tom's training volume varied between 75,000 and 85,000 yd or m per week. He trained 10 times per week. Training sessions were held twice per day on Monday, Tuesday, Thursday, and Friday, once on Wednesday afternoon, and once on Saturday morning.

Table 15.25 Weekly Training Cycle for Tom Dolan

DAY	AM	PM
Monday	Low- to moderate-intensity aerobic swimming, freestyle pulling, kicking drills. 7,000 yd	Threshold training. 10,000 yd
Tuesday	Low- to moderate-intensity aerobic swimming. Breaststroke emphasized. Fin kicking, sprint-assisted and sprint-resisted training. 7,000 yd	Active/rest. Breaststroke emphasized. 9,000 yd
Wednesday	Off	$\dot{V}O_2$max set or descending endurance set. 8,000 yd
Thursday	Low- to moderate-intensity aerobic swimming. Drills, fin kicking, hypoxic training. 7,000 yd	Threshold training. 9,000 yd
Friday	Low- to moderate-intensity aerobic swimming. Backstroke emphasized. Breaststroke kicking, sprint-assisted and sprint-resisted training. 7,000 yd	Active rest, backstroke emphasized. 8,000 yd
Saturday	$\dot{V}O_2$max or lactate tolerance training. 8,000 yd	Off

Adapted from Urbanchek 1998.

Tom's taper was 14 days in length. Table 15.25 presents a typical weekly training schedule. He generally trained at altitude twice per year for 3 weeks at a time during December and May.

Weekday morning sessions were generally devoted to basic endurance training in the form of swimming, kicking, and pulling. The Monday morning session emphasized freestyle pulling and kicking drills. Tuesday and Friday morning sessions focused on breaststroke and backstroke swimming. Tom often did 2,000 m of breaststroke kicking drills on those days as well. He did not use a kickboard. He also did combinations of sprint-resisted and sprint-assisted training in all strokes during that workout. An example of his sprint training was to swim a set of 50s, swimming out against the resistance of the cords on the first 25 and swimming while being pulled back by the cords on the second 25. He took Wednesday morning off. On Thursday morning Tom did freestyle pulling at basic endurance speeds, kicking drills, and hypoxic training. He generally swam a high-quality sprint set on Saturday morning. For example, he might do 6 × 100 on a send-off of 8 min, usually swimming a variety of strokes during the set.

Tom swam long threshold sets on Monday and Thursday afternoons. These sets were between 50 and 60 min long. Tom usually swam them freestyle although he sometimes used mixed strokes. He was expected to maintain heart rates between 150 and 180 bpm on these sets, and his rest periods between repeats were very short, usually 10 to 15 sec. He was expected to swim at higher intensity on Thursday afternoon than on Monday afternoon, so his send-off times were longer to allow him to do that. Those send-off times usually allowed rest of 20 and 30 sec between repeats.

His training for Tuesday and Friday afternoon was described as active rest. The repeat sets he completed were combinations of long swims at low to moderate speed interspersed with short, fast swims or sets of repeats. Breaststroke repeats were emphasized on Tuesday and backstroke on Friday afternoons.

Table 15.26 Sample Week of Tom Dolan's Major Training Sets*

Monday PM Threshold	4 × 100 choice/1:40, descend 1–4, 1 × 400 IM/5:30, 4 × 100 freestyle/1:20 at moderate speed, 1 × 400 freestyle/4:40 at anaerobic threshold speed. Repeat this set three more times, swimming butterfly for the first segment of set #2, backstroke on set #3, and breaststroke on set #4. The 400 IMs were to be descended from 90% to maximum effort.
Tuesday PM Active rest	6 × 50 butterfly easy/:45 + 150/2:00 (100 backstroke + 50 breaststroke). 6 × 50 backstroke easy/:45 + 150/2:00 (100 breaststroke + 50 freestyle). 6 × 50 breaststroke easy/:50 + 150 freestyle/2:00. 4 × (50 freestyle easy + 50 butterfly fast). 4 × (50 freestyle easy + 50 backstroke fast). 4 × (50 freestyle easy + 50 breaststroke fast). 4 × (50 freestyle easy + 50 freestyle fast).
Wednesday $\dot{V}O_2$max	100 butterfly/2:00 from dive, 2 × 100 backstroke/2, 3 × 100 breaststroke/2, 4 × 100 freestyle/2, swim 300 easy. Repeat set 2 more times.
Thursday	2 × 400 freestyle/4:40 at moderate speed, 4 × 200 freestyle/2:30 at threshold speed, 8 × 100 freestyle/1:20 faster than threshold speed. Repeat this set.
Friday Active rest	6 × (100 backstroke + 100 easy). Descend 1–3 to 400 IM pace. 6 × (2 × 50 backstroke/:40 + 100 easy). Descend 1–3 to 400 IM pace. 6 × (100 backstroke/breaststroke + 100 easy). Descend 1–3 to 400 IM pace. 6 × (100 breaststroke/freestyle + 100 easy). Descend 1–3 to 400 IM pace.
Saturday	6 × 200/8:00 (#1 butterfly, #2 backstroke, #3 breaststroke, #4–6 freestyle). Repeat set. 8 × 50/1 (2 of each stroke in IM order).

*All training was in short-course yards.

Adapted from Urbanchek 1998.

His training on Wednesday consisted of a $\dot{V}O_2$max set or a descending set of repeats that included all levels of endurance swimming from slow to very fast. Tom did all strokes on this set. Table 15.26 provides an example of one week of Tom's afternoon training. The table also includes his major high-intensity workout on Saturday morning.

Summer Sanders

Summer Sanders (Quick,1994) was the gold medalist for the 200 m butterfly at the 1992 Olympic Games. She also established an American record for the 200 IM with a time of 2:11.91. She won the silver medal in the 200 IM at the 1992 Olympics. Richard Quick of Stanford University was her coach.

Summer trained year-round. Her training was divided into two seasons, a short-course season and a long-course season. She used the following plan for 26 weeks before the 1992 U.S. Olympic Trials.

Her short-course season comprised five parts. The first was a preparation phase during which she trained at altitude for 4 weeks. Training was primarily composed of low- to moderate-intensity endurance swimming. She trained nine times per week, swimming 6,000 to 7,000 m per training session by the end of this period.

The next phase of the season, lasting 7 weeks, was termed the general aerobic base phase. She swam 10 times per week. The purpose of the training was to improve her aerobic capacity. For that reason, the majority of the training was endurance oriented on short rest. An example of two training sets for this phase of the season follows.

Set 1

1 × 400 freestyle, 1 × 400 IM, 1 × 400 backstroke, 1 × 400 IM, 1 × 400 breaststroke, 1 × 400 IM, 1 × 400 free, 1 × 400 IM. She took 15 to 20 sec rest after each 400.

Set 2

3 × 200 pull, 4 × 150 (50 backstroke, 50 breaststroke, 50 freestyle), 5 × 100 freestyle, 6 × 50 (2 butterfly, 2 backstroke, 2 breaststroke). She repeated this set three times. She took 10 sec after each repeat.

Endurance training made up between 70% and 80% of her total mileage. The remaining 20% to 30% was devoted to sprint training. Summer made every effort to maintain her sprint ability during this period. For that purpose she swam sprint sets similar to the following three or four times per week.

16 × 50/1 (25 easy + 25 fast using all strokes)

6 × 50/1:30 at race pace – 2 sec per 50

The next phase was for specific endurance training, although it also included a considerable amount of sprint training. Proportions for this 5-week phase were approximately 60% endurance and 40% sprint. The number of weekly training sessions was reduced to nine during this period. Summer took Tuesday and Thursday mornings off. A typical endurance repeat set during this period was similar to the following:

1 × 100 freestyle at 80% effort, 1 × 100 (50 butterfly, 50 backstroke, negative split), 1 × 100 freestyle at 80 effort, 1 × 100 (50 backstroke, 50 breaststroke, negative split), 1 × 100 freestyle at 80% effort, 1 × 100 (50 breaststroke, 50 freestyle, negative split), 1 × 100 freestyle at 80% effort, 1 × 200 IM at maximum effort. She took 10 sec rest between the 100 swims.

Examples of her sprint sets follow:

20 × 20 yd, 20 sec rest, with no breath

20 × 20 yd, 15 sec rest, breathing as needed

10 × 20 yd, 40 sec rest, all out, swimming all strokes

The next period was designed to improve specific sprinting speed. During this 4-week period, training was approximately 50% endurance and 50% sprinting. Summer continued to train 9 times weekly. Tuesday and Thursday afternoons became recovery training sessions to rest from the intense training on Monday, Wednesday, and Friday.

The final phase was the taper period, which also lasted 4 weeks. Table 15.27 summarizes Summer's preparation for the U.S. Olympic Trials.

Summer also performed water and dry land circuit training. The water circuit began in the 7th week of the season and included a variety of sprint training procedures. One was a combination of sprint-resisted and sprint-assisted training. Summer used stretch cords to swim 20 × 50 on a 1 min send-off time. She did the sprint-resisted training by swimming against the tubing on the first 25 and then swam back using sprint-assisted training on the second 25. Later in the season this set became 4 × 6 × 25 on a 1 min send-off time. She did sprint-resisted training on the odd repeats and sprint-assisted training on the even repeats.

The Power Rack was another station in the water circuit. Summer swam out until the weight was at the top of the rack and then continued swimming for several seconds. She swam 7 × 12 to 15 sec against resistance and then 7 × 6 to 8 sec against resistance.

Vertical kicking was also part of the circuit. She held a weight on her chest while kicking for various lengths of time, such as 15, 30, 45, and 60 sec. She rested for 15 sec after each kicking effort. At another station she did sets of 5 × 3 × 100 with zoomer fins on a 1:15 send-off time.

Table 15.27 Training Phases for Summer Sanders Leading Up to the 1992 U.S. Olympic Trials

PHASE	WEEKS	EXPLANATION
Preparation	4	Nine training sessions, each 6,000–7,000 m. Most of the training was aimed at preparing for more intense training later.
General aerobic	7	Ten training sessons/wk. Aimed at improving aerobic capacity while maintaining speed. Water circuit training was introduced during this period. Training proportions were 70% to 80% aerobic and 20% to 30% anaerobic.
Specific aerobic and anaerobic base	5	Nine training sessions/wk. More intense endurance training in all strokes. A considerable amount of sprint training was also included during this phase. Training proportions were 60% aerobic and 40% anaerobic. Goal was to increase specific aerobic muscular endurance.
Anaerobic and speed training	4	Nine training sessions/wk. Two afternoon recovery days were introduced. Goal was to increase specific anaerobic muscular endurance and anaerobic power. Training proportions were 50% aerobic and 50% anaerobic.
Taper	4	

Adapted from Quick 1994.

Summer lifted weights three times per week, progressing from exercises designed to increase her strength to those designed to increase her muscular power. For 3 days each week she also did dry land circuit training, which included calisthenics, jumping rope, abdominal exercises, pull-ups, and medicine ball exercises. Summer went through the six-station circuit three times. She spent 2 min at each station, doing 1 min of exercise with 15 sec rest and then 30 sec of exercise followed by 15 sec of rest as she moved to the next station.

16

Monitoring Training

New in this edition:

- A section on tests for anaerobic power as well as aerobic and anaerobic muscular endurance
- Updated information on blood testing procedures
- An expanded section on procedures for monitoring heart rate

The effective administration of a swim training program requires accurate monitoring of changes in both the aerobic and anaerobic performances of athletes to determine whether they are improving, and if not, why not. In addition, it is important to monitor training speeds accurately so that they will produce the desired effects. Blood testing is currently the most precise method for monitoring training available to coaches and athletes. This procedure, however, is not without its pitfalls. Furthermore, most coaches do not have the equipment, funds, time, or expertise to use blood testing for these purposes. For this reason, other noninvasive procedures are needed for monitoring training. Alternative methods involve swimming standardized repeat sets, monitoring heart rates, and rating perceived exertion (RPE). In this chapter I will discuss those procedures for monitoring training as well as some commonly used procedures that are not accurate and should be discarded.

Blood Testing

Many people consider measuring oxygen consumption the most accurate method for monitoring training. This procedure requires expensive equipment and a certain amount of scientific expertise and training. Consequently, in the 1970s Dr. Alois Mader proposed blood testing as an alternative to the measurement of oxygen consumption (Mader, Heck, and Hollmann 1976). To date, that method is the best poolside procedure available for monitoring the aerobic and anaerobic effects of training. Much can be learned from blood testing about the responses of athletes to training, even by those who never intend to take blood samples. For that reason, in the next several sections I will describe how blood testing can be used for monitoring the training of athletes. First, however, I will describe the physiological basis for the procedure.

Physiological Basis for Blood Testing

The premise behind blood testing is that increases of lactate in the blood reflect increases of lactic acid in the muscles. Much of the lactic acid produced during exercise both diffuses and is transported out of the muscles and into the blood. Thus, the extent of anaerobic metabolism in muscles can be inferred by the content of lactic acid in blood.

The fastest speed at which the rate of lactic acid entry into the blood and the rate of its exit from the blood remain in balance has been proposed to be the anaerobic threshold, or more accurately, the lactate threshold. That speed is the fastest speed an athlete can maintain without the occurrence of severe acidosis in the muscles. Over time, if the blood lactate concentration produced by a particular swimming speed decreased, it was assumed that less was being produced in the muscles, that more was being eliminated from them, or that some combination of these two desirable endurance training effects had occurred. As a result, the athlete would be able to swim faster without incurring acidosis, and his or her performance would improve.

On the other side of the coin, an increase in blood lactate at a particular swimming speed was taken as a sign that aerobic metabolism had deteriorated and that more lactic acid was being produced in the muscles. The athlete would suffer acidosis at slower speeds, and his or her performance would worsen.

The results of several pieces of research suggest that blood lactate concentrations are indicators of muscle lactic acid concentrations up to levels of 4 to 5 mmol/L. At exercise intensities that elicit higher blood lactate concentrations, the rate of lactate accumulation in blood is probably slower than the rate of accumulation in muscles (Jacobs and Kaiser 1982; Jorfeldt, Julin-Dannfelt, and Karlsson 1978; Robergs et al. 1989). Regardless, evidence shows that a rapid increase of blood lactate signals an even more rapid accumulation of lactic acid in muscles. Therefore, it seems reasonable to assume that rapid accumulation of lactate in blood indicates that an athlete has exceeded anaerobic threshold speed.

Actual measurement of muscle lactic acid during exercise would obviously be more accurate. Such measurements are not practical, however, because the lactic acid in muscles can be measured only by removing a small sample of muscle tissue during a break in exercise. The tissue must be frozen immediately and analyzed later. The expense and expertise required for this procedure precludes its widespread use by coaches. For that reason, measurements of blood lactate are the best means available for inferring the relationship between aerobic and anaerobic metabolism in muscles during exercise.

Aerobic and Anaerobic Thresholds

One of the principle uses for blood testing is identifying the aerobic and anaerobic thresholds. Determining the swimming speeds that correspond to the aerobic and anaerobic thresholds can serve two purposes. First, those determinations provide a good estimate of the optimum range of speeds for endurance training. Second, identification of thresholds can be useful in evaluating changes in aerobic capacity. Specifically, endurance has probably improved if the athlete is able to swim faster at his or her individual aerobic and anaerobic thresholds. These thresholds are generally expressed by the swimming velocity at which they occur. For ease of communication, they are usually converted to a time per 100 yd or a time per 100 m, depending on the type of pool in which the blood tests were conducted. Procedures for converting swimming velocities for swimming times will be shown later in figure 16.15.

The method for determining the anaerobic threshold by measuring oxygen consumption has become known as the *respiratory threshold*. Several terms have been proposed for the anaerobic threshold as measured by blood testing. All of these use the word *lactate* rather than *anaerobic* as part of the name to emphasize the fact that this is a measure of the blood lactate response to exercise. Some of the most popular terms for this concept have been *onset of blood lactate accumulation (OBLA)* (Sjodin and Jacobs 1981), *lactate threshold* (Ivy et al. 1980), *lactate breakpoint* (DiVico et al. 1989), and *maximal lactate steady state (MAXLASS)* (Griess et al. 1988). Of these, the maximal lactate steady state is probably the most descriptive term. Nevertheless, I will continue to use the term *anaerobic threshold* when referring to this phenomenon because it has become firmly entrenched in the lexicon of coaching terminology.

The graph in figure 16.1 illustrates what is meant by the term *anaerobic threshold* as determined from blood testing. A graph displays the relationship between blood lactate concentrations and swimming velocity for an athlete who attempted three 30 min swims at progressively faster speeds. These speeds ranged from 1.36 m/sec (1:14 for 100 m) to 1.42 m/sec (1:10 for 100 m). Notice that the swimmer was able to maintain a constant level of lactic acid in his muscles up to a swimming velocity of 1.40 m/sec. At the next fastest speed, 1.42 m/sec, lactic acid increased markedly from the beginning of the swim, producing acidosis that caused the swimmer to be unable to maintain the prescribed pace after approximately 20 min. The results demonstrated that this swimmer's anaerobic threshold, or the maximum speed at which the rate of lactate being produced in the muscles and the rate of its removal from them were in equilibrium, was between a swimming speed of 1.40 m/sec (1:11 for 100 m) and 1.42 m/sec (1:10 for 100 m).

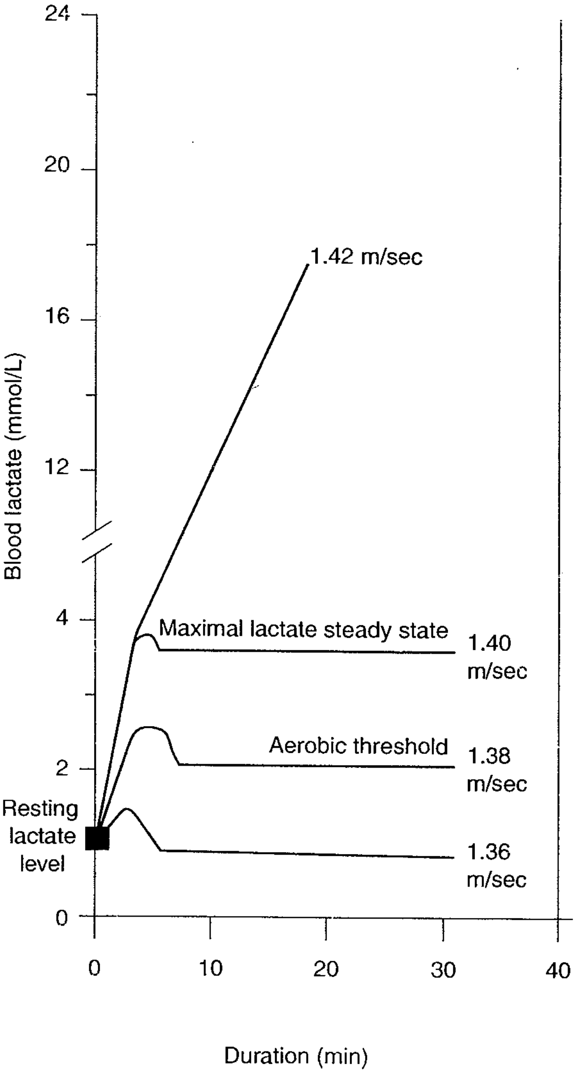


Figure 16.1 The relationship between blood lactate concentrations and swimming velocity for an athlete who attempted three 30 min swims at progressively faster speeds.

The method I just described, although excellent for estimating the swimming velocity that corresponds to the anaerobic threshold, is too time consuming and difficult to be practical for this purpose. Consequently, several other methods for estimating the location of the anaerobic threshold that are easier to administer have been developed. These methods involve a graded exercise, or step-test procedure. I will describe one of the most common of these step-test protocols for blood testing in the next section.

Procedures for Conducting a Blood Test

Most blood tests involve swimming a series of repeats at progressively faster speeds. A small sample of blood (3 to 25 microliters) is collected from the ear or fingertip after each swim and placed in a device that measures the amount of lactic acid in that blood.

Several devices have been developed that will quickly and accurately measure the quantity of lactic acid in these small samples of blood. Figure 16.2 shows one such device, an Accusport™ portable lactate analyzer. The blood sample is dropped onto a

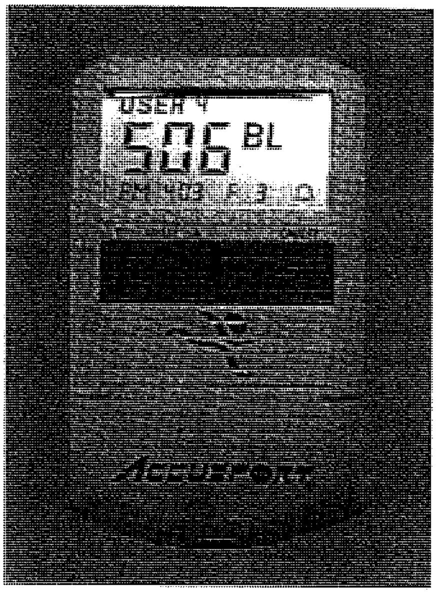


Figure 16.2 An Accusport portable lactate analyzer. This device will determine, by photo-optical procedures, the lactate content of a small sample of blood within 1 min after a test strip is inserted into the analyzer.

The Accusport and Accutrend lactate portable lactate analyzers are manufactured by Roche Diagnostics, Mannheim, Germany.

small sampling strip, which is then inserted into the Accusport analyzer. The lactate value appears on the screen within 1 min.

In most cases, measurements of blood lactate are placed on a graph opposite the swimming speed that produced them to show the athlete's blood lactate response. The line that results from connecting the points on the graph is referred to as a lactate-velocity curve. The lactate-velocity graph in figure 16.3 is an example of the results of one such test.

In this particular protocol, the athlete was asked to complete five 300 m swims with 1 min of rest after each swim. The time for the first swim was set so that the swimmer could easily achieve it. The time for each of the next four swims was reduced by approximately 5 sec, and the last swim was a maximum effort. A resting blood sample was taken after the warm-up and before the first swim. The content of lactic acid in the resting sample was 1.0 mmol/L. Blood samples were taken during the rest period after each of the first four swims. Multiple blood samples were then taken at 1, 3, 5, 7, and 9 min after the completion of the fifth swim to ensure that a maximum blood lactate concentration was detected for that swim. Lactic acid continues to diffuse from the muscles into the blood for several minutes after maximum and near-maximum efforts until equilibrium exists between the compartments. After that, blood lactic acid will decline because the amount pouring out of the muscles diminishes.

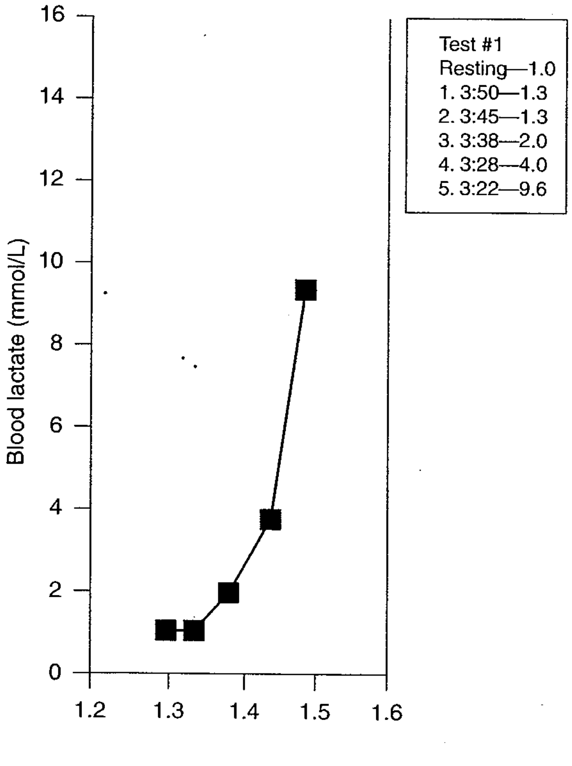


Figure 16.3 Results of a typical blood test.

The times for these swims, in minutes and seconds, and the blood lactate concentrations they produced, are listed at the right side of the graph for easy reference. Swimming times have been converted to meters per second for graphing purposes. This method has two advantages. The first is that the graph has a positive orientation, with blood lactate increasing as swimming velocity increases. Graphing swimming times would give the graph a negative orientation, with blood lactates going higher as swimming times decline. The second advantage is that the velocity associated with any particular blood lactate concentration can be converted to a time for any swimming distance.

No increase of blood lactate occurred from the first swim to the second swim, despite the fact that the time for the second swim was 5 sec faster than the first. This result suggests that no lactic acid was accumulating in the swimmer's muscles. Most of the pyruvate that had been produced was oxidized and removed in other ways, while the small amount of lactic acid that may have been produced was removed from the muscles and blood during the swim. These results suggest that this athlete was able to swim at a velocity of 1.33 m/sec (3:45) without accumulating any significant amount of lactic acid in the blood. In other words, aerobic metabolism supplied most of the energy for swimming at this speed.

Blood lactate increased between the second and fourth swims (1.3 to 4.0 mmol/L). This increase suggests that some lactic acid was accumulating in the swimmer's muscles. The first significant increase from resting level occurred during swim #3, with blood lactate increasing to 2.0 mmol/L as the athlete's swimming speed increased to 1.38 m/sec (3:38). This value suggested that some lactic acid was accumulating in his muscles at that speed. The rate of accumulation was slow, however, as evident from the slope of the curve between swims #2 and #3. The swimmer's time improved nearly 12 sec, yet his blood lactate concentration increased only 1 mmol/L. This outcome indicates that the increase in lactic acid accumulation was well within the athlete's ability to incur it without producing severe acidosis. Most of the lactic acid produced in his muscles was probably being removed from them and oxidized in other areas of the body, and the amount that was accumulating was being buffered so that muscle pH was not declining greatly. He was probably also producing lactic acid at a slow rate because he was still able to supply most of the energy he needed for muscular contraction through aerobic metabolism. Even so, the gradual increase of blood lactate between swim #3 and swim #4 indicates that aerobic metabolism and lactate removal mechanisms were being overloaded. Therefore, this athlete should be able to improve both of these mechanisms by training between the speed of swim #2 and the speed of swim #4.

The swimmer's blood lactate concentration increased over 5.0 mmol/L to 9.6 mmol/L during the fifth swim, but his time for 300 m improved only 6 sec, from 3:28 to 3:22. The slope of the velocity curve thus increases sharply, becoming linear between swims #4 and #5, suggesting that muscle lactic acid was also increasing rapidly. Thus, aerobic metabolism was unable to supply much of the needed energy at this speed. A great deal of energy was being supplied anaerobically, with the result that the rate of production of lactic acid in muscles was probably well above its rate of removal from them. Severe acidosis was probably imminent.

The relationship between swimming times and various measures associated with blood testing, such as the aerobic and anaerobic thresholds, are generally expressed in the form of time per 100 m, which is calculated by dividing the distance, 100 m, by the swimming velocity at either of these thresholds.

Warning! Blood Testing Can Be Dangerous

We are all aware that blood can carry the AIDS virus and can transmit it from one person to another. For this reason, blood tests should be conducted by medical personnel and then only under the safest sanitary conditions. New, sterilized lancets should be used each time a sample is taken, and athletes should clean their hands with a sterile gauze pad after each test. Test administrators should wear rubber gloves and clean them with a disinfectant after taking each blood sample. Testers should also wear rubber gloves when analyzing samples and clean the analyzing equipment thoroughly after each use. All blood samples should be disposed of in separate containers clearly labeled as containing dangerous and contaminable products.

Interpreting the Results of Blood Tests

Four parts of a typical lactate-velocity curve provide important information about the athlete. The first two are reference points for aerobic capacity, the aerobic threshold and the anaerobic or lactate threshold, which have already been described. The third reference point is the peak blood lactate concentration after a maximum effort, and the fourth concerns the slope or inclination of the steep phase of the lactate-velocity curve. That portion of the curve extends from the anaerobic threshold to the peak blood lactate concentration. In the next sections I will discuss how each of these reference points is located, beginning with the aerobic threshold.

Locating the Aerobic Threshold

Most experts consider the aerobic threshold to be the speed at which the first increase of blood lactate above the resting level occurs, the so-called *first breakpoint* in the lactate-velocity curve. In figure 16.3 the first breakpoint occurred during swim #3. Thus, the aerobic threshold for this athlete was somewhere between a velocity of 1.33 m/sec (1:15 for 100 m) and 1.37 m/sec (1:13 for 100 m). The aerobic threshold approximates the minimum training speed that will improve aerobic endurance. The reasoning behind this belief is that the gradual increase of blood lactate at the aerobic threshold velocity indicates that the process of aerobic metabolism has been overloaded.

Obviously, determining the exact location of the aerobic threshold is difficult. I suggest using the first increase of blood lactate above resting levels for this purpose rather than some fixed blood lactate level or some fixed increase above resting. The best advice for accurately estimating the location of the aerobic threshold is to use a graded protocol in which the differences in time are very small between the early swims. This should allow the tester to determine the swimming speed at which the first increase in blood lactate above resting occurs within a range of 1 to 2 sec per 100 yd or m. The lower limit of that range would be the minimum speed for basic endurance swimming. Using this method the aerobic threshold velocity would be 1.33 m/sec, or a swimming speed of 1:15 for 100 m for the swimmer in figure 16.3.

Locating the Anaerobic Threshold

Much time and effort have been put into developing methods for estimating the anaerobic threshold speed because it is widely used. As they do with the aerobic threshold, members of the scientific community disagree about how to measure the anaerobic threshold speed and exactly where it is located along the lactate-velocity curve. The methods proposed for locating the anaerobic threshold speed have included fixed blood lactate concentrations, increases in blood lactate above some predetermined baseline, and points of intersections between the horizontal and vertical components of the lactate-velocity curve. Most agree, however, that the anaerobic threshold speed is somewhere along the curvilinear portion between the aerobic threshold and the point where the curve become linear. The so-called *second breakpoint*, where the shape of the curve changes from curvilinear to linear, occurs after swim #4 in figure 16.3. The following sections discuss some of the most popular procedures for determining anaerobic threshold speeds.

Fixed Blood Lactate Concentrations In the 1970s and early 1980s many persons believed that a fixed blood lactate concentration of 4 mmol/L represented the anaerobic threshold. Research had demonstrated that most athletes could maintain training speeds that produced a constant blood lactate level of 4 mmol/L for approximately 30 min. But this method has not turned out to be very accurate. Experts generally agree that a fixed blood lactate concentration of 4 mmol/L overestimates the anaerobic threshold speed for most endurance-trained athletes. A number of reasons account for this. Most important, a fixed blood lactate level does not represent the same relationship between aerobic and anaerobic metabolism for all athletes. For some endurance athletes, it represents a very intense level of effort (Furian et al. 1998). These athletes are able to remove lactic acid from their muscles and blood so efficiently that they can swim at near-maximum speeds before their blood concentration reaches 4 mmol/L. Consequently, they would be swimming well beyond the intensity at which the rate of lactate entry into the blood and exit from it are in equilibrium if they trained at speeds that produced a blood lactate of 4 mmol/L. In fact, for many of these athletes, lactate may be accumulating rapidly in the muscles when their blood lactate concentration reaches 4 mmol/L. Consequently, a better choice for determining threshold endurance training paces is to use one of the methods for estimating the individual anaerobic threshold.

No one fixed blood lactate concentration can identify the anaerobic threshold speed. Therefore, that method gave way to other procedures for locating the *individual anaerobic threshold* by examining the shape of a particular swimmer's lactate-velocity curve. Two methods suggested for this purpose were

1. to locate the threshold at some increase of blood lactate above a predetermined base measure, and
2. to locate the threshold according to a point of intersection between horizontal and vertical components of the lactate-velocity curve.

Relationships between individual anaerobic thresholds and performance have generally been higher than those for fixed thresholds, whether they be at 2.0, 2.5, or 4.0 mmol/L (Farrell et al. 1979; Hagberg and Coyle 1983). The following two sections will discuss these procedures.

Lactate Increases Above Baseline One of the methods in this category has been to place the anaerobic threshold at a speed at which blood lactate increases 1.0 mmol/L above its resting level. Another method locates the anaerobic threshold where blood lactate increases 1.0 mmol/L above the first noticeable breakpoint in the lactate-velocity curve. Still another method places it at a velocity corresponding to an increase of 1.5 mmol/L above the first breakpoint.

The results of the blood lactate test shown in figure 16.3 have been used to estimate the location of the anaerobic threshold with each of these three methods, and the results are displayed in figure 16.4. Each method results in a different swimming velocity, ranging from 1.38 m/sec (1:13 for 100 m) for a 1.0 mmol/L increase above resting to 1.41 m/sec (1:11 for 100 m) for an increase of 1.5 mmol/L above the first breakpoint on the lactate-velocity curve.

Both of these methods for pinpointing anaerobic threshold speeds, like the fixed thresholds, have demonstrated a significant relationship with endurance performance. Roecker and associates (1998) reported correlations of 0.88 and 0.91 between a threshold located at 1.5 mmol/L above the aerobic threshold and performances in 1,500 and 5,000 m runs. Pfitzinger and Freedson (1998) reported correlations of 0.96 and 0.97 between velocities at which blood lactate increased 1.0 mmol/L above the aerobic threshold and other methods for locating the anaerobic threshold. When an increase of 1.0 mmol/L above resting was used, the correlations between it and other measures of the anaerobic threshold ranged from 0.90 to 0.96.

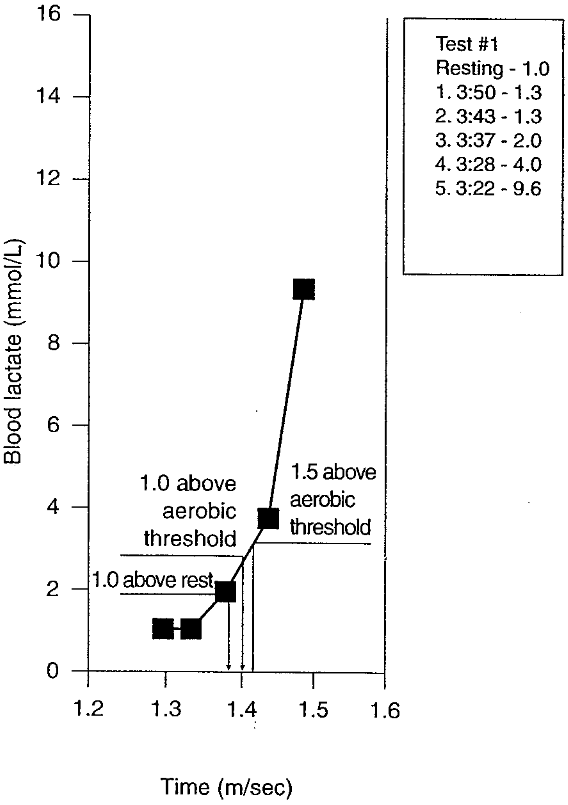


Figure 16.4 Various methods for locating the anaerobic threshold using increases of blood lactate above certain predetermined baseline values.

Intersection Methods The simplest method for determining the individual anaerobic threshold by intersection is to locate the speed at which the rise in the lactate-velocity curve changes from curvilinear to linear. As I mentioned earlier, this is the second breakpoint in the lactate-velocity curve. That breakpoint occurred at a velocity of 1.44 m/sec (1:09 for 100 m) in figure 16.3, which represents the fastest speed at which the balance between lactate entry into and removal from the blood will remain in equilibrium for a reasonable period.

Graphing the test results to locate the swimming velocity that would correspond to the second breakpoint is not even necessary. The swimming times and blood lactate levels could be *eyeballed* to ascertain where the rate of blood lactate increase becomes substantially greater than the reduction in time. This would be between swims #4 and

#5 in figure 16.3 because blood lactate increased 5.6 mmol/L while the swimmer's time improved only 6 sec.

Some experts think that the second breakpoint of the lactate-velocity curve represents a speed that is too fast to be the true anaerobic threshold because it is too close to the point where disequilibrium occurs. A rapid increase in muscle lactate accumulation may have already begun before the rapid increase in blood lactate occurs. Therefore, the swimming speed at which blood lactate begins to accumulate rapidly may actually be above the anaerobic threshold. The other problem is that it is often difficult to determine with reasonable accuracy the point at which the shape of the lactate-velocity curve changes from curvilinear to linear. Some lactate-velocity curves remain somewhat curvilinear at high blood lactate concentrations. Others show a step-wise increase in linearity at low blood lactate concentrations, making it difficult to determine where true linearity began. For this reason, several other intersection procedures locate the anaerobic threshold somewhat below this second breakpoint. These procedures are based on locating it somewhere along the curvilinear portion of the lactate-velocity curve between the first and second breakpoints by projecting the horizontal and vertical portions of that curve to some point of intersection.

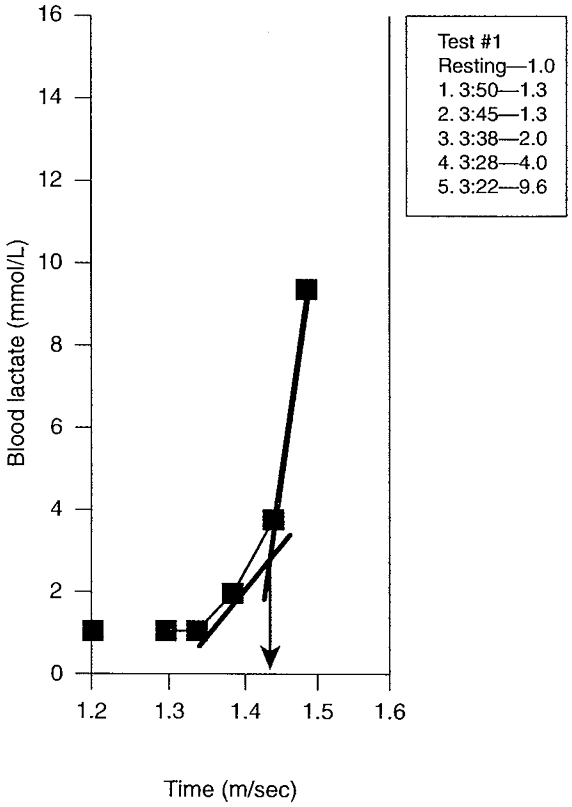


Figure 16.5 A simple method for determining the location of the anaerobic threshold.

Figure 16.5 shows the simplest of these procedures, using the results of the blood test from figure 16.3.

Notice in figure 16.5 that a straight line has been extended along the horizontal slope of the lactate-velocity curve until it intersects with another straight line drawn along the vertical slope of the curve. The swimming velocity where they intersect is considered the anaerobic threshold. In this case, it corresponds to a swimming velocity of 1.44 m/sec, or 1:09 per 100 m.

A second intersection method uses the entire lactate-velocity curve instead of simply the curvilinear portion, as illustrated in figure 16.6. With this procedure, the points corresponding to the first and last swims are joined to form the letter *D* with the lactate-velocity curve. A line is then extended from the middle of the straight line to the farthest point in the curvilinear portion of the lactate-velocity curve. The anaerobic threshold speed corresponds to the point of intersection between that line and the lactate-velocity curve. Using this procedure, the speed at the anaerobic threshold was determined to be 1.43 m/sec, or 1:10 per 100 m. This procedure for locating the anaerobic threshold speed has been termed the *D-max* method (Bishop, Jenkins, and MacKinnon 1998). Many believe it to be better than the previous intersection procedure because it uses more of the lactate-velocity curve.

A modification of the D-max method may be even more accurate for pinpointing anaerobic threshold speeds. In this method, the straight line is extended from the highest point on the lactate-velocity curve to the point where the first increase of blood lactate above the exercise baseline is noticed. The speed corresponding to the anaerobic threshold is then located in the same manner as described for the D-max procedure. For obvious reasons, this method has been termed the *modified D-max* procedure. The method has been used with swimmers at the Australian Institute of Sport. The modified D-max procedure is illustrated in figure 16.7. The swimming velocity at the anaerobic

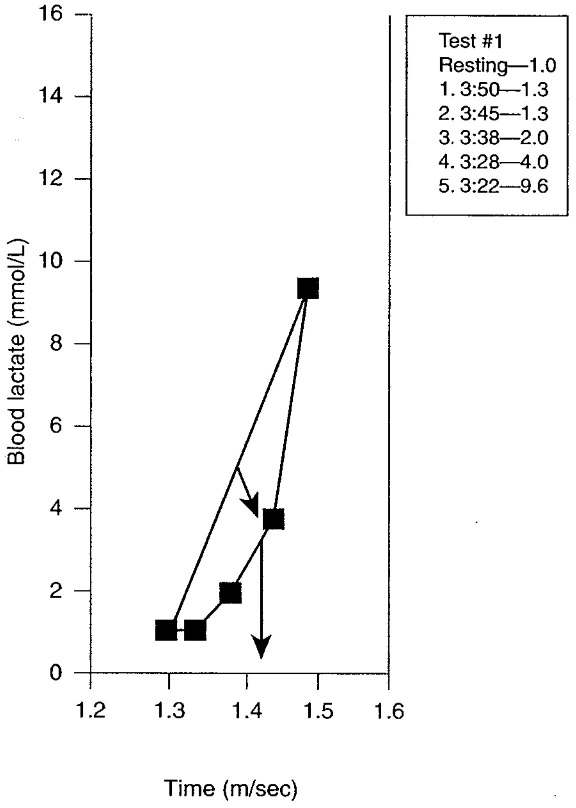


Figure 16.6 The D-max method for determining the location of the anaerobic threshold.

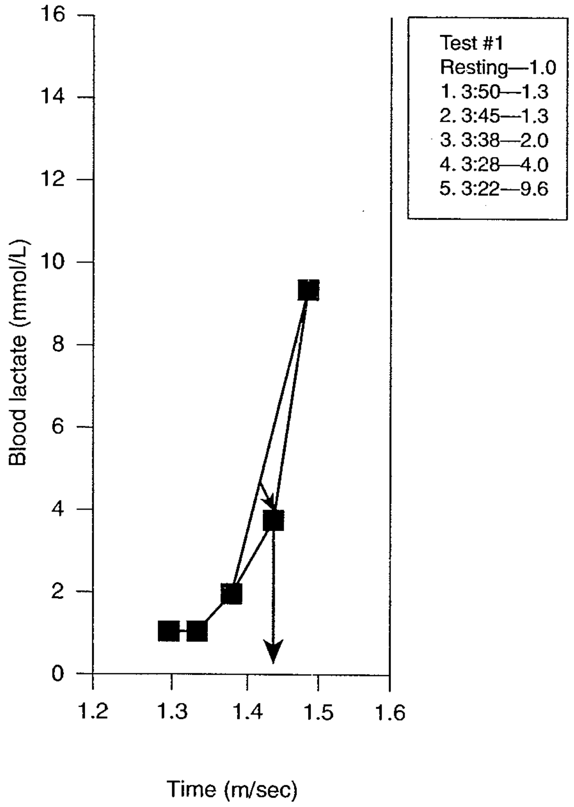


Figure 16.7 The modified D-max method for determining the location of the anaerobic threshold.

threshold was determined to be 1.44 m/sec, or 1:09 per 100 m with this procedure. The modified D-max method is believed to be superior to other intersection methods because it includes only those portions of the lactate-velocity curve where an increase in blood lactate has occurred.

Lactate Minimum Test The final procedure that I want to present for locating the anaerobic threshold is quite different from the others. Developed by Griess (1988) and Tegtbur and associates (1993), it has been termed the *lactate minimum test.*

With this procedure, athletes first swim two maximum effort 50 m repeats with a 10 sec rest interval after the first. The purpose of these swims is to produce a very high blood lactate concentration. That occurrence is verified by taking a sample of blood 8 min after the second 50 m swim. After that, the athletes swim a series of five 300 m repeats, starting at a slow speed and swimming each succeeding repeat 6 sec faster than the one before. A blood sample is taken and analyzed for lactate content after each swim. The results of a lactate minimum test are shown in figure 16.8.

In this case, the athlete's blood lactate concentration was 9.6 mmol/L when she started the first 300 m swim. Because the blood lactate level was high when she started, any speed slower than threshold speed should result in an even lower lactate level at the end of the swim. That is what happened in this example. The blood lactate after the first swim declined to 7.0 mmol/L, indicating that lactate was being removed faster than it was produced at the speed of the first swim. Blood lactate was measured after each of the four succeeding swims. Blood lactate continued to decline until the athlete was swimming at a speed at which the rate of lactate production exceeded its rate of removal and blood lactate started to increase. That increase signals that the anaerobic threshold has been exceeded. This athlete's blood lactate concentration increased during swim #4 in figure 16.8, rising from a concentration of 3.6 mmol/L on the previous swim

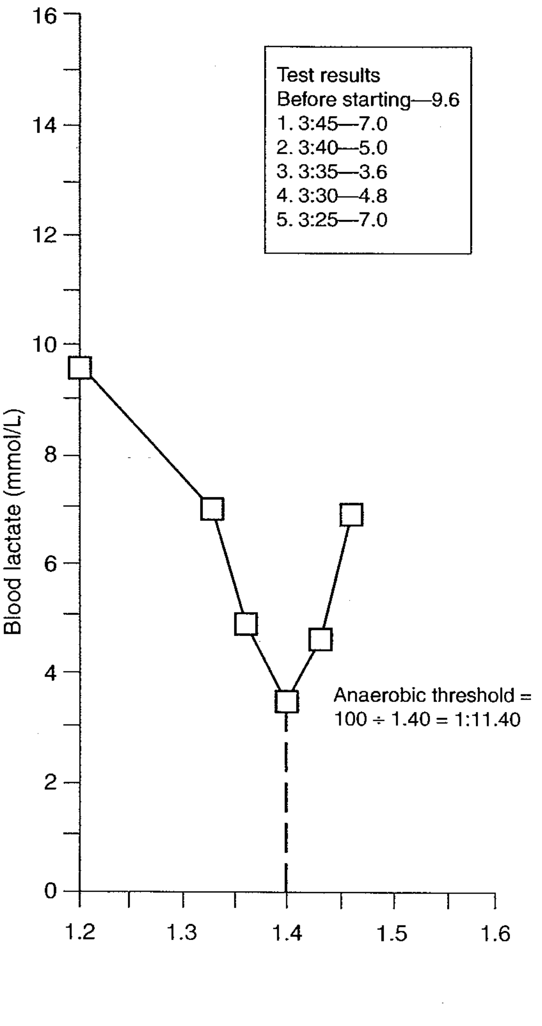


Figure 16.8 The lactate minimum test.

to 4.8 mmol/L at the end of the fourth swim. The velocity of the third swim was recorded as the anaerobic threshold speed because it was the fastest speed before the level of lactate began to increase in this athlete's blood. The velocity for that swim was 1.40 m/sec, or 1:11 per 100 m.

Although this procedure seems a reasonable way to estimate an athlete's anaerobic threshold speed, there is one problem with its use. The test determines the fastest speed at which the rate of lactate removal from the blood was greater than its rate of entry. It did not locate the fastest swimming speed at which those rates were in equilibrium. Therefore, the speed resulting from the lactate minimum test may be somewhat slower than the true anaerobic threshold speed.

Locating the anaerobic threshold with pinpoint accuracy is obviously difficult, but coaches and athletes should not be too concerned about accuracy. Although the various procedures produce somewhat different anaerobic threshold velocities, all demonstrate a high positive relationship with performance and with each other. Consequently, all produce values close enough to a particular athlete's true individual anaerobic threshold that they can serve as valid reference points for evaluating changes in aerobic endurance.

Peak Blood Lactates: What Do They Tell Us?

Because the rate of lactic acid production in muscles will rise in proportion to an increase in the rate of anaerobic metabolism, peak blood lactates following all-out efforts have been suggested to indicate the rate of anaerobic metabolism occurring in muscles. Because much of that lactic acid will be transported to the bloodstream, it has been assumed that high peak blood lactate concentrations indicate a rapid rate of anaerobic metabolism. It is not clear, however, what aspects of anaerobic metabolism are reflected by high peak blood lactates. Peak blood lactates after maximum efforts, like lactate values at lower levels of effort, are an indirect way of assessing the nature of the metabolic activity in muscles during exercise. Accordingly, high peak values could represent a rapid rate of anaerobic metabolism, a high level of buffering, or both. Let me explain this statement.

Peak blood lactates usually occur in muscles and blood after maximum efforts of 1 to 2 min. Shorter efforts do not provide enough time for maximum accumulation, whereas longer efforts provide time for a significant amount of the lactic acid to be removed from muscles and blood. When a large amount of lactic acid accumulates in muscles during a maximum effort of 1 to 2 min, a rapid rate of anaerobic metabolism is undoubtedly the cause. Anaerobic metabolism could not continue at that high rate, however, unless buffering slowed the drop in muscle pH. Therefore, peak blood lactates probably reflect both the rate of anaerobic metabolism and the effectiveness of muscle buffers.

Sprinters regularly attain higher peak blood lactate values than distance athletes do (Komi et al. 1977), and significant relationships have been reported between peak blood lactates and performances in sprint events (Berg and Keul 1985; Cheetham and Williams 1987; Cheetham et al. 1986; Fujitsuka et al. 1982; LaCour, Bouvat, and Barthelemy 1990; Ohkuwa et al. 1984).

This may occur because sprinters tend to have more fast-twitch muscle fibers and higher rates of anaerobic metabolism. Distance swimmers, on the other hand, have fewer fast-twitch muscle fibers and lower rates of anaerobic metabolism; consequently, their peak blood lactates are generally lower.

The extent to which training can change peak blood lactates is a matter of debate among scientists. Sprint training undoubtedly increases the rate of anaerobic metabolism and therefore the amount of lactic acid produced in muscles during maximum efforts. One study reported a 20% increase (Nevill et al. 1989). What is not clear, however, is whether peak blood lactate values also increase after sprint training. Several researchers have reported increases (Cunningham and Faulkner 1969; Hermansen 1969; Jacobs 1986; Jacobs et al. 1987; Sharp et al. 1986), whereas others found no increase despite the fact that performances improved during sprinting tests (Cheetham and Williams 1987; Medbo and Burgers 1990; Roberts, Billeter, and Howald 1982; Trappe 1996).

Evidence suggests that measurements of peak blood lactates have some predictive value concerning improvements in sprint performance. Making accurate measurements, however, is problematic. For one, athletes must provide a maximum effort to get a true measure of their peak blood lactate concentration. In addition, they must be willing to reproduce that effort from test to test to accurately measure the magnitude of training-induced changes in the rate of anaerobic metabolism from those peak blood lactates. Athletes must be highly motivated when a peak blood lactate test is administered. For this reason, the best time to measure peak blood lactates may be following races in competition. In this respect, Sawka and his associates (1979) reported that post-competition blood lactates were higher than blood lactate concentrations after time trials at the same race distances for a group of competitive swimmers.

I mentioned earlier that several blood samples should be taken after a maximum effort to achieve an accurate measurement of peak blood lactate because a great deal of lactic acid will still be in the muscles when a swim is finished. Three to 12 min may pass before enough of that lactic acid is transported out of the muscles and into the blood for the amounts in both compartments to become equal.

Another problem in determining a true peak blood lactate is that the amount of glycogen stored in subjects' muscles must be similar from test to test to achieve an accurate comparison of peak blood lactates. A reduction in muscle glycogen will produce lower peak blood lactate levels, whereas an increase in the amount of muscle glycogen stored in muscles will increase the amount of lactic acid that appears in the blood after a maximum effort. In one study with swimmers, peak blood lactates fell by 25% on a low carbohydrate diet and increased by 25% when the athletes consumed a high carbohydrate diet (Reilly and Woodbridge 1999).

A final consideration concerns the lactate level in an athlete's blood before a maximum effort swim. Blood lactate concentrations should be at resting levels before the start of a maximum effort. Any increase in the resting level resulting from previous swims will add to the lactate poured into the blood during the maximum effort. This addition will cause a false increase in the peak blood lactate, which could be misinterpreted as an improvement in anaerobic metabolism when none had taken place. Subjects need to rest until their resting blood lactate levels return to normal before attempting any swim used to measure peak blood lactates. A rest of 30 min is usually required.

For best results, measurement of peak blood lactates should be carefully controlled and interpreted. Some suggestions for taking accurate measurements follow:

- Tests for peak blood lactates should be taken after athletes have rested for a day or two to ensure that muscle glycogen concentrations are high.
- Athletes should be highly motivated for these tests. Testing after competitions will probably produce more reliable results than testing with time trials.

- The test distance should be standardized. Distances of 100 to 200 yd or m are probably best suited for producing peak blood lactates, although distances of 400 m and 500 yd could be used if athletes race at those distances.
- Maximum effort tests should not be attempted until athletes have completely recovered from any previous swims and their blood lactate concentrations are at resting levels.
- Finally, several samples of blood should be collected at 2 min intervals after a maximum effort. The first sample should be taken within 2 or 3 min after the athlete has completed the swim, and each succeeding sample should be taken 2 min later until a drop in blood lactate occurs from one sample to the next. To ascertain the maximum level of lactate in the blood after a maximum effort, it may be necessary to take samples at 2 min intervals for up to 13 min after the completion of a swim.
- Coaches should use peak blood lactate measurements in conjunction with some other test or tests of sprinting performance to aid in making accurate judgments.

Slope of the Lactate-Velocity Curve: What Does It Mean?

The slope, or angle of inclination, of the steep portion of the lactate-velocity curve can provide some information about the aerobic and anaerobic muscular endurance of middle distance and distance swimmers and about the anaerobic capacity of sprinters. I will use the results of the blood test shown in figure 16.3 (page 544) to help explain what is meant by the slope of the lactate-velocity curve.

The slope of interest is on the steep portion of the lactate-velocity curve where the rise in blood lactate becomes linear. That occurs between the second lactate breakpoint and the last plot on the curve in figure 16.3. The angle of inclination for this portion of the curve is 70 degrees. In general terms, a smaller angle, that is, a flatter slope, indicates better aerobic and anaerobic muscular endurance because blood lactate will be accumulating at a slower rate relative to increases in swimming velocity. The assumption is that blood lactate is accumulating at a slower rate because lactic acid is accumulating at a slower rate in the muscles. Therefore, muscle pH will not be declining at a rapid rate. On the other hand, a steeper rise in the curve, one that is closer to perpendicular, indicates the opposite effect. Muscle lactate is probably accumulating rapidly for small increases in swimming speed, and severe acidosis is imminent. Because swimmers are usually on the steep portion of the lactate-velocity curve, some scientists have suggested using changes in swimming velocity at fixed blood lactate concentrations of 6, 8, or 10 mmol/L to evaluate changes in aerobic and anaerobic muscular endurance.

Using peak fixed blood lactate values is a simple way to evaluate changes in the slope of the lactate-velocity curve. They can be misleading with certain athletes, however, for the same reasons that fixed values can be misleading when they are used to locate the aerobic and anaerobic thresholds. Those values may not mean the same thing for athletes with unusually high or low peak blood lactate concentrations or for those who have unusually high or low blood lactate values at their individual anaerobic thresholds. Swimmers with low values could be swimming at maximum speeds before their blood lactate concentrations reach 6 mmol/L, whereas athletes with very high blood lactate concentrations may only be approaching their anaerobic threshold speeds at blood lactate concentrations of 6 or 8 mmol/L. Based on this reasoning, the swimming velocity at 6 mmol/L should work better for evaluating the aerobic and anaerobic muscular endurance of distance swimmers than it does for sprinters and middle distance swimmers because most distance swimmers do not have peak blood lactate values much higher than 8 to 12 mmol/L. Consequently, this value would be approximately midway between their blood lactate concentrations at their individual anaerobic thresholds and their peak blood lactate values. Swimming speeds that produce a blood lactate value of 8 or 10 mmol/L may work better for middle distance and distance swimmers because the blood lactate values at their individual anaerobic thresholds and their peak blood lactate values are usually higher.

The Australian Institute of Sport has used an excellent procedure for interpreting changes in the slope of the lactate-velocity curve. They calculate the differences between an athlete's swimming velocities at two points along the steep portion of the lactate-velocity curve. The larger the difference, the better the result. A large difference indicates that the slope of the curve is not very steep and that the athlete can increase his or her velocity considerably along the anaerobic portion of the curve before acidosis sets in. They calculate the difference in swimming velocities between blood lactate concentrations of 5 and 10 mmol/L for this purpose. This procedure, called the dV5-10 method, is illustrated in figure 16.9.

The swimmer completes a standard graded test, swimming a series of repeats at progressively faster speeds. The repeat distances can be 100 to 400 m. The shorter distances of 100 and 200 m are best for sprinters, and the longer distances of 300 and 400 m are better suited for evaluating middle distance and distance swimmers. A repeat distance of 200 m has been used in the example in figure 16.9. Samples of blood are taken and analyzed for lactate after each of five swims. The blood lactate concentrations are then graphed opposite the swimming velocities that produced them.

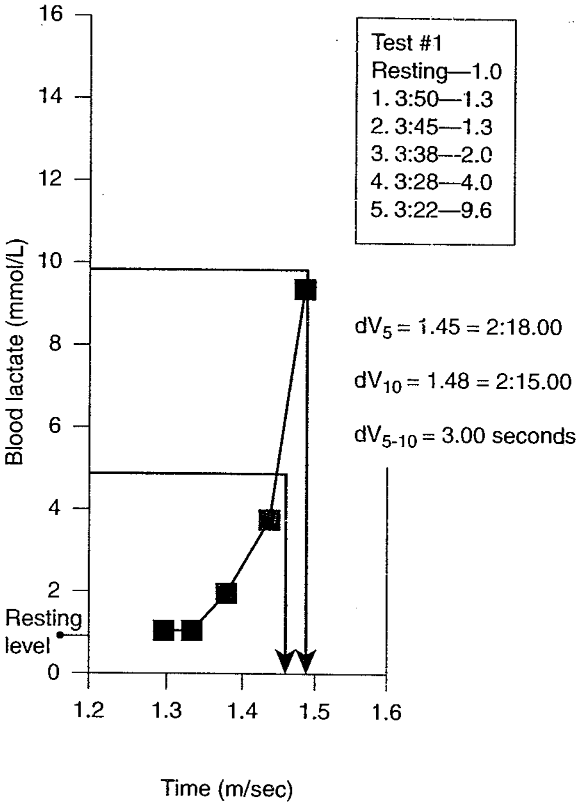


Figure 16.9 The dV5-10 method for estimating aerobic and anaerobic muscular endurance.

The velocity at blood lactate concentrations of 5 mmol/L and 10 mmol/L are then determined from the swimming velocities corresponding to the points of intersection of these lactate values with the lactate-velocity curve. Next, those swimming velocities are converted to times for 200 m. In figure 16.9, the time at 5 mmol/L was 2:18, and at 10 mmol/L it was 2:15. The time corresponding to a blood lactate concentration of 10 mmol/L is then subtracted from the time at 5 mmol/L and the difference is recorded as the dV5-10 time. That time is 3 sec in figure 16.9. As I mentioned earlier, indications are that an athlete's performance potential increases when this difference becomes greater. The athlete is probably accumulating less lactic acid in the muscles and he or she will be able to swim longer at race speed before muscle pH drops to very low levels and severe acidosis occurs. Similarly, a smaller difference indicates that the slope of the lactate-velocity curve has become steeper. In that case, blood lactate is probably accumulating more rapidly at race speeds, and the athlete will fatigue more quickly.

Using Blood Tests to Train Swimmers

Blood testing results such as those in figure 16.3 can be used to monitor training in several ways. The first is to evaluate changes in aerobic and anaerobic metabolism. A second is to prescribe optimum speeds for endurance and sprint training, and the third is to determine performance potential. I will discuss how blood testing can be used for each of these purposes in the next sections. Before doing so, however, I want to comment on the effect that different repeat distances have on the results of blood tests.

Effect of Repeat Distances on Thresholds

Different repeat distances will not yield the same swimming velocities at reference points along the lactate-velocity curve. For example, the swimming velocity at any fixed blood lactate concentration will be greater when repeat distances of 100 yd or m are used in the testing protocol, and it will be slower when longer repeat distances are used. This probably occurs because more lactic acid can be eliminated during the longer swims. In one study, the swimming velocity that produced a blood lactate concentration of 4 mmol/L was approximately 1.38 m/sec when 300 m repeats were used in the test protocol. When 100 m repeats were used, a swimming velocity of approximately 1.47 m/sec was required to produce the same blood lactate concentration (Keskinen, Komi, and Rusko 1989). That difference is nearly 2.50 sec per 100 m. Consequently, blood testing protocols in which short repeats are used will overestimate the individual anaerobic threshold speeds of athletes. Note that the swimming velocities corresponding to the aerobic threshold were nearly identical regardless of whether 100 or 300 repeats were used in the test protocol.

Lactate step tests apparently reflect the performance potential of athletes more accurately when the repeat distances are close to the race distances for which they are training. That is, a protocol using 100 repeats works best for sprinters, a protocol with 200 repeats is best for 200 swimmers, and a protocol using 400 repeats is best for middle distance and distance swimmers. Protocols that use repeat distances of 300 to 500 yd or m seem to be best, however, when the purpose is to identify individual anaerobic threshold speeds or prescribe endurance training speeds. Shorter repeat distances will overestimate those speeds.

Evaluating Changes in Aerobic and Anaerobic Metabolism

Blood tests should be administered every 3 to 4 weeks and the results compared with previous tests to evaluate changes in aerobic and anaerobic metabolism. When the results of two or more blood tests have been graphed and compared, judgments about the nature of changes in aerobic and anaerobic metabolism are generally based on the direction that the lactate-velocity curve has moved on the later tests.

In the early days of blood testing, people thought that making interpretations was simple and straightforward. Three possible assessments could be made:

1. The athlete was improving if the lactate-velocity curve moved to the right on a subsequent test. This occurred because less lactate was accumulating in the blood at speeds similar to those in the first test or because the athlete was swimming faster without increasing blood lactate.
2. The athlete's physical conditioning was becoming worse if the lactate-velocity curve moved to the left on a subsequent test. This occurred because blood lactate concentrations were higher at speeds similar to those in the first test or because blood lactate concentrations were similar at slower speeds.
3. The athlete's physical condition had not changed if the curve did not move to the right or left.

These simple interpretations did not recognize that training causes complex and conflicting changes in the rates of aerobic and anaerobic metabolism. As indicated earlier, endurance training tends to reduce the rate of anaerobic metabolism, and sprint training will increase it. When the rate of anaerobic metabolism is high, a great amount of pyruvic acid will be produced rapidly at submaximal swimming speeds and a greater portion of that pyruvate will combine with hydrogen ions to form lactic acid. As a result more of that lactic acid will be transported out of the muscles and into the bloodstream so that the lactic acid concentration in the blood will be higher at lower levels of effort. When this happens, the lactate-velocity curve will move to the left, giving the appearance that aerobic capacity has declined. But it may not have changed at all, or it may have even improved. On the other hand, when the rate of anaerobic metabolism declines, less pyruvic acid will be produced at submaximal swimming speeds. Therefore, less lactic acid will be produced and transported to the blood, and the blood lactate concentration will be lower than it was on previous tests. The lactate-velocity curve will move to the right, even if no real improvement occurred in aerobic capacity. Table 16.1 summarizes this complex relationship between aerobic and anaerobic metabolism.

Table 16.1 Effects of Changes in Aerobic Capacity and Anaerobic Power on Blood Lactate

PHYSIOLOGICAL MECHANISM	CHANGE	EFFECT ON BLOOD LACTATE
Aerobic capacity	Improved	Reduced
	Reduced	Increased
Anaerobic power	improved	Increased
	Reduced	Reduced

Based on these reactions, when the blood lactate concentration for a particular swimming speed decreases from one test to the next, aerobic capacity may have improved or the rate of anaerobic metabolism may have decreased. The former adaptation, of course, would be considered a positive effect of training for any athlete. On the other side of the coin, the latter change would be considered negative for sprinters and middle distance swimmers because their performance would probably suffer if their rates of anaerobic metabolism decreased. Their ability to make energy available at an accelerated rate would decrease, so their speed would probably decline. The performance of distance swimmers could even suffer for the same reason if their rates of anaerobic metabolism fell by an unusually large amount.

To complicate matters further, several other factors can cause results of blood tests to be misleading:

- Changes in muscle glycogen storage from one test to the next can alter results. Research has shown that the lactate-velocity curve will shift to the right on a subsequent blood test when the glycogen level in muscles is considerably lower than it was on a previous test (Ivy et al. 1980; Reilly and Woodbridge 1999). This result can occur even when aerobic capacity has not improved. The curve shifts to the right because anaerobic metabolism cannot proceed at a fast rate unless an adequate supply of glycogen is available in muscles. In one study, the swimming velocity corresponding to a blood lactate concentration of 4 mmol/L increased 0.30 m/sec after only a few days when muscle glycogen was reduced by a combination of a low carbohydrate diet and heavy training (Reilly and Woodbridge 1999). Drinking caffeine before testing will also increase fat metabolism and cause swimming velocity at the aerobic and anaerobic thresholds to increase when aerobic capacity has not improved.

Unusually high amounts of glycogen in the muscle during a subsequent test can cause the opposite reaction from low muscle glycogen. The lactate-velocity curve will shift back to the left, with blood lactate increasing at the same or slower velocities when no change has taken place in aerobic capacity. The blood lactate increase would be particularly evident if muscle glycogen had been especially low at the time of the first test.

An increase of muscle glycogen on a subsequent test provides a probable explanation for the false losses of aerobic capacity that have been reported during periods when swimmers are tapering (Gullstrand 1985; Sharp 1984). Several researchers and coaches have reported that the lactate-velocity curve shifted back to the left during the taper. At first, people believed that this effect represented a loss of aerobic capacity. That evaluation was reassessed, however, after several swimmers performed well despite this leftward movement of the lactate-velocity curve. The increase of blood lactate at slower swimming speeds during the taper probably does not indicate a loss of aerobic capacity. More likely, the increase occurs because of a supercompensating effect on the amount of glycogen stored in muscles. Day-to-day training during previous phases of the season often depletes muscle glycogen, creating a stimulus for muscles to store up to double the usual amount of this foodstuff when the workload decreases during a taper. Consequently, with more glycogen in the muscles, the rate of lactic acid production increases during slow swims, which is why a blood lactate test taken during this period would produce a result of more lactate at slower speeds even when the rate of aerobic metabolism has not decreased.

- Weight training within 24 hr of a blood test is another factor that can result in misleading results. Intense exercise of this nature can cause muscle damage that will result in a greater rate of lactate accumulation at slower speeds.
- Intense training within 24 hr of a blood test may cause errors of interpretation. Training of this type will reduce muscle glycogen and swimming velocity at the aerobic and anaerobic thresholds, causing blood lactate to increase more at the same or slower swimming velocity for the reasons stated earlier with respect to glycogen depletion (Fric et al. 1988; McKenzie and Mavrogiannis 1986).
- Sprinting during the warm-up before a blood test may cause blood lactate values to increase for similar speeds, causing the lactate-velocity curve to shift back to the left even when no loss of aerobic endurance has occurred. Sprinting will cause blood lactate levels to rise above normal resting levels before the blood test begins, so the blood lactate values during the test will be higher than they would have been otherwise.
- Blood testing in the morning can cause a false leftward shift of the lactate-velocity curve. Blood lactate concentrations tend to be higher at a given swimming velocity when testing is conducted in the morning as compared with testing completed in the afternoon. Athletes can usually swim about 1 sec faster per 100 m in the afternoon, or about 2% faster, with no increase in their blood lactate concentrations than they can swim in an identical step test conducted in the morning (Olbrecht et al. 1988).
- Testing in short-course pools will result in faster threshold velocity than testing in long-course pools. For this reason, test results from 25 m and 50 m pools cannot be compared with one another. The swimming velocities that produce certain blood lactate concentrations will be somewhat slower when the testing is done in long-course pools, probably because swimmers turn less. Olbrecht and coworkers (1988) found that athletes produced the same blood lactate concentrations at speeds that were 5.6% slower on average (3 to 5 sec slower per 100 m) when tested in a 50 m pool instead of a 25 m pool.

From this discussion, it should be obvious how important it is to make accurate assessments of the reasons for changes in the relationship of blood lactate and swimming velocity from one test to the next. Otherwise, the potential performance of a particular swimmer could be worsening when it seems to be improving. Conversely, it may actually be improving when it seems to be deteriorating. But when the conditions for blood tests have been carefully controlled to eliminate possible misinterpretations from factors such as those just described, the results can provide useful information concerning the effects of training on aerobic and anaerobic metabolism.

One simple procedure can help evaluate whether changes in blood lactate truly represent improvements of aerobic and anaerobic metabolism or are instead caused by one or more of the factors just cited. The solution is to include a maximum or near-maximum time trial as part of the blood testing protocol. After completing a typical step test, the athlete should rest for 30 min or more and then complete a fast swim of 100 to 200 m. When this swim produces a high peak blood lactate and a fast time, one can be reasonably certain that muscle glycogen levels were high during the test. If it produces a high peak blood lactate at a slow speed, the possibility exists that factors such as weight training or sprinting may have resulted in an elevated blood lactate during the preceding step test. Therefore, the results should be evaluated cautiously. Conversely, a low peak blood lactate at a slow speed could indicate that muscle glycogen was low during the step test. The addition of a swim at maximum or near-maximum effort can also provide some insight about the effect training has had on an athlete's anaerobic power. The graphs in figure 16.10 through 16.14 depict some ways in which the lactate-velocity curve from a typical step test can change from time to time and the way that peak blood lactates can be used to interpret these curves more accurately. I will begin with a discussion of the possible interpretations for rightward shifts and then present some information on how to interpret certain leftward shifts. Finally, I will discuss some confusing shifts of lactate-velocity curves that cannot be described as either completely leftward or rightward movements.

Evaluating Rightward Shifts of the Lactate-Velocity Curve The graph in figure 16.10 shows the results of two blood tests in which the lactate-velocity curve shifted to the right during the second test. The time between tests was 4 weeks. The athlete swam 5 × 300 m at progressively faster speeds on both tests. He also swam one maximum effort 200 m time trial 30 min after finishing the fifth 300 swim. Blood samples were taken after each swim and analyzed for lactate content. Next, the blood lactate concentrations were graphed opposite the velocities for the swims that produced them.

Notice that for every swim on the second test, blood lactate concentrations were lower at the same velocity. As a result, the lactate-velocity curve for the second blood test moved to the right and downward with respect to the first test. The athlete's peak blood lactate has also increased from the first to second tests, as did his velocity for the maximum effort 200 m swim. This caused the plot for peak blood lactate to move to the right and upward.

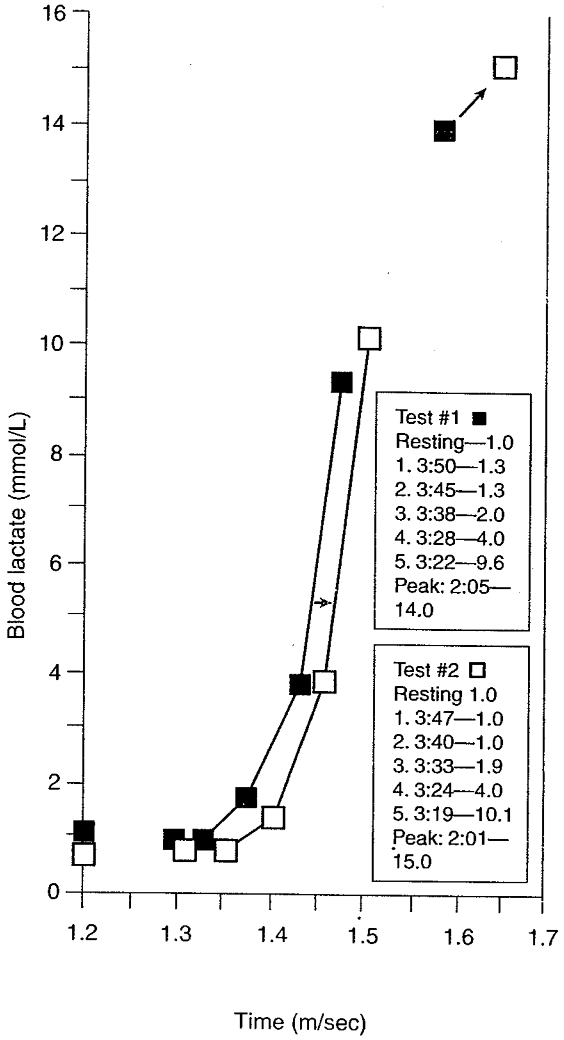


Figure 16.10 Results of two blood tests taken 4 weeks apart in which both the aerobic and anaerobic aspects of metabolism improved.

A comparison of the results of the first and second blood tests shows that this athlete has improved both aerobic and anaerobic metabolism. The movement of the lactate-velocity curve to the right and downward between the first and second lactate breakpoints on the second blood test indicates an improvement in aerobic capacity. The shift to the right on the linear portion of the lactate-velocity curve suggests that aerobic and anaerobic muscular endurance have also improved. The higher peak blood lactate concentration at a faster speed on the second test suggests that this athlete's anaerobic power may have also improved.

The movement of the curvilinear portion of the lactate-velocity curve to the right and downward from the first test to the second test suggests that aerobic capacity has improved. That movement could also mean that the rate of anaerobic metabolism had decreased or that muscle glycogen was greatly depleted on the second test. But the rightward movement of the linear portion of the curve and the combination of a higher blood lactate and a faster speed on swim #5 provide an indication that real improvement has occurred in aerobic and anaerobic muscular endurance. The fact that the peak blood lactate was higher and that the time for the swim that produced it was faster suggests that anaerobic power has also improved. This in itself is a good effect. In addition, the higher blood lactate and faster speed supplies evidence that the rightward movement of the lactate-velocity curve in figure 16.10 resulted from improvement of aerobic metabolism instead of a decrease of anaerobic metabolism.

The results of two blood tests in which a rightward movement of the lactate-velocity curve on the second test is misleading are shown in figure 16.11. In this case, the athlete did not improve his aerobic capacity. The lactate-velocity curve moved to the right because he lost anaerobic power. Notice that the athlete's time was slower and that his blood lactate concentration was lower on swim #5 of the second test. The time and blood lactate concentration was 3:25 and 7.5 mmol/L on the second test compared with 3:22 and 9.6 on the first. This is the first indication that an improvement in aerobic metabolism has not taken place, although by itself it does not provide conclusive evidence of a loss of anaerobic power. A low muscle glycogen level may have caused the slower time, or it may be that the athlete did not try as hard during swim #5 on the second test as he had on the first. The swimmer's slower time and lower blood lactate on the 200 time trial for the second test provide the conclusive evidence that he has probably lost anaerobic power. His time was 2:07, and his blood lactate concentration was 12.0 mmol/L on the second test compared with a time of 2:05 and a blood lactate concentration of 14.0 mmol/L on the first test. Assuming that he was equally motivated for both swims, this result, together with the results of the 300 swims, strongly suggests that the rightward movement of the lactate-velocity curve on the second test was caused not by an improvement in aerobic metabolism but by a reduction in his rate of anaerobic metabolism or by a low muscle glycogen level at the time of the second test. A low muscle glycogen level can be eliminated as the cause for this rightward shift if the athlete was given a few days of easy swimming before the second test. The logical explanation would be that his anaerobic power decreased. With a result like this, the athlete should reduce his endurance training and increase his lactate production training until he achieves a high peak blood lactate on a subsequent test.

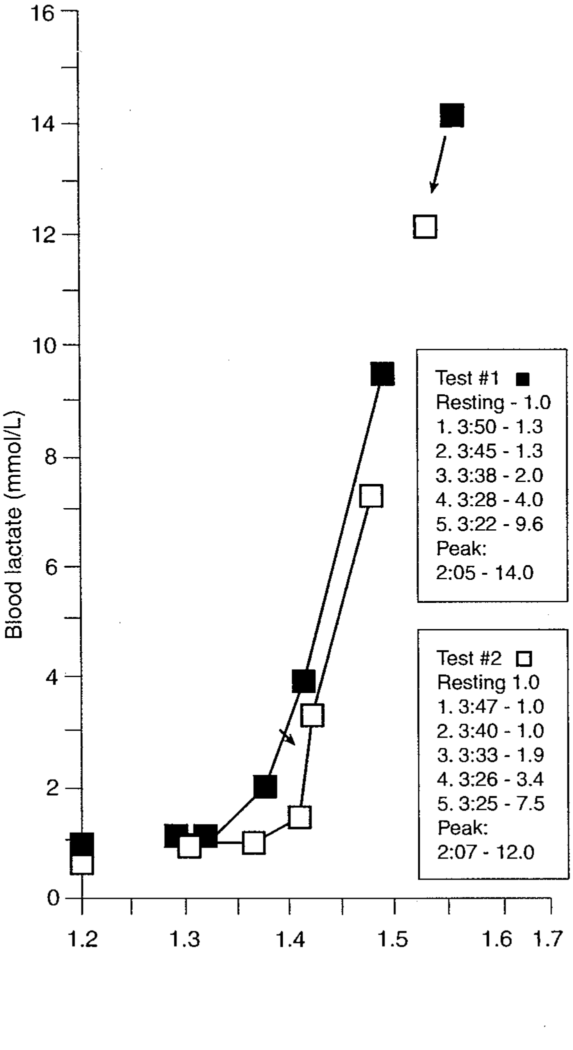


Figure 16.11 The results of before and after blood tests taken 4 weeks apart in which the rightward movement of the lactate-velocity curve on the second test probably indicates a reduction in the rate of anaerobic metabolism or a low level of muscle glycogen instead of an increase in the rate of aerobic metabolism.

Evaluating Leftward Shifts of the Lactate-Velocity Curve A leftward shift of the lactate-velocity curve usually signals a reduction of aerobic capacity, which, of course, is undesirable. But it could also mean that an athlete's rate of anaerobic metabolism has increased. This would be a desirable effect for sprinters and, under certain conditions, for middle distance and distance swimmers. Figures 16.12, 16.13, and 16.14 show the results of before and after blood tests in which leftward movements of the lactate-velocity curve indicate desirable and undesirable responses to training. I will begin with the lactate-velocity curve in figure 16.12, which indicates a loss of both aerobic and anaerobic capacity.

A movement to the left on the curvilinear portion of the lactate-velocity curve in figure 16.12 suggests that more lactic acid is being produced and is accumulating in the muscles at similar or slower speeds during the second test. This, of course, indicates that this athlete's rates of aerobic metabolism and lactate removal have probably deteriorated from the first to second testing period. The swimmer is likely not oxidizing pyruvate or removing lactate from his muscles and blood as rapidly as he did 4 weeks earlier. Although this effect could be caused by an increase in anaerobic metabolism, two aspects of the lactate-velocity curve for test #2 indicate that a loss of aerobic capacity rather than an increase of anaerobic metabolism caused the leftward shift.

First, no increase in peak blood lactate occurred on the second 200 test. The peak blood lactate value is the same as it was for test #1, and the time for the swim was slower. The swimmer's time for the 200 time trial was 2:07 on the second test versus 2:05 on the first, whereas blood lactate concentrations were 14.0 mmol/L on both. This suggests the athlete's rate of anaerobic metabolism had not increased at the time of the second test. Peak blood lactate probably would have been higher if an increase in the rate of anaerobic metabolism was causing a false leftward movement of the lactate-velocity curve.

The second factor is that the lactate-velocity curve moved left at slow swimming speeds on test #2. Aerobic metabolism should have provided most of the energy at those speeds. Therefore, blood lactate should not increase unless the rates of aerobic metabolism and lactate removal had deteriorated.

The lactate-velocity curves in figure 16.13 demonstrate an instance in which a leftward movement of the lactate-velocity curve was probably caused by an increase in anaerobic power rather than a loss of aerobic capacity. In this figure, the results of the second test show large increases of blood lactate for both the final 300 swim and the 200 time trial. The fact that this athlete has improved his anaerobic power without losing endurance is indicated by the improvement in his time for the 200 swim on the second test. A result like this should not be cause for concern. This swimmer will probably swim well in competition.

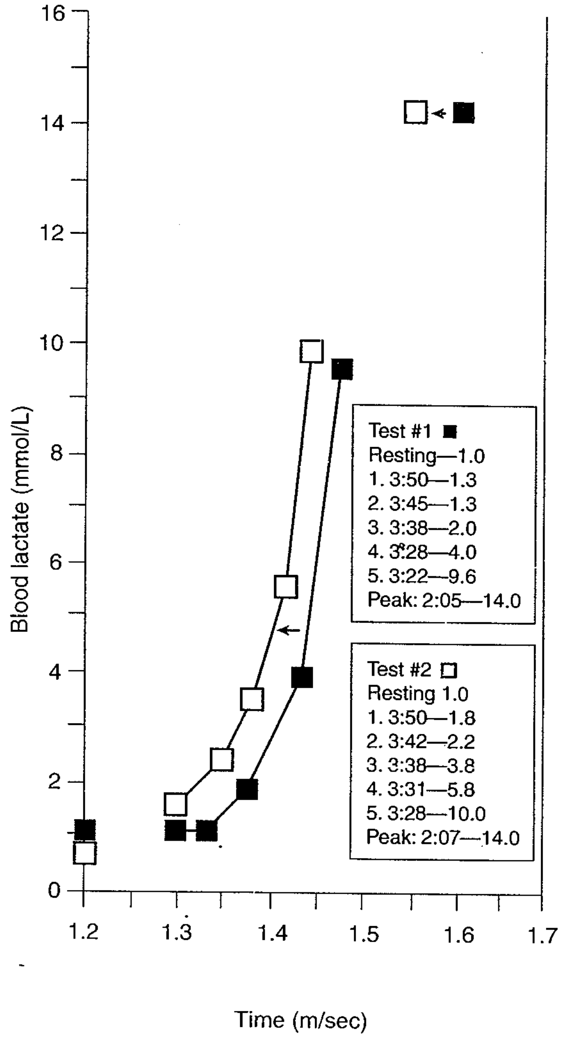


Figure 16.12 The results of before and after blood tests taken 4 weeks apart that indicate a loss of aerobic capacity.

Figure 16.14 shows a result that should cause concern. In this case the blood lactate concentrations are higher for all swims and the times are slower on the second test. These results suggest a considerable loss of aerobic capacity, which will almost certainly result in poor performance. A comparison of the lactate-velocity curves shows that the athlete's blood lactate values are higher at slower velocity during the second test. Of course, weight training within 24 hr of the second test or swimming too intensely during the warm-up before the second test could have caused these results. But the higher blood lactate and a slower time for the second 200 swim indicate that this athlete has probably lost aerobic capacity. He would most likely have a lower blood lactate and a slower time on that 200 swim if his anaerobic power had declined.

Prescribing Training Speeds From Blood Tests

The best way to prescribe training speeds with blood testing is to use one of the methods described earlier for determining the swimming speeds of athletes at their individual aerobic and anaerobic thresholds. Those speeds can be expressed as swimming velocities in m/sec and then converted to times for the repeat distances to be used in training. Figure 16.15 illustrates the procedure for doing this. The aerobic threshold for this swimmer was calculated to be 1.33 m/sec (the first breakpoint on the lactate-velocity

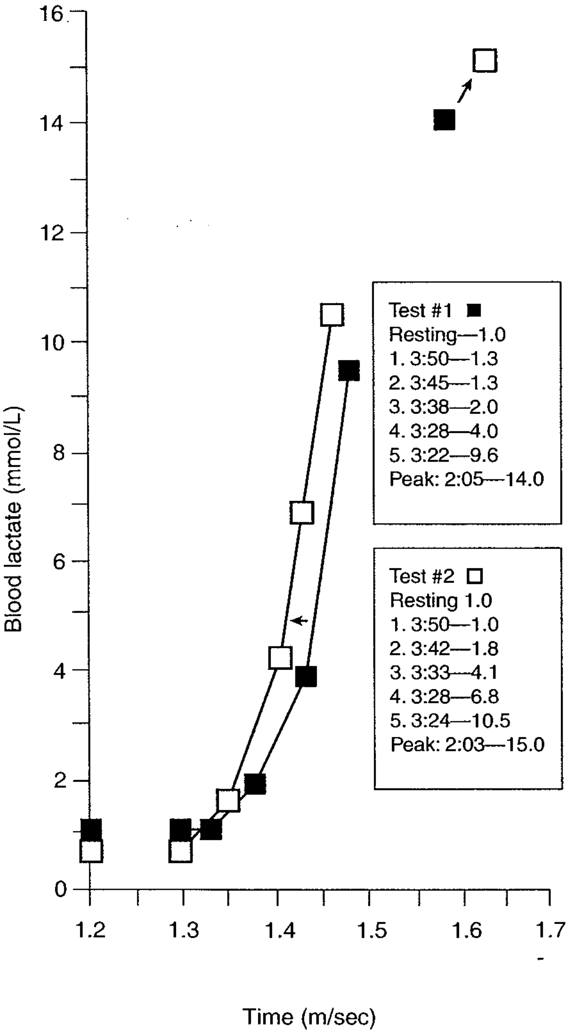


Figure 16.13 Results of two blood tests taken 4 weeks apart in which the rate of anaerobic metabolism has probably increased.

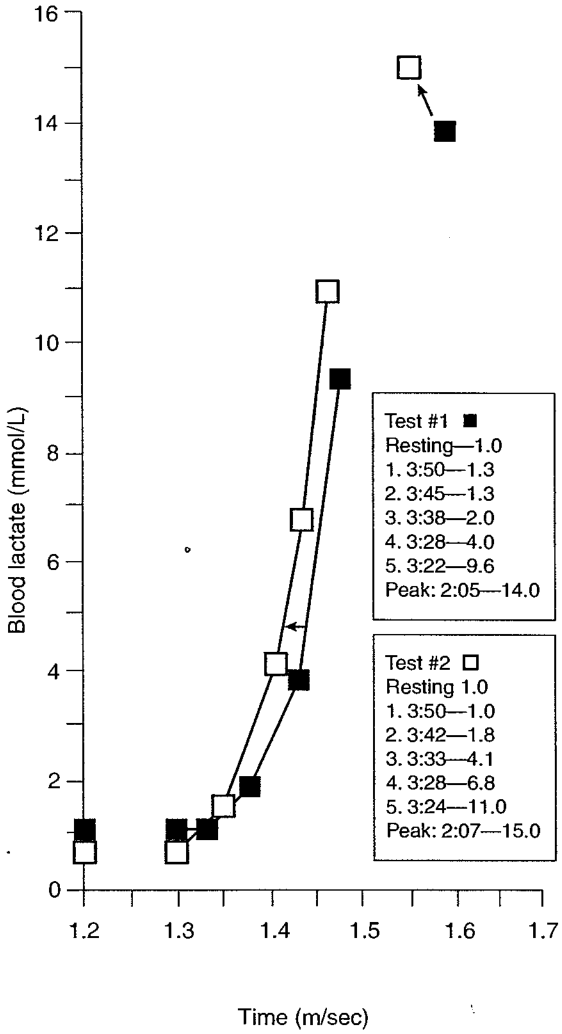


Figure 16.14 Results of two blood tests taken 4 weeks apart that indicate a significant loss of aerobic capacity and an increase of anaerobic power.

curve). The D-max method has been used to locate the athlete's individual anaerobic threshold velocity, which was 1.43 m/sec. The calculations are shown for converting the anaerobic threshold velocity into a time per 100 m. The calculated time is 1:10. If this swimmer wants to swim 200 repeats, he simply doubles the time, for 300 repeats, he triples it, and so on for longer repeat distances.

An athlete should do most endurance training in the range of times encompassed by his or her aerobic and anaerobic thresholds. A swimmer should do basic endurance repeat sets in the bottom half of that range and threshold endurance repeats in the top half. He or she should swim overload endurance and lactate tolerance repeat sets at speeds in excess of those that correspond to the anaerobic threshold. The swimmer should perform recovery training at speeds slower than those at the aerobic threshold.

Some people believe that the results of blood tests cannot be used to prescribe training speed because swimmers have day-to-day variations in aerobic capacity and anaerobic power that invalidate the results of previous tests (Johnson 1998). Actually, blood lactate responses to certain training speeds vary little from day to day until significant changes take place in aerobic or anaerobic capability. This conclusion was shown by the results of a study in which the reliability of several methods for determining the anaerobic threshold were compared with repeated testing over a 5-day period (Pfitzinger and Freedson 1998). The swimmers' times and corresponding blood lactate concentrations remained remarkably similar from one day to the next. Coefficients of correlation between velocities at each threshold ranged between 0.97 and 0.99 over the 5-day period.

Progressive overload should be the cornerstone of any training program. Therefore, swimmers should establish a faster range of speeds for the three levels of endurance training when their lactate-velocity curves move to the right on subsequent tests. Aerobic capacity and aerobic and anaerobic muscular endurance will not improve if athletes swim at the same speed from week to week and from season to season unless they increase their training volume or reduce the rest they take between repeats. Reference points, such as swimming speed at individual aerobic and anaerobic thresholds, let athletes know when they are ready to train faster.

Coaches need to be aware of several sources of error when prescribing training paces from blood lactate tests so that they can determine those paces accurately. The first of these was mentioned earlier. The best repeat distances for prescribing endurance training speeds are between 300 and 400 m and 400 and 500 yd. Shorter repeat distances can and should be used to evaluate changes in aerobic and anaerobic metabolism, but they are not accurate for prescribing training speeds. Another source of error is that test distances of 300 m to 500 yd are only effective for prescribing training speeds for repeats at similar distances. Those speeds must be adjusted somewhat for shorter and longer repeats. Training speeds need to be somewhat faster for shorter repeat distances and somewhat slower for longer repeats because the length of the repeats plays a role in their metabolic intensity. Shorter repeats are both easier to complete and easier to recover from, whereas longer repeats are more difficult to complete and require more recovery time, even when the velocity is the same for both. The cause of this difference, of course, is that lactic acid gradually accumulates as repeat distances increase.

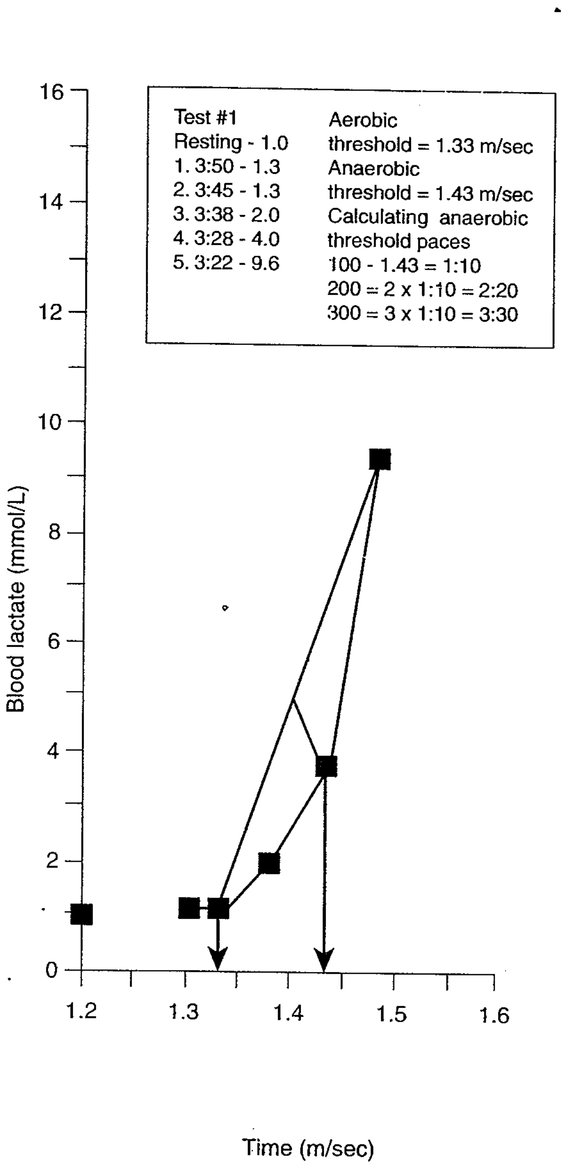


Figure 16.15 The calculations for prescribing training times from blood test results.

Rest intervals between repeats also play a role in determining metabolic cost. The metabolic intensity of repeats swum at a given velocity increases when the rest intervals are short and decreases when they are longer because athletes are able to remove more lactic acid from their muscles during a longer rest period.

Madsen and Lohberg (1987) have published correction factors for various repeat distances and rest intervals. These factors, listed in table 16.2, are based on training speeds predicted from blood lactate tests that used 400 m repeats.

The graph in figure 16.16 shows typical lactate-velocity curves for a sprinter and a distance swimmer. Both swimmers completed five 300 m swims at progressively faster speeds. Blood samples were taken and analyzed for lactate content after each swim. Those blood lactate results were then graphed opposite the times that produced them. Following the five swims, the athletes swam one maximum effort 200 m time trial. The

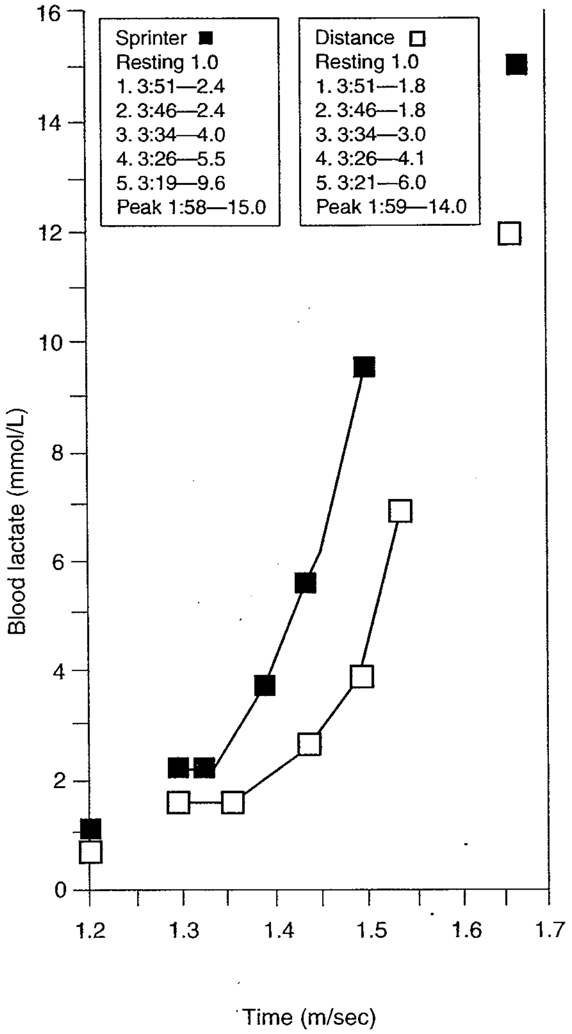


Figure 16.16 Blood tests for a sprinter and a distance swimmer.

peak blood lactates from those swims were graphed opposite the times that produced them.

Note that the lactate-velocity curve for the distance swimmer lies to the right of the sprinter's curve. When compared with the sprinter, the distance swimmer has faster swimming velocities at similar blood lactate concentrations all along the curve. Notice also that the peak blood lactate for the distance swimmer is lower, even though his time for the 200 swim is similar to that of the sprinter.

If a coach asked both the swimmers in figure 16.16 to swim at speeds that produced a blood lactate concentration of 4.0 mmol/L, the distance swimmer would be swimming faster than his anaerobic threshold pace and, therefore, would be working more anaerobically than the sprinter. The distance swimmer would be swimming at overload endurance speed, whereas the sprinter would be swimming near his anaerobic threshold speed. If the goal of the training set were to swim at threshold endurance speeds, the training intensity for the distance swimmer would obviously be misdiagnosed.

The results in figure 16.16 show why the training speeds of different athletes should not be prescribed from fixed blood lactate concentrations. Likewise, it is not a good idea to use fixed blood lactate concentrations to prescribe training speeds for one athlete at different times of the year. The relationship between a particular blood lactate concentration and swimming intensity can change through training or by poor control over the testing conditions, such as muscle glycogen storage or weight training within 24 hr of the test.

Table 16.2 Correction Factors for Different Repeat Distances and Rest Intervals

The following are correction factors for adjusting 4 mmol/L threshold speeds for male and female swimmers as determined from the two-speed test at 400 m to other repeat distances and for rest intervals of 10 and 30 sec.

		Repeat distances			
SEX	**REST INTERVAL**	**400**	**200**	**100**	**50**
Females	10 sec	100.0%	101.5%	103.0%	110.0%
	30 sec	100.5%	102.5%	106.5%	114.0%
Males	10 sec	99.5%	101.5%	103.0%	108.0%
	30 sec	100.5%	102.5%	108.0%	115.0%

Adapted from Madsen and Lohberg 1987.

The blood lactate concentrations that correspond to the individual aerobic and anaerobic thresholds of athletes are generally reduced by endurance training and increased by sprint training. This occurs because endurance training reduces the rate of lactic acid production and increases the rate of its removal from muscles. Therefore, although the swimming velocity that corresponds to these thresholds may increase, the concentration at which lactate begins accumulating rapidly in the blood may actually decrease.

Sprint training will produce the opposite effect. It will increase the blood lactate concentrations that correspond to the various thresholds, even when no change has occurred in aerobic or anaerobic capability. The swimming velocities that correspond to those thresholds may not change, however, because sprint training increases the rate of lactic acid production. Therefore, more lactate may be in the blood at a particular swimming speed when the rates of movement of that substance into and out of the blood are in equilibrium. Using one of the intersection methods, such as the modified D-max method, can reduce errors of interpretation when sprint or endurance training causes those errors. This method will identify the swimming speeds at which the thresholds occur even when the blood lactate concentrations that correspond to those thresholds have increased or decreased. The lactate breakpoints will simply begin at lower or higher blood lactate concentrations. Nevertheless, the swimming velocities corresponding to those thresholds will be accurate (McKenzie and Mavrogiannis 1986).

Verifying the Results of Blood Tests

So many possible errors can be made during both the administration and interpretation of blood tests that coaches should never prescribe training speeds without first verifying that the results they based them on were accurate. One way to do this is to take a *spot* blood sample when athletes are swimming a set of repeats at some prescribed pace. If the repeat distances, training speeds, and rest intervals are properly corrected according to the figures provided in table 16.2, the blood sample, when analyzed, should produce the same lactate concentration that resulted from a similar velocity during the blood test.

Another way the results of blood tests can be verified is to have athletes swim two long sets of repeats at their prescribed threshold paces. The set distance should be between 2,000 and 4,000 yd or m in length. Repeat distances should be similar to those used during the test, and the send-off times should correspond to typical training send-off times. Repeat times should be corrected according to table 16.2 if the send-off times provide rest intervals longer than 10 to 30 sec. If a particular swimmer cannot complete one of these verification sets, the average speed for the repeats was obviously faster than his or her present anaerobic threshold speed. If the swimmer can complete the set easily, the average speed was below present anaerobic threshold speed. Those who complete the set with difficulty are probably training very near their individual anaerobic thresholds, and they can use their blood test results with assurance for prescribing speeds for other repeat sets.

Swimmers who could not complete their verification sets can find their actual threshold paces by completing similar sets at gradually slower speeds, on successive days, until they find the average fastest speed at which they can complete the set. That speed will be their threshold training pace, and they can adjust it to prescribe endurance training for other repeat sets.

Swimmers who completed their verification sets easily should use the opposite procedure. They should repeat the verification set on successive days, at gradually increasing average speeds, until they fail to complete it. The speed of the last set they completed probably approximates their individual anaerobic threshold speed.

These verification tests may seem burdensome because of the large amount of time required to determine a true threshold pace. But they are worth the effort. Verification sets serve as good endurance training vehicles, and their experimental nature provides a purpose that makes practice more interesting.

Comparing Performance Potential With Blood Tests

The final use for blood testing is to compare the performance potential of one swimmer with that of another. Two general assumptions are made when such a comparison is attempted. The first is that athletes who swim faster with lower blood lactate levels will be faster than competitors who produce higher blood lactate concentrations at the same swimming speeds. The second is that potential middle distance and distance swimmers will have faster aerobic and anaerobic threshold speeds than sprint swimmers.

That first assumption is justified for heterogeneous groups of swimmers, but caution should be exercised when making judgments among members of homogeneous groups. Sharp and associates (1984a) compared the lactate-velocity curves for members of the 1984 United States Olympic team with those of non-Olympic college swimmers. The Olympians had significantly faster velocity at a fixed blood lactate concentration of 4 mmol/L. The Olympic males averaged 1.54 m/sec versus 1.44 m/sec for the non-Olympic male collegians. For women the difference was 1.47 m/sec versus 1.29 m/sec, in favor of the Olympians. These differences were significant. But it was not possible to select the best performers within the homogeneous group of Olympic males and females by their swimming velocity at 4 mmol/L, probably because the difference in that velocity was smaller among the Olympians than it was between the group of Olympians and non-Olympic swimmers.

Coaches must be careful when using threshold velocity to compare the performance potential of swimmers with similar ability. Although the relationship between performance and both fixed and individual anaerobic thresholds is quite high, it accounts for only 80% of the difference in times for events of 400 m and longer, and only 60% of the difference for events of 100 and 200 yd or m. Both percentages leave a considerable portion of the performance unaccounted for. So, it would be difficult to predict which of two Olympic swimmers would win an event from their threshold speeds alone.

Other Blood Testing Protocols

The blood testing examples I have used thus far have all involved a step test with repeat distances of 300 m followed by a maximum effort 200 m swim. I have used this protocol over the years and been happy with the results. This procedure provides good estimates of the various threshold speeds and a good basis for evaluating training-induced changes in aerobic and anaerobic metabolism. If the increase in speed from one 300 swim to the next is kept within 6 sec, it is possible to locate the aerobic and anaerobic thresholds within a range of 1 or 2 sec per 100 m. The use of the 300s test also reduces the number of corrections required for common repeat speeds. Therefore, it provides a good method for prescribing training paces. Many other blood testing protocols are in use, however, and I would like to describe some of the best ones in the next sections.

5 × 200 Step Test. One of the most popular step tests for blood testing is the 5 × 200 step test. This test is an excellent protocol for evaluating changes in aerobic and anaerobic metabolism through the full range of effort from slow to maximum. The test has one major drawback. It is not useful for prescribing training paces because the repeat distance is too short. This causes an athlete's speed at the anaerobic threshold to be overestimated. The protocol for a 5 × 200 step test is as follows:

1. The athlete swims 2 × 200 at speeds approximately 24 to 27 sec slower than his or her best time for a 200 distance. A 1 min rest occurs between swims. A blood sample is taken within 1 min after the second 200 swim.
2. The athlete swims 1 × 200 at best time plus 16 to 18 sec and rests for approximately 5 min after the swim. Two blood samples are taken during the rest period, the first at 1 min after completion of the swim and the second at 3 min after the swim.

3. The athlete swims 1 × 200 at best time plus 8 to 9 sec and rests for 20 min following the swim. Three blood samples are taken, the first at 3 min following completion of the swim, the second at 5 min, and the third at 7 min.
4. The athlete swims 1 × 200 at maximum effort. Three blood samples are taken, at 3, 5, and 7 min after completion of the swim.

8 × 100 Step Test Another excellent test for evaluating changes in aerobic and anaerobic metabolism is the 8 × 100 step test. This test is particularly good for use with sprinters because of the short repeat distance but those short distances make it invalid for estimating thresholds and prescribing training paces.

1. The athlete swims 3 × 100 at 75% effort, taking 1 min of rest between swims. After the third swim the athlete rests for 3 min. A blood sample is taken between the 2nd and 3rd min of that rest period.
2. The athlete swims 2 × 100 at 85% effort, taking 1 min of rest after the first swim and 4 min of rest after the second swim. A blood sample is taken between the 3rd and 4th min after completion of the second swim.
3. The athlete swims 1 × 100 at 90% effort and then rests for 6 min. A blood sample is taken between the 4th and 5th min of the rest period.
4. The athlete swims 1 × 100 at 95% effort and then rests for 20 min. A blood sample is taken between the 5th and 6th min of the rest period.
5. The athlete swims 1 × 100 at 100% effort. Blood samples are taken at 3, 5, 7, and 9 min following the completion of the swim.

The same protocol can be followed using 8 × 200 repeats. That procedure is well suited for evaluating training-induced changes in aerobic and anaerobic metabolism for 200 swimmers, but, like the 8 × 100 step test, it is not a valid procedure for estimating threshold speeds or prescribing training paces for athletes who compete in 200 events or at other race distances.

6 × 400 Step Test A good test for evaluating training-induced changes in aerobic and anaerobic metabolism for middle-distance and distance swimmers is the 6 × 400 step test. Unlike the previous two protocols, it will provide reasonably accurate estimates of the various threshold speeds, and it can be used for prescribing training paces. The protocol is conducted in the following manner.

1. The athlete swims 3 × 400 repeats at 85% effort, taking 1 min of rest after each swim. The swimmer rests for 3 min following the third swim. A blood sample is taken between the 2nd and 3rd min of that rest period.
2. The athlete swims 1 × 400 at 90% effort and rests for 6 min after completing the swim. A blood sample is taken between the 5th and 6th min of the rest period.
3. The athlete swims 1 × 400 at 95% effort and rests for 20 min. A blood sample is taken between the 5th and 6th min of the rest period.
4. The athlete swims 1 × 400 at 100% effort. Three blood samples are taken, one each at 5, 7, and 9 min after completion of the swim.

V4 Protocol Mader and colleagues (1976) suggested using a fixed blood lactate value of 4 mmol/L to evaluate changes in aerobic capacity and prescribe paces for endurance training. They called the swimming velocity that produced this concentration the *V4 velocity*. Contrary to popular belief, they never meant to represent the V4 velocity as the individual anaerobic threshold. They believed instead that it was an excellent reference point for measuring changes in aerobic capacity.

The protocol for determining aerobic capacity by means of the V4 velocity consists of swimming two 400 m or 500 yd swims at progressively faster speeds. In addition, one maximum effort swim of 100 to 200 yd or m can be included in the protocol so that the effects of training on anaerobic capacity can also be evaluated. Combining these tests of aerobic and anaerobic capacity provides an excellent procedure for evaluating changes in both aerobic and anaerobic metabolism. With only a small amount of additional testing, the protocol can also be used for prescribing training speeds. The V4 protocol is conducted in the following manner:

1. The resting blood lactate concentration of the athlete is measured before the first swim. The blood lactate concentration should be at a normal resting level. If it is not, the athlete should swim easy until it falls to that level.
2. The athlete swims two 400 m or 500 yd swims, resting for 15 min between swims to prevent blood lactate stacking. The athlete swims easy for 10 to 12 min during the rest period to lower blood lactate concentrations more rapidly. The time for the first swim should be approximately 30 sec slower than the swimmer's best time for the repeat distance, and the second swim should be between 15 and 20 sec slower than the swimmer's best time. Blood lactate samples are taken at 1 and 3 min after each swim. The higher of the two blood lactate samples is recorded as the official value for that swim. The blood lactate readings should be near or above 4 mmol/L on the first swim and above 4 mmol/L on the second. The test will have to be repeated with adjusted swimming times if the blood lactate concentrations are not high enough.
3. The athlete rests for 30 min following the second 400 swim and swims easy for 10 to 15 min of that time to improve lactate removal from the blood.
4. The blood lactate concentration is measured to be certain it has returned to resting levels. The swimmer rests longer if it has not.
5. The athlete swims 1 × 100 at maximum speed. Starting 3 min after completion of that swim, blood samples are taken at 2 min intervals until values begin to decline. The highest blood lactate concentration is recorded as the peak value.

Paced 200 Swim David Costill developed the paced 200 swim. Suitable for evaluating changes in aerobic capacity, the procedure is easy to administer and interpret (Wilmore and Costill 1999). But the test cannot be used to prescribe training paces.

The protocol consists of having athletes complete one swim at a distance of 200 yd or 200 m. The distance should be swum at a steady pace, and the test should be repeated periodically throughout the season to evaluate changes in aerobic capacity. A pacing machine should be used to ensure that athletes swim the same time with the same even pace from test to test. The time for the first paced 200 swim of the season should represent a difficult effort for the swimmer, completed at a speed of 90% to 95% of the swimmer's present best time for the distance. Blood samples should be taken at 2 min intervals, starting 1 min after the swim is completed, until the athlete's highest blood lactate has been determined. Nontraining factors that could influence the test results, weight training or muscle glycogen depletion, for example, should be controlled from one test to the next. Athletes should not lift weights on the day of the test or the day before the test, and they should be permitted to swim easy for a few days before each test. The test should be conducted in the afternoon.

One can feel confident that an athlete's aerobic capacity is improving if his or her peak blood lactate decreases following the paced 200 swim from one test to the next. Reasons for failing adaptation should be examined if the athlete's blood lactate concentration increases from one test to the next.

The graph in figure 16.17 shows how blood lactate concentrations for a paced 200 swim declined for one athlete over the course of a season of competition. This test has several advantages over other blood testing procedures. One is that the time and pace of the swim are carefully controlled from one test to the next. Therefore, complicating variables such as poor pacing or poor recovery are less likely to influence the blood lactate concentrations from test to test . Another advantage is the ease of administration. Athletes complete only one submaximal swim, and only a few blood samples need to be taken following that swim. A final advantage is its ease of interpretation. Graphing the results and interpreting threshold values is not necessary. The peak blood lactate value following the swim either increases or it does not. Consequently, it is easy to evaluate whether the athlete's aerobic capacity has improved.

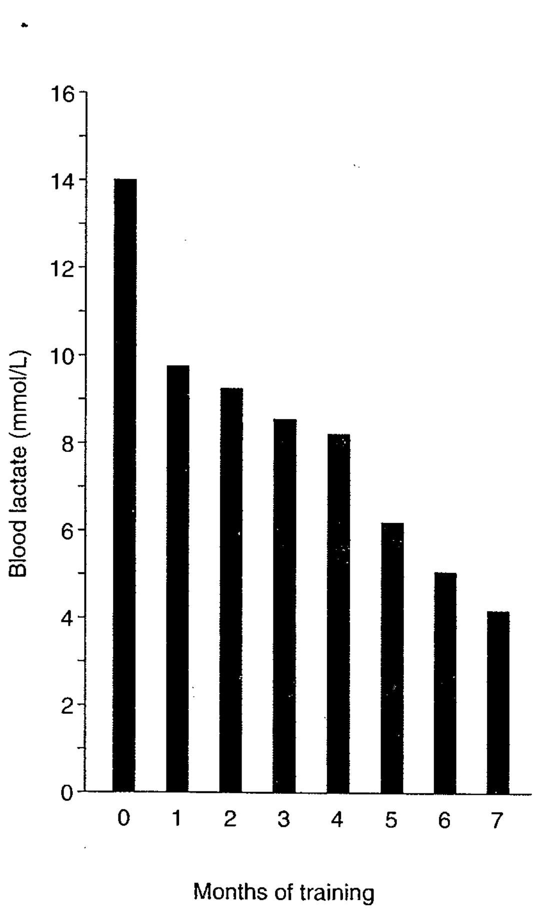


Figure 16.17 The paced 200 swim protocol for evaluating changes of aerobic capacity. This test uses one paced 200 swim administered periodically throughout the swimming season to evaluate changes in aerobic capacity. The initial swim should represent a reasonably difficult effort. A decline in blood lactate for these swims throughout the season, as shown here, suggests that aerobic capacity has improved.

Adapted from Wilmore and Costill 1999.

Other Methods for Monitoring Endurance Training

Monitoring endurance training is important to the success of swimmers. Although blood testing is certainly the best method for this purpose, it is not readily available to most coaches and athletes. They lack the equipment, expertise, funding, and, with large teams, the time to conduct blood testing. Sterile conditions must be maintained during testing to eliminate the danger of contracting the HIV virus. These reasons make it imperative that other methods be developed to monitor the effects of training and prescribe training speeds.

The time-honored ways that coaches have monitored training are

1. with the stopwatch or pace clock,
2. with heart rates, and
3. through intuition.

All these methods have strengths and weaknesses. Their strength is their ease of administration. Their main weakness is their lack of precision. Nevertheless, they provide quantitative and qualitative data that can assist coaches in making better judgments about the effectiveness of their training. The sections that follow will present some of the best tests and discuss some procedures in common use that are not very accurate. A special section will discuss using heart rates for monitoring training because they are such a popular method for doing so.

The first noninvasive monitoring procedure for evaluating the nature of training effects and prescribing training speeds is one of the best. The test has been called the T-30 test and the T-3,000 test. I will use the latter term.

T-3,000 Test

Developed by Olbrecht and his associates (1985) from the Institute for Sports Medicine in Cologne, West Germany, the T-3,000 test can be done in two ways. In the first method, athletes can swim for 30 min and record the distance covered. In the second, athletes can swim a 3,000 yd or m time trial. Whichever method is used, a 30 min swim or a 3,000 swim, the effort should be maximum and evenly paced from start to finish. The results are then converted to an average speed per 100 m by dividing the distance swum in 100s into the time for the entire swim in seconds. The procedure for calculating a threshold pace per 100 m from a 3,000 m swim is illustrated in figure 16.18.

T-3,000 Test

3,000 swim time = 35 min (2,100 sec)
Pace per 100 m = 2,100 ÷ 30 = 1:10
Pace for other repeat distances = 1:10 × (distance in 100s)
Example: Time for 400 m = 1:10 × 4 = 4:40
Correction factors: 200s = T-3,000 time – 2 sec
100s = T-3,000 time – 1.5 sec
50s = T-3,000 time – 1 sec

Figure 16.18 The procedure for calculating a threshold training speed from a 3,000 m swim. The time for the swim, in seconds, is divided by 30 (the number of 100s swum), and the threshold pace per 100 m is the quotient.

In this case the swimmer completed a 3,000 m swim in 35 min (2,100 sec), which calculates to an average speed of 1:10 per 100 m (2,100 ÷ 30 = 70 sec).

Olbrecht and coworkers found that the average speed for a T-3,000 swim corresponded closely to the pace that produced a blood lactic acid concentration of 4 mmol/L during a typical blood test. Later research showed that the time for a T-3,000 corresponded even more closely to each swimmer's individual anaerobic threshold (Matsunami et al. 1999b). My own unpublished research has also shown that the T-3,000 test corresponds closely to the individual anaerobic threshold of swimmers.

The T-3,000 produces an accurate estimate of a swimmer's individual anaerobic threshold pace because it is so long. Most swimmers cannot maintain a pace above their individual anaerobic thresholds for much longer than 30 min without disturbing the balance between lactic acid production and removal from their muscles and incurring acidosis (Stegmann and Kindermann 1982).

Although the T-3,000 test is easy to administer, a few precautions should be taken to improve the result. For one, swimmers should pace the swim evenly. Those who start out too fast will fall off later in the swim because of acidosis, with the result that the time of the swim will yield a threshold pace that is slower than the pace that corresponds to the athlete's anaerobic threshold. If swimmers pace the distance evenly and treat the T-3,000 test as a maximum effort 3,000 time trial, the results will provide an accurate threshold pace. The T-3,000 test performed at maximum effort may produce a result more accurate than that of a blood test because the result is not as amenable to misinterpretation.

The results of T-3,000 swims are useful in evaluating changes in aerobic capacity. Obviously, an improvement in an athlete's time means that his or her rates of aerobic metabolism and lactate removal from muscles and blood have improved. The meaning of slower times is more difficult to interpret. A slower time on a subsequent test could mean that aerobic capacity has worsened or that the swimmer did not try as hard. For this reason, swimmers must be motivated to complete the 3,000 distance as a maximum effort time trial.

The threshold pace calculated from a maximum effort T-3,000 test can also be used to prescribe training at other repeat distances and at other levels of endurance training. Other repeat distances for threshold training would simply be multiples of the threshold pace. For example, if 1:10 is the threshold pace calculated from a T-3,000 test; 300 repeats would be swum at times approximating 3:30 (3 × 1:10), and 800 repeats would be swum at times in the neighborhood of 9:20 (8 × 1:10). Paces for basic endurance training can be determined by adding 3 to 6 sec per 100 yd or m to the threshold pace, and paces for overload endurance training should be faster than the threshold pace.

I should mention that threshold paces per 100 yd or m calculated from a T-3,000 test are only accurate for repeat distances of 300 m and longer and for rest intervals of 10 to 20 sec. An adjustment is necessary for shorter distances and longer rest intervals. Correction factors for repeat distances of 200 m and shorter are listed in figure 16.18.

The T-3,000 test is a practical method for evaluating the aerobic capacity of senior swimmers, and it can easily be adapted for younger swimmers, older swimmers, and swimmers with less ability who are not able to complete 3,000 yd or 3,000 m in times approximating 30 min. This can be done by shortening the length of the swim to a distance they can complete in approximately 30 to 35 min.

T-2,000 Test

This test was developed as an alternative to the T-3,000 swim because some swimmers found the shorter test distance more to their liking. The T-2,000 test was found to produce threshold times per 100 yd or m that were similar to those of the T-3,000 test despite its shorter distance. In one study, the average time per 100 m calculated for a group of competitive swimmers from the two tests differed by only 0.20 sec—1:10.92 for the T-3,000 test versus 1:11.12 for the T-2,000 test (Matsunami et al. 1999).

Like the T-3,000 test, the results of a subsequent T-2,000 swim are useful in evaluating changes in aerobic capacity. The average 100 m time for a T-2,000 test can also predict training paces. In this case, however, the times for repeat distances of 100 m and less must be reduced slightly because of fewer turns, and the times for repeats of 200 yd or m and longer must be adjusted upward because of the shorter distance covered in this test. Generally, the time for repeats of 50 m should be half of the T-2,000 threshold pace per 100 m minus 2 sec, and the time for repeats at the 100 distance should be 1 sec faster than the T-2,000 threshold pace for 100 yd or m. Generally, 2 to 4 sec per 100 m should be added to the T-2,000 threshold pace for repeat distances of 300 yd or m and longer (Touretski 1994). For example, a swimmer with a T-2,000 threshold pace of 1:10 per 100 m would swim 400 m repeats in the neighborhood of 4:56 (4 × 1:14). As with the T-3,000 test, paces for basic endurance swimming calculated from a T-2,000 test should be adjusted upward by 3 to 6 sec per 100, and paces for overload endurance swimming should be faster than the T-2,000 threshold pace.

T-1,000 Test

Recently, Matsunami and colleagues (1999a) compared the accuracy of a number of test distances from 3,000 m down to 600 m for estimating the anaerobic threshold. Their criterion measure was a lactate step test that estimated the speed at which blood lactate began to accumulate in a linear manner. They reported that a test distance of 1,000 m provided the closest relationship to the anaerobic threshold speed as predicted from the criterion measure. Consequently, they proposed that a 1,000 yd or m time trial could be used in place of a 2,000 or 3,000 yd or m time trial to evaluate changes in aerobic capacity and prescribe training speeds.

Having used a variety of such tests over a number of years, I find it difficult to accept these results. My experience is that athletes can swim faster than their anaerobic threshold speeds for a distance of 1,000 m. I doubt that this test could be used with confidence to determine anaerobic threshold training speeds, but it may have some value for evaluating changes in aerobic capacity. Because of the test distance, the T-1,000 may be an excellent test for reflecting a change in the slope of the velocity curve at blood lactate concentrations between 5 and 10 mmol/L. As such, it could be used to evaluate changes in the slope of the linear portion of the lactate-velocity curve.

Critical Swimming Speed

Wakayoshi and associates (1992a, 1992b) developed the critical swimming speeds test to estimate the threshold pace for endurance training. They defined the *critical swimming speed (CSS)* as the fastest swimming speed that a swimmer could maintain continuously without exhaustion. Therefore, they believe that it represents the swimming velocity that corresponds to an athlete's maximal lactate steady state. The literature also refers to this test as *critical velocity* (V_{crit}).

The procedure for determining the critical swimming speed was developed from the concept of critical power (W_{crit}) first proposed for single muscle groups by Monod and Scherrer (1965). They defined critical power as "the maximum rate a muscle can maintain for a very long time without fatigue." Researchers tested the critical power work level for whole body exercise in cycling (Jenkins and Quigley 1990; Moritani et al. 1981), kayaking (Ginn and Mackinnon 1989), and treadmill running (Hughson, Orok, and Staudt 1984), and all reported it to be similar to the level of intensity that corresponds to the individual anaerobic threshold.

As mentioned, Wakayoshi and coworkers (1992a, 1992b) adapted the concept of critical power to swimming by developing several protocols for determining the critical swimming speed that would correspond to an athlete's individual anaerobic threshold. These procedures involve swimming a minimum of two time trials from a pushoff, although three or more time trials are recommended. Any combination of the following time trial distances have been recommended for this purpose: 50, 100, 200, and 400 yd or m. When only two time trials are used, the distances should be considerably different. For example, time trial #1 should be at a distance of 50 or 100 m, and time trial #2 should be at a distance of 400 yd or m. Swimmers should rest for at least 30 min after each time trial to ensure adequate recovery.

The test developers recommend that the swims be performed over a 2- or 3-day period when three or four time trials are used. For example, when three time trials are used, swimmers could complete two time trials on day 1 and the third on day 2. When four time trials are used, swimmers could perform two on day 1, the third on day 2, and the fourth on day 3.

After swimmers have completed the time trials, the times and distances for the swims can be used to calculate a standard regression equation. This regression equation is essentially a *line of best fit* established between the time trial distances and the athlete's times for those swims. The slope of that regression line defines the expected change in time for each change in distance. In other words, it represents the average number of meters covered during each second of swimming for distances between 50 and 400 m. The slope of that regression line is, therefore, equal to the critical swimming velocity. That velocity can be represented as a time per 100 m simply by dividing it into 100.

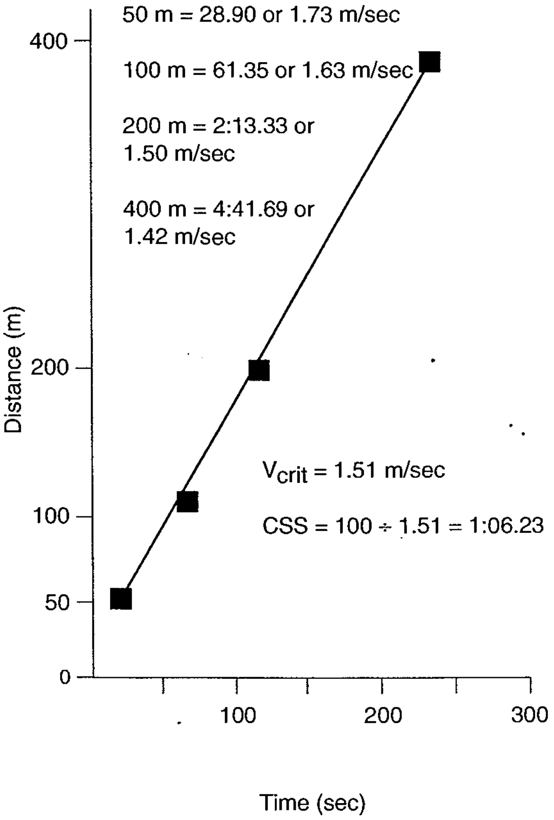


Figure 16.19 A graphic representation of the calculation of a regression line from the results of times trials of 50, 100, 200, and 400 m.

A graphic representation of the process of calculating the slope of a regression line from the results of time trials of 50, 100, 200, and 400 m is shown in figure 16.19. Plotting the times versus the distances for those time trials produces a slope that expresses the critical velocity as 1.511 m/sec. That, supposedly, is the velocity at which the swimmer's anaerobic threshold occurs. To prescribe training speeds, the critical swimming speed (or threshold speed) for any repeat distance can be calculated by dividing this critical velocity in meters per second into the desired repeat distance. The critical swimming speed for a distance of 100 m was calculated in figure 16.19, yielding a result of 1:06.23 for 100 m.

Figure 16.20 illustrates a simpler procedure for calculating the critical swimming speed from two time trials. In this case, the distance and time of the shorter trial were subtracted from the same for the longer trial. The remainder in distance was then divided by the remainder in time, and the quotient was the critical swimming velocity in m/sec, calculated to be 1.518 m/sec in the example. Calculation of a time per 100 m resulted in a critical swimming speed of 1:05.80.

When calculating critical swimming speed from the formula in figure 16.20, using time trials of 200 and 400 m is best. Using shorter repeat distances, say 50 and 100 m, will overestimate the critical swimming speed (Pelayo et al. 2000).

Once calculated, the critical swimming speed can be used to prescribe training times for repeat sets. For example, if the swimmer represented by the data in figure 16.20 wanted to complete a set of 400 m repeats at his critical swimming or threshold speed, his times should be approximately 4:24 per swim (4 × 1:05.80). His times for basic endurance training should be adjusted upward by 3 to 6 sec per 100 m, and his times for overload endurance training should be faster than his critical swimming speed.

$$V_{crit} = \frac{d_2 - d_1}{t_2 - t_1}$$

$$\frac{400 - 200}{250.50 - 118.75} = \frac{200}{131.75}$$

$$\frac{200}{131.75} = 1.518$$

$$\text{CSS} = 100 \div 1{:}52 \text{ m/sec} = 1{:}05.80$$

d_2 = 400 m

d_1 = 200 m

t_2 = 400 m time = 4:10.50

t_1 = 200 m time = 1:58.75

Figure 16.20 A simplified method for calculating critical swimming speed (CSS) from two time trials, the first at 200 m and the second at 400 m.

My experience indicates that critical swimming speed overestimates individual anaerobic threshold pace. Therefore, if the results of tests of critical swimming speed are used to prescribe training paces, I suggest that the speed of those training repeats be 2 or 3 sec slower per 100 m than the actual critical swimming speed.

Although the critical swimming speed may overestimate the individual anaerobic threshold pace, it is still sufficiently sensitive to use for evaluating changes in aerobic endurance. In other words, an improvement of critical swimming speed probably reflects an improvement in aerobic capacity for athletes. MacLaren and Coulson (1999) reported that competitive swimmers were able to increase their critical swimming speed by approximately 2 sec per 100 m after a period of intense endurance training.

Swimming Step Test

Another test developed to evaluate changes in aerobic capacity and determine individual anaerobic threshold training speeds is the swimming step test. The athlete swims several short sets of repeats at progressively faster speeds until he or she can no longer complete the repeat set at the prescribed pace. Sets of 5 × 200 on a send-off time that allowed 10 to 15 sec of rest between repeats were selected for this purpose, although longer or shorter repeat distances and sets could have been used.

The swimmer should swim the first set at a slow speed known to be below his or her threshold speed. The average time per 200 should be reduced by approximately 4 sec on the next set and by an additional 4 sec per swim for each succeeding set until the swimmer fails. The athlete takes no additional rest between sets.

Besides being slower than the athlete's threshold speed, the starting speed for the first set of repeats should be set so that swimmers will be able to complete at least three sets before failing. Failure is defined as being unable to swim at the prescribed speed for two repeats in a row. Defining failure in this way improves the accuracy of the test results. The test administrator is responsible for recording the average speed for each completed set of repeats and the number of the repeat at which the swimmer failed during the final set. Once this information has been compiled, the swimmer's threshold pace can be estimated in the following manner. If failure occurred late in the final set, the swimmer's threshold pace will be the average speed of the previous set. If failure occurred during one of the first two repeats in the final set, the threshold pace will be the swimmer's average time from two sets earlier.

The assumption behind selecting the threshold pace in this way is that swimmers who failed late in a set probably exceeded their anaerobic threshold and incurred acidosis during that set. Consequently, the average time of the previous set is the fastest speed they could maintain without upsetting the balance between the production of lactic acid in muscles and its elimination from them. On the other hand, athletes who fail early in a set probably exceeded their anaerobic threshold speed somewhere in the latter half of the previous set. Nevertheless, they were able to complete the set before acidosis became severe. After only the first one or two repeats of the next set, however, acidosis became severe and they failed to match the prescribed pace. Therefore, their threshold pace was probably closer to the average time two sets back, before the equilibrium between lactate production and removal was first upset.

The swimming step test is an excellent procedure for evaluating changes in the physical condition of athletes. Their aerobic and anaerobic muscular endurance and their aerobic capacity have probably improved when they can complete a greater number of repeat sets before failing.

Athletes should normally swim the first and later sets of a subsequent step test at the average speed of the previous test to provide better control and interpretation of results. To save time, however, the average time can be reduced for the first set of a subsequent test when the results of the previous test show that the athlete's threshold speed has improved. For example, when an athlete is able to complete one additional set of repeats on a subsequent test, the starting time can be reduced by 4 sec for the first set of 200 swims on the next test.

Repeat distances of 200 yd or m are recommended for most swimmers for this step test. As a result, the threshold pace computed from this distance is probably accurate only for repeats of 200 yd or m and less. The threshold pace should probably be increased by 1 to 2 sec per 100 when longer repeat distances are swum in training. A more accurate estimate of threshold paces for longer repeats can be gained by using distances of 300 yd or m to 400 yd or m on these sets. In this case the number of repeats per set should be reduced to four. The reduction in time from one set to the next should be maintained at 2 sec per 100 m, so times should be reduced by 6 sec for each set of 300 repeats and by 8 sec for each set of 400 repeats.

The results of two step tests to failure shown in figure 16.21 demonstrate the procedure for estimating threshold paces. Swimmer A had a threshold pace of 1:12 for 100 m. He failed during the fourth repeat of the third set of 200s, so his threshold pace was the average time of the previous set, which was 2:24, or 1:12 per 100 m. Swimmer B failed in the first repeat of the fourth set, so his threshold pace was the average speed of the second set (2:24), which was also a time of 1:12 for 100 m.

Swimming Step Test
Sets of 5 × 200 With 10–15 sec Rest

Swimmer A	Swimmer B
Set 1 – 2:28 – Completed	Set 1 – 2:28 – Completed
Set 2 – 2:24 – Completed	Set 2 – 2:24 – Completed
Set 3 – 2:20 – Failed on #4	Set 3 – 2:20 – Completed
	Set 4 – 2:16 – Failed on #1
Aerobic pace is 1:12.00 for 100 m	Aerobic pace is 1:12.00 for 100 m
2:24 ÷ 2 = 1:12.00	2:24 ÷ 2 = 1:10.00

Figure 16.21 The results of two athletes who completed swimming step tests show two methods for calculating threshold speeds from the results.

The validity of threshold paces derived from the swimming step test was examined by comparing them to individual anaerobic threshold paces estimated from a typical graded intensity blood test (5 × 300). The subjects were a group of 38 male and female collegiate swimmers. The blood test was administered first, and the swimming step test was carried out 2 days later. The relationship was calculated at a highly significant 0.94, which indicated that the swimmers' individual anaerobic thresholds could be estimated accurately with the swimming step test.

The major advantage of the swimming step test is that it reduces the likelihood that substandard efforts will affect the results. Coaches can be reasonably certain that swimmers have given a maximum effort when they swim to failure. A disadvantage is that it is not possible to pinpoint the exact speed at which a swimmer surpassed his or her individual anaerobic threshold pace. The best estimate that the test can provide is within a range of 2 sec per 100 yd or m. This is not a serious disadvantage, however, because various blood testing procedures produce errors of similar size.

Step tests in which the repeats are 200 m in length or longer can be intimidating for most swimmers and difficult, if not impossible, for many butterfly swimmers. Consequently, some coaches have used repeat distances of 100 yd or m in their step tests. Sets of 4 to 8 × 100 on a send-off that permits 10 to 15 sec of rest have been used for this purpose. The threshold speeds that result from a step test with 100 repeats will probably overestimate the anaerobic threshold speed of athletes. Consequently, they are not suitable for this purpose. Step tests with 100 repeats, however, can be used with confidence to test for improvements in aerobic and anaerobic muscular endurance. In other words, they would probably provide an accurate estimate of changes in the lactate-velocity curve at blood lactate values between 5 and 10 mmol/L.

Research has been sparse concerning the relationship between step tests with 100 repeats and swimming performance. In one of the few studies conducted, Barber and associates (1999) used a step test to failure that consisted of sets of 4 × 100 m to estimate the anaerobic threshold speeds of butterfly and breaststroke swimmers. Results of this test compared favorably with the anaerobic threshold that resulted from blood testing in which a descending set of 4 × 200 swims in the same strokes was used. The coefficients of correlations between the anaerobic threshold speeds estimated from the sets of 4 × 100 to failure and the descending set of 4 × 200 were 0.91 for breaststrokers and 0.94 for butterfly swimmers.

These results are in general agreement with my earlier contention that a swimming step test will overestimate an athlete's actual anaerobic threshold pace. The criterion measure used in this study, a descending set of 4 × 200 swims, probably also overestimated the swimmers' true anaerobic thresholds. As indicated earlier, repeat distances of 300 m or longer are required to get an accurate estimate of the anaerobic threshold.

The swimming step test can be adapted for younger swimmers and swimmers of less than average ability. They could use repeats sets such as 5 × 150 or 8 × 100 for evaluating changes in aerobic and anaerobic muscular endurance and for determining threshold speeds because their times for these repeats would be similar to the times of senior swimmers on longer repeats.

Standardized Repeat Sets

Perhaps the simplest method of testing for changes in aerobic capacity and prescribing training paces is for athletes to swim a long set of repeats on short rest. The average speed for a set of repeats that requires between 30 and 40 min to complete should correspond closely to the results of a T-3,000 swim and, therefore, to the individual anaerobic threshold speeds of athletes. The best repeat distances for sets like these are between 200 and 400 yd or m because the estimated threshold pace will apply to the usual range of practice repeat distances. Once the repeat distance, number of repeats, and send-off time for a standardized repeat set have been established, that set could be repeated periodically to test for changes in aerobic capacity. An athlete's aerobic capacity has probably improved when he or she can swim the set at an average faster speed, and that speed is likely to be close to the swimmer's individual anaerobic threshold pace.

A standardized test set of the type suggested can provide an accurate method for prescribing threshold paces for a wide range of other repeat distances. Some slight adjustments in threshold speeds must be made, however, for repeats of 100 yd or m and less and for repeats of 800 yd or m and longer.

Standardized test sets have several advantages over other methods for prescribing training speeds. Obviously, they are less expensive to administer, and they do not require any special expertise for testing or interpretation. Another important advantage is that administering the tests requires no breaks in training. Threshold paces can be established from typical sets in regular training sessions. A further advantage of this method over the T-3,000 test is that it can be used for testing butterfly and breaststroke swimmers. Standardized test sets can also be adapted for use with age-group and older masters swimmers by simply changing the number or distance of the repeats and rest intervals to fit the ability levels of the swimmers. The rules of thumb for adapting test sets for younger and older swimmers are the following:

- The set should require 30 to 40 min to complete.
- Each repeat should require 2 to 5 min to complete.
- The rest intervals between repeats should be short, 30 sec or less.

An example of a good test set for younger swimmers would be 15 or 20 × 100 on 1:50. That set should suffice for a group of 9 to 10 yr old swimmers who generally repeat 100s at speeds of 1:25 to 1:40.

Heart Rates

Other than swimming times, heart rates are the principal method that coaches and athletes use to monitor training. Heart rates are used in many ways to measure training intensity and evaluate changes in physical condition. They have the advantages of being readily accessible and relatively simple to count, but they are subject to nontraining influences that can lead to misinterpretations. My purpose in this section will be to describe the various ways that coaches and athletes can use heart rates to monitor training. I will also discuss errors of interpretation that can result from their misuse.

The four categories of heart-rate measurements used for monitoring training are the resting heart rate, maximum heart rate, submaximal heart rate, and recovery heart rate. Let me discuss the relationship of each of these to training, starting with the resting heart rate.

Resting Heart Rates

The resting heart rates of well-trained athletes are generally in the neighborhood of 30 to 70 beats per minute (bpm). The resting heart rates of untrained persons are usually in the range of 60 to 80 bpm. Training causes a reduction in the resting heart rate, usually at the rate of one beat per week during the first several weeks of training. Training causes the hearts of athletes to become larger and stronger so that they can push more blood out with each beat. Consequently, fewer beats can supply the quantity of blood their bodies require at rest.

The resting heart rate can be used to gauge the effects of training on the stroke volume of the heart. The assumption is that the stroke volume increases as the resting heart-rate declines. This effect is noticeable only in the early weeks of training. After that, the resting heart rate stabilizes and does not change (Uusitalo, Uusitalo, and Rusko 1998). Consequently, resting heart rates are best for measuring improvements in physical condition as athletes move from an untrained to a trained state. Once they are reasonably well conditioned, other more sensitive tests will be needed to evaluate further changes in physical condition.

Once it has stabilized, the resting heart rate offers an effective way to monitor the possibility of overtraining or approaching illness. A consistent increase of 8 to 20 bpm over a few days is generally a warning sign that the athlete is failing to adapt to training or becoming ill. One must be cautious in making this interpretation, however, because factors other than those involved with training and illness can cause an increase in the resting heart rate. Some of those factors are time of day, prior exercise such as walking and running, emotional excitement, and emotional upset.

When using it to test for failing adaptation, athletes should count the resting heart rate under the same conditions each day to reduce the effect of nontraining influences. Most experts recommend taking the resting heart rate each morning upon awaking and before getting out of bed. The person should count the resting heart rate for at least 30 sec and preferably for 60 sec to reduce the measurement error that could result from converting shorter counts (for example, 10 sec) to a minute rate. Another procedure is for athletes to count the resting heart rate just before training each day. If they use that method, they should rest quietly for 5 to 10 min before counting to reduce the effects of outside influences.

Maximum Heart Rates

The maximum heart rate for most athletes ranges between 175 and 220 bpm. The rate does not change appreciably with training, although some experts have suggested that it will decline by a small amount after several weeks of endurance training (Wilmore and Costill 1999).

Maximum heart rates tend to decline with age. They are highest in children, who commonly have maximum rates of 210. They decline during the teenage and adult years, usually to a range of 180 to 200 bpm. Maximum heart rates for senior athletes are often below 180 bpm. Let me emphasize that the maximum heart rates I just listed are average values for the various age groups. Wide variations are evident at all stages of development, so predicting a person's maximum heart rate from age alone is difficult.

Maximum heart rates generally do not provide any useful information about changes in physical condition, although a sudden decrease in the maximum heart rate that persists over several days may be a sign of overtraining (Uusitalo, Uusitalo, and Rusko 1998).

Every athlete should know his or her maximum heart rate because that information makes possible accurate determination of the heart-rate ranges for submaximal work. A popular procedure for estimating an athlete's maximum heart rate is to subtract his or her age from a maximum value of 220 bpm. As mentioned earlier, however, this method is simply not accurate enough for use by athletes. Therefore, athletes should determine their maximum heart rates during or immediately after several maximum efforts of at least 1 to 2 min.

The most accurate method for determining a maximum heart rate, of course, is to use one of several monitoring devices that can measure heart rates during an actual swim and then hold the results in memory for recording after the swim is finished. If a device of this type is not available, swimmers can count their heart rates for 10 sec immediately after they complete a maximum effort. They must begin the count immediately after completing the swim because in well-conditioned athletes the exercise heart rate begins to decline toward resting within the first 10 to 20 sec of rest. The period for counting should begin simultaneously with a heartbeat, and that beat should be counted as 0. The best sites to count immediate postexercise heart rates are at the thumb side of the wrist and at the carotid artery on the side of the neck just under the chin.

Note that a 10 sec immediate postexercise heart-rate count has a potential error of plus or minus 6 bpm. For example, if the heart-rate count was 30 beats for 10 sec and the last beat occurred slightly before the end of the period, the closest estimate one can make of the actual maximum heart rate is that it falls in a range between 180 and 186 bpm.

A person will generally have a lower maximum heart rate when swimming than when exercising on land. Rates when swimming will be between 10 and 15 bpm slower than those that a person can achieve during whole body land activities (DiCarlo et al. 1991; McArdle et al. 1978). Two possible reasons may account for this. First, swimmers are in a horizontal position so their hearts do not have to work as hard to pump blood back from their legs. Second, the cooling effect of water reduces body temperature and lessens dehydration, reducing the stress on the circulatory system. I include this information because any system for evaluating the training intensity of swimmers based on their maximum heart rates requires an accurate determination of maximum rates when they are swimming, not when they are performing land activities.

Athletes should count their heart rates after several maximum efforts over a period of a few days until they are satisfied that they have determined the actual maximum rate they can achieve. Because the potential error of measurement is so great, it is probably best to average the various attempts to count the maximum heart rate rather than to select the highest rate counted. For this reason, the maximum heart rate should probably be recorded as the highest rate a particular athlete can reproduce several times during the testing period.

Maximum heart rates indicate that athletes are swimming faster than threshold speeds, but they may not be swimming as fast as possible. A maximum heart rate does not mean maximum speed. Athletes can swim still faster after their heart reaches its maximum rate. They will not be able to do so for long, however, because lactic acid will accumulate rapidly in their muscles. Most athletes can maintain an effort that stimulates a maximum heart rate for only 8 to 15 min before acidosis causes them to slow considerably.

Submaximal Heart Rates

Athletes' heart rates during swims that they complete at submaximal effort can provide an excellent vehicle for

1. measuring changes in aerobic capacity and aerobic and anaerobic muscular endurance and
2. gauging the intensity of training.

Heart rates at submaximal swimming speeds will usually decrease by 10 to 20 bpm over several weeks of training. Although a decline in the heart rate at submaximal swimming speeds can provide a good indication that aerobic capacity has improved, accurately measuring the extent of the heart-rate decline is difficult. The best procedure is to use a heart-rate monitor because the error in counting heart rates for 10 sec immediately after a swim can be, as mentioned earlier, plus or minus 6 bpm. An error of this size could cause an improvement or lack of same to go unnoticed.

A second problem concerns the lack of reliability in counting heart rates even when a monitor is used. The graph in figure 16.22 shows the results of two heart-rate tests conducted on the same swimmer within a few days (Peyrebrune and Hardy 1992). A heart-rate monitor was used to measure the subjects' heart rates in both instances. On each test day, they swam 500 yd continuously while increasing their speed with each 50 yd segment until they were swimming at maximum speed during the final 50 yd. The results of the two tests were inconsistent, especially at slow speeds. Heart rates differed by as much as 20 bpm at the slower swimming velocities. The differences in heart rates were much smaller at near-maximum speeds. This finding indicates that athletes should swim reasonably fast in any test that uses heart rates to evaluate changes in physical condition. At slow speeds, outside influences such as stress, water and air temperature, and humidity easily upset heart rates, whereas those factors affect heart rates less at faster speeds.

The potential for error is so great when counting heart rates during and immediately following exercise that any procedure for evaluating changes in physical condition must be designed and administered carefully. The procedure should include several measurements at a variety of speeds, so that measurements unlike most of the other counts can be eliminated from the data pool. To improve its predictive power, the test should also include measurements of both working and recovery heart rates. Later in this chapter I will offer some suggestions for designing sets in which heart rates can be used to evaluate changes in physical condition.

Traditionally, submaximal heart rates have been used to gauge the intensity of training in the manner listed in table 16.3. Heart rates in the range between 120 and 140 bpm indicate low to moderate swimming intensity that falls at the lower end of the basic endurance range. Heart rates between 140 and 160 bpm indicate moderate swimming intensity that corresponds to the upper end of basic endurance speeds. Swimming intensity that corresponds with an athlete's individual anaerobic threshold is in the range of 160 to 180 bpm. Rates between 180 bpm and maximum indicate swimming intensity in the overload endurance range.

Graduated ranges of heart rates like those in table 16.3 have the advantage of being easy to understand and useful for prescribing training speeds. Coaches and athletes can use the lowest range of heart rates with reasonable confidence for prescribing speeds for low-intensity basic endurance training. In the higher ranges, however, the ranges are simply too large to identify differences between high-level basic, threshold, and overload endurance training intensities with sufficient accuracy, although, as I will explain later, they are reasonably accurate for athletes who have maximum heart rates of 190 or less. Each heart-rate range in table 16.3 encompasses 20 bpm, and the implication is that training at any heart rate within that range will affect the body similarly. In reality, training at one end of the range may affect the body in a much different way than training at the other end does. For example, in one study, the range of heart rates that corresponded to the anaerobic thresholds for a group of runners was between 142 and 172 bpm (Farrell et al. 1979). Obviously, an athlete with a threshold heart rate of 142 bpm would be working much more intensely than an athlete with a threshold heart rate of 172 if both were training at an intensity that placed them in a range of heart rates between 160 and 180 bpm. In another study, the average difference in heart rates for exercise intensities that produced blood lactate concentrations of 2 and 4 mmol/L was only 10 bpm (173 versus 183 bpm) for a group of subjects (Gullstrand, Sjodin, and Svedenhag 1994). Thus, a heart-rate range of 20 bpm could easily encompass training intensities that differ from easy to moderate or from moderate to high.

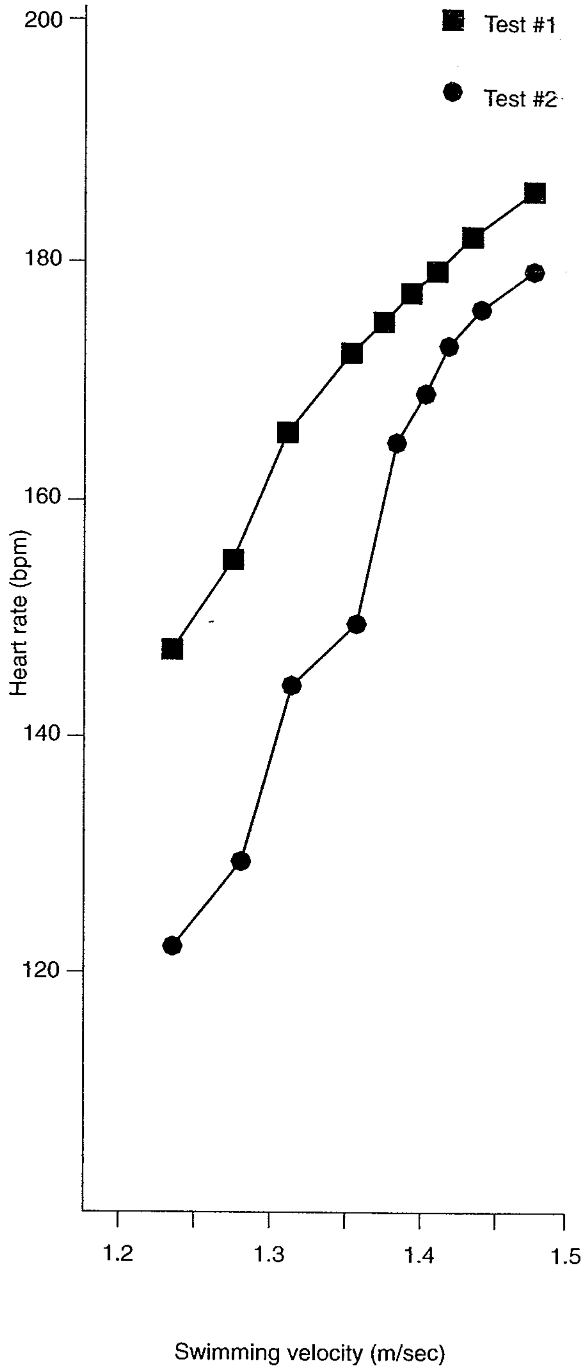


Figure 16.22 The data in this graph illustrates the variability of submaximal heart-rate measurements. They show the results of two tests conducted within a few days of one another.

Adapted from Peyrebrune and Hardy 1992.

Another problem with these ranges has to do with the wide variation in maximum heart rate among various athletes. For example, a heart-rate range of 160 to 180 bpm might work well for prescribing threshold training for an athlete with a maximum heart rate of 190 bpm. But an athlete with a maximum heart rate of 210 bpm is not likely to be swimming at threshold speed in that same range. For the second athlete, a

Table 16.3 A Simple Method for Prescribing Training Intensities According to Heart-Rate Ranges

HEART RATE RANGE	TRAINING PRESCRIPTION
120–140 bpm	Low intensity, equivalent to swimming at the lower end of basic endurance speeds.
140–160 bpm	Moderate intensity, equivalent to swimming at the higher end of basic endurance speeds.
160–180 bpm	High-intensity endurance training, equivalent to swimming at threshold endurance speeds.
180–Maximum	Very high intensity training, equivalent to swimming at overload endurance speeds.

heart rate in the range of 160 to 180 bpm would more likely indicate high-intensity basic endurance training.

Because heart rates lack accuracy in the higher ranges, other methods have been suggested for prescribing training intensities. Those methods are based on swimming at a certain number of beats below an athlete's maximum rate or on swimming at submaximal heart rates that represent a percentage of the maximum rate. The scale in table 16.4 was developed based on these procedures. Exercise heart rates 30 to 60 bpm below maximum or in the range of 65% to 80% of maximum indicate low to moderate training intensity, and rates 10 to 20 bpm below maximum or in the range of 85% to 95% of maximum probably correspond to threshold training speeds for most athletes. The estimated percentages of maximal oxygen consumption represented by these procedures for prescribing training speeds are also indicated in table 16.4. Those estimates were adapted from data presented by McArdle, Katch, and Katch (1996).

Karvonen has suggested a procedure that includes the resting heart rate when calculating training intensity as a percentage of the maximum rate. He developed this procedure, called the *heart-rate reserve formula,* because he believed it was even more accurate. The procedure is based on training at a percentage of the difference between resting and maximum heart rates. With the heart-rate reserve formula, the heart rate that corresponds to any particular training intensity is calculated by taking a percentage of the maximum heart rate and adding it to the resting heart rate. The percentage of the maximum heart rate used for each training intensity was the same as that listed in table 16.4.

The following sample calculation uses the heart-rate reserve formula. An athlete who wishes to train at 80% of his or her heart-rate reserve would add the resting heart rate to a figure that is 80% of the difference between his or her resting and maximum heart rates. Because this athlete has a resting rate of 40 bpm and a maximum rate of 185 bpm, the exercise heart rate that corresponds to 80% of his heart rate reserve is 156 bpm. The heart-rate reserve formula is proposed to be a more accurate procedure for

Table 16.4 Heart-Rate Ranges for Training Based on a Percentage of Maximum Heart Rate (% MHR) or Maximum Heart Rate Minus a Certain Number of Beats/min (MHR–)

% MHR	MHR–	ESTIMATED %$\dot{V}O_2$MAX	TRAINING INTENSITY
65%–80%	30–60 bpm	50%–70%	Low to moderate intensity, equivalent to basic endurance training.
85%–95%	10–20 bpm	80%–90%	High intensity, equivalent to threshold endurance training.
100%	Maximum	100%	Very high intensity, equivalent to overload endurance training.

individualizing the selection of heart-rate ranges that correspond to various training intensities because it includes resting heart rates in the calculations.

In general, the percentage of the heart-rate reserve that corresponds to a particular training intensity will be approximately 5% lower than the % MHR that indicates the same intensity.

Any of the three methods, MHR–, % MHR, or the HRR procedure, that considers the actual maximum heart rate of swimmers, and in some cases the resting heart rate as well, is superior to the range of heart rates provided in table 16.3 for prescribing training speeds. The figures in table 16.5 demonstrate differences in the range of submaximal heart rates that correspond to different training intensities when each of the methods is used. The athlete in this example was assumed to be 16 yr of age with a maximum heart rate of 185 bpm and a resting heart rate of 50 bpm. The least accurate procedure for prescribing training speeds with heart rates is the method based on 220 minus the athlete's age. That method gives a result that differs from those of the other methods by 6 to 26 bpm for prescribing both basic and threshold endurance training speeds. Estimating the range of heart rates for threshold training by this method could easily overestimate the proper intensity for a great number of swimmers. Surprisingly, all the other methods, including the simple scheme of equating heart-rate ranges with training intensities presented in table 16.3, are within 3 to 5 bpm of each other. Therefore, any of these procedures could be used with equal confidence, provided the athletes have maximum heart rates in the range between 180 and 190 bpm. A maximum heart rate of 195 bpm or more would cause the heart-rate differences between the simple method and the remaining three procedures to differ by 10 or 15 bpm for both basic and threshold endurance swimming. Consequently, it would be more accurate to use the MHR–, % MHR, or HRR method to prescribe training intensity when an athlete's maximum heart rate exceeds 195 bpm.

Karvonen's Heart-Rate Reserve Formula

$$HRR = HR\ rest \times 0.80\ (HR\ max - HR\ rest)$$

$$HRR = 40 + 0.80\ (185 - 40)$$

$$HRR = 156\ bpm$$

Swimmer's resting heart rate = 40 bpm

Swimmer's maximum heart rate = 185 bpm

Adapted by permission from M.J. Karvonen, E. Kentals, and O. Mutala. 1957. The effects of training heart rate: A longitudinal study. *Annales Medicinae Experimentalis et Biologiae Fenniae* 35:307–315.

Recovery Heart Rates

The time required for the heart rates of athletes to return to resting levels after exercise has long been considered an excellent measure of their adaptation to training. Effective training increases the rate of decline in heart rate at the completion of exercise. Therefore, a faster return following a standardized effort indicates an improvement in physical condition, and a slower recovery indicates failing adaptation or impending illness. For these reasons, the recovery heart rate provides an excellent means for monitoring the effects of training on the physical condition of athletes.

Table 16.5 A Comparison of Several Methods for Determining the Range of Heart Rates That Corresponds to Basic and Threshold Endurance Training

TRAINING CATEGORY	220–AGE	SIMPLE RANGE	MHR–	% MHR	HRR
Basic endurance	144–174	120–160	125–155	120–148	138–158
Threshold endurance	184–194	160–180	165–175	157–176	165–178

Athlete's data: 16 years of age; maximum heart rate = 185; resting heart rate = 50.

The most important conditions to meet when using the recovery heart rate to monitor the effects of training are

- that the workload be sufficient to cause a reasonable amount of fatigue,
- that the workload be the same from test to test,
- that the recovery heart rate be taken at the same interval following completion of the exercise,
- that the recovery heart rate be counted in the same way from test to test, and
- that the recovery period be passive.

Athletes will recover quickly from workloads that are easy whether they are well trained or poorly trained. Consequently, the workload should be intense enough to create some fatigue so that differences in recovery time will be evident as physical condition improves. Heavier workloads require longer recovery periods than lighter workloads, regardless of an athlete's physical condition. Therefore, the workload must be the same from test to test. If it is not, changes in the rate of recovery will not accurately reflect changes in physical condition.

When using the recovery heart rate to monitor the effects of training, it is not necessary to wait until an athlete's heart rate returns to its normal resting level. Doing so would take too much time. Several minutes usually pass before the heart rate returns to its resting level following strenuous exercise. Counting for 1 or 2 min after exercise will provide results that are just as accurate because the heart rate declines in two stages after exercise. During the first stage, which generally lasts 1 to 2 min, the decline is rapid, with the heart rate often decreasing by 40 to 60 bpm during this time interval. After that, the rate of decline slows. Several additional minutes may pass before the heart rate declines an additional 40 to 50 bpm to the athlete's normal resting level. For that reason, recovery heart rates are generally counted after only 1 or 2 min of rest after the work has ended. To reduce error, the recovery heart-rate count is usually taken for 15 or 30 sec starting at 30 to 45 sec after the work has ended when the recovery period is 1 min in length. The count is started 1:30 to 1:45 into the recovery period if the recovery period is 2 min in length.

Passive recovery causes the heart rate to decline faster than active recovery because even easy swimming during the recovery period provides some stimulation to the heart rate. Passive recovery, however, does not remove lactic acid from muscles as quickly as active recovery does. Thus, although the heart rate declines more rapidly, the actual precipitator of fatigue, lactic acid, is removed more slowly. In one study, the heart rate of rowers dropped from an average of 169 bpm at the end of exercise to an average of 87 bpm after 12 min of recovery (Koutedakis and Sharp 1985). Average values for blood lactate dropped from 12.61 mmol/L to only 8.05 mmol/L during the same period. A normal resting blood lactate concentration is 1.00 mmol/L. When the subjects used active recovery procedures after the same workload, their average heart rates were 138 bpm after 12 min, and their average blood lactate concentrations were 6.08 mmol/L.

Research has not established why training causes the heart rate to recover faster toward resting levels, only that it does. The reason could be that muscle and blood pH are restored more rapidly after training, and this is reflected by the decline in heart rate if passive recovery procedures are followed. Another possibility is that because training reduces the hormonal response to exercise, the heart rate recovers toward resting faster after exercise ends.

Can the Anaerobic Threshold Be Located With Heart Rates?

Over the years many attempts have been made to develop methods that would allow coaches to determine anaerobic threshold speeds with exercise heart rates. None of these have been successful, however. There are two problems. First, the heart rates that correspond to anaerobic threshold training speeds can vary considerably from athlete to athlete. Second, the heart rate that corresponds to an athlete's individual anaerobic threshold changes with training. In studies with cyclists (Craig et al. 1993) and runners (Farrell et al. 1979), heart rates that corresponded to anaerobic threshold speeds varied between 142 and 187 bpm. In another study, heart rates between 150 and 175 bpm were found to correspond to the maximal lactate steady state for trained runners (Oyono-Enguelle et al. 1990)

At present, no test can predict an athlete's anaerobic threshold speed accurately using exercise heart rates. Nevertheless, for many well-trained athletes, heart rates within 10 to 20 bpm of maximum approximate threshold training speeds (Rutt et al. 1987). This range may be accurate enough for monitoring threshold endurance training because, as indicated earlier in part II, it is not vital to train exactly at threshold speeds to gain maximum improvements in aerobic capacity. Be aware, however, that this range will overestimate the threshold training speed of some athletes, particularly sprinters, by a considerable margin. Consequently, any athlete who has problems maintaining a training speed that produces a heart rate within 10 to 20 beats of his or her maximum rate should be allowed to slow down during threshold training.

Using Heart Rates to Monitor Training Intensities for Pulling, Kicking, and Other Strokes

No current evidence indicates that a heart rate corresponding to an athlete's individual anaerobic threshold speed in one competitive stroke can be used to estimate the threshold training pace for other strokes, for kicking, or for pulling. Although it seems logical that a heart rate indicating threshold intensity for one stroke would indicate that same intensity for other strokes, that assumption remains to be proven. In fact, the results of one study suggest that heart rates cannot be used in this manner (Kelly et al. 1992). Heart rates will probably be higher at any relative swimming intensity for strokes like butterfly and breaststroke than they would be for freestyle and backstroke because the former strokes have a greater difference between their minimum and maximum velocity during each stroke cycle. These intracyclic velocity differences should cause heart rates to increase somewhat more in swimming butterfly and breaststroke than they would in swimming freestyle or backstroke at similar intensity. Therefore, athletes would have to exert more force to accelerate their forward speed in butterfly and breaststroke even when they are swimming at threshold speed or slower.

Similarly, swimming heart rates probably do not represent the same intensity when athletes are kicking only. When flutter kicking, athletes can expect their heart rates to be somewhat higher because kicking is not nearly as efficient a means of propulsion as swimming. Heart rates may also be higher because in some strokes swimmers must use their large leg muscles more to maintain even a submaximal effort when they kick as compared to when they swim. They tend to relax their legs when they are swimming at submaximal speeds, particularly when swimming the front crawl and backstroke. The result of both of these effects is that swimmers' heart rates will be stimulated as much or more when they kick alone as compared to when they swim.

The opposite effect probably occurs when athletes try to use swimming heart rates to monitor pulling. Heart rates will be lower at similar submaximal training intensity when athletes pull as compared with when they swim because they are not using their leg muscles.

Heart-Rate Profiles

Although heart rates have limitations for prescribing training paces, they may be very useful for monitoring changes in physical condition. Sharp and his associates (1984b) have suggested a practical method for monitoring changes in aerobic capacity using heart rates. With this procedure, each swimmer should complete at least two time trials at 90% and 100% of maximum effort. Swims of 200 yd were used when developing this test, although any distance could be used if it does not change from one test to the next.

The swimmer should take 20 min of rest after each time trial. Three 15 sec heart-rate counts should be taken and recorded after each time trial. The first count should commence 15 sec after the completion of the swim, the second 45 sec after completion, and the third 90 sec after completion. The three counts should then be summed and plotted against the swimming velocity that produced them. The results of each time trial can be expressed as time in seconds or as velocity in meters or yards per second. Figure 16.23 summarizes the protocol for a heart-rate profile.

1. Swim two time trials with 20 min rest between each. Distances can be 100 to 400 yd/m. The first swim should be at 90% effort; the second at 100%.
2. Take three 15-sec heart rate counts after each time trial: the first at 15 seconds postswim, the second at 45 sec postswim, and the third at 90 seconds postswim. Sum these and graph with swim times.

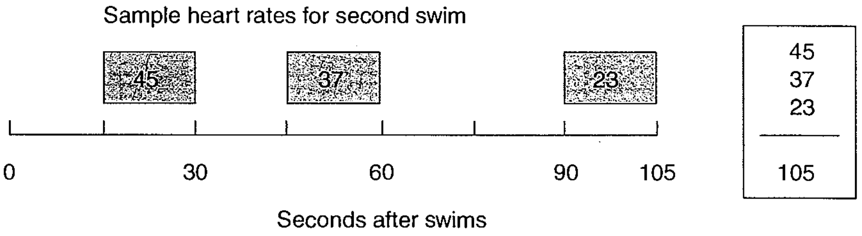


Figure 16.23 The protocol for collecting data to construct a heart-rate profile.

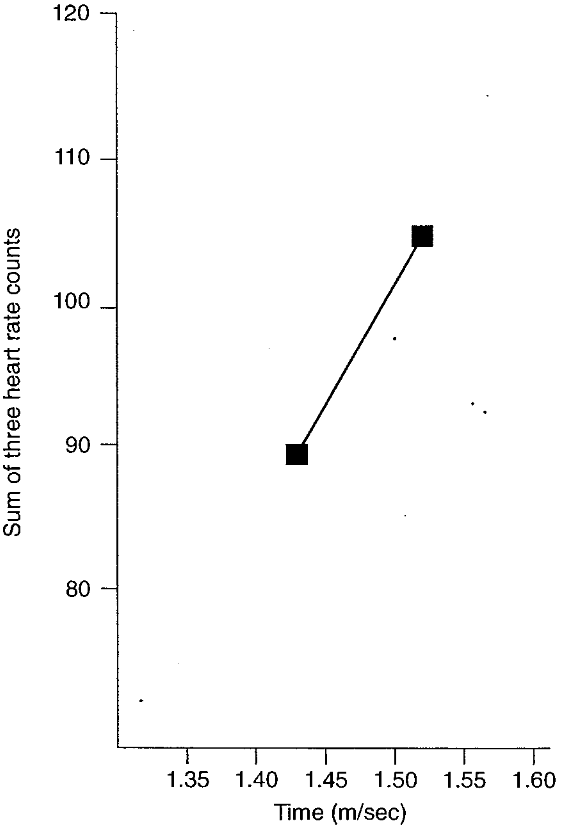


Figure 16.24 A heart-rate profile constructed from two 200 m time trials.

The results of the time trials and heart-rate counts should be plotted on a graph like the one in figure 16.24. This figure illustrates the graphing procedure for a heart-rate profile in which the times for the two 200 m swims were 2:20.35 and 2:11.15 and the sums of the respective heart-rate counts for those swims were 88 bpm and 105 bpm. The athlete's speed is graphed in meters per second.

Similar heart-rate profiles should be developed periodically during a season to evaluate changes in aerobic capacity. The results of three heart-rate profiles constructed during the course of a typical swimming season are shown in the graph at the top of figure 16.25. They show that the heart-rate velocity line moved to the right with each succeeding test. This shift indicates that the athlete's aerobic capacity has improved just as a rightward shift of a lactate-velocity curve would be an improvement of aerobic capacity. To test this hypothesis, Sharp and his coworkers compared the results of heart-rate profiles and blood tests conducted at the same time of the season for a group of swimmers. The subjects were 12 members of a university swim team who were tested during the early, middle, and late portions of the season. Heart-rate profiles were constructed from these tests in the manner described earlier. In addition, blood samples were collected after every swim of each test. The samples were

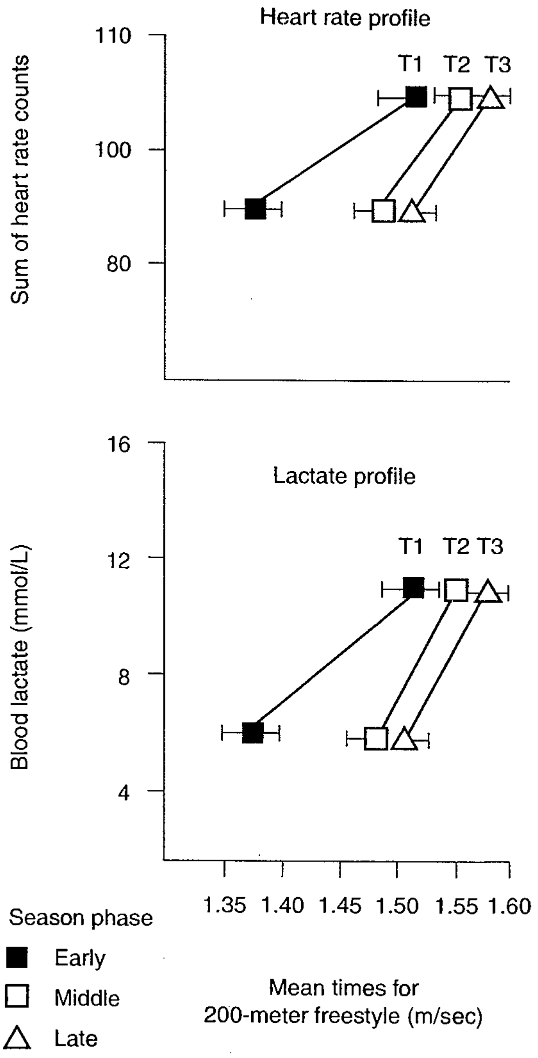


Figure 16.25 A comparison of heart-rate and lactate profiles during one swimming season.

Adapted from Sharp et al. 1984b.

taken at 1,3,5,7, and 9 min after the completion of each time trial to determine the highest blood lactic acid concentrations produced by that swim. These blood lactate values were plotted opposite the swimming velocities that produced them so that movements of the subjects' lactate-velocity curves could be compared with the movements of their heart-rate velocity profiles from test to test. The results of this comparison are displayed at the bottom of figure 16.25.

Both profiles moved to the right from the first (T1) to the second test (T2) and from the second to the third test (T3). The magnitudes of those rightward movements and the slopes of the lines for the lactate-velocity and heart-rate velocity profiles were similar. The authors concluded from these data that heart-rate profiles were capable of sensing changes in performance capacity in the same manner as blood tests. They also stated that heart-rate profiles could not be used to prescribe training speeds, nor would they provide any information about the balance between endurance and sprint training.

The test developers noted that the heart-rate profiles of some subjects tended to show more variation than their lactate profiles. They concluded, therefore, that counting heart rates was not as reliable as measuring blood lactate for sensing changes in aerobic capacity. Nevertheless, because they are much easier to administer than blood testing, heart-rate profiles can provide coaches with an inexpensive, accessible, and valuable tool for monitoring training.

Perceived Exertion

Perhaps the most direct way to monitor training intensity is simply to rate the degree of exertion. With this method athletes rate how hard they feel they are working by assigning a number to their sensation of effort. This method, known as *rating perceived exertion (RPE)*, was originally developed to monitor training during cardiac rehabilitation. Patients were taught to equate work intensity to a number on a scale known as the *Borg scale*, after the man who developed it. Researchers found that their cardiac patients could learn to monitor the intensity of their training quickly and with acceptable accuracy when they used this procedure (Bellew, Burke, and Jensen 1983; Purvis and Cureton 1981).

Because of its effectiveness for monitoring the training intensity of cardiac patients, coaches and athletes are now using the Borg scale for the same purpose in a variety of sports and exercise training programs (Simon, Segal, and Jaffe 1987). The original Borg scale rated exercise intensity from 6 (easy) to 20 (extremely hard). That scale is presented in table 16.6. The exercise intensity and probable training effects corresponding to each number on the scale are also listed.

I should make it clear that ratings of perceived exertion cannot be used to monitor training intensity without educating the swimmers beforehand. They must first become familiar with the physical and mental sensations associated with swimming below, at, and above their anaerobic thresholds before they can use this scale with any degree of accuracy for prescribing training speeds. They can develop that familiarity by establishing their threshold pace with one of the many tests described previously. Then the

Table 16.6 The Borg Scale

RATING	PERCEIVED EFFORT	PROBABLE EFFECT	TRAINING CATEGORY
6	No exertion at all		
7	Extremely light		
8			
9	Very light	Useful for warming up and swimming down.	Recovery training (Rec)
10			
11	Light	Maintains aerobic endurance while recovering from more intense training.	Basic endurance (En-1)
12			
13	Somewhat hard	Improves aerobic capacity.	Basic endurance (En-1)
14			
15	Hard (heavy)	Improves aerobic capacity. Work at or slightly below the present anaerobic threshold.	Threshold (En-2)
16			
17	Very hard	Improves aerobic and anaerobic muscular endurance. Intensity is above the present anaerobic threshold.	Overload endurance (En-3)
18			
19	Extremely hard	Improves anaerobic metabolism.	Lactate tolerance (Sp-1) and race-pace training (R-P)
20	Maximal exertion		

G. Borg, 1998, *Borg's Perceived Exertion and Pain Scales* (Champaign, IL: Human Kinetics) p. 47.

athletes should swim some repeat sets that are both faster and slower than their threshold pace while trying to assign a value from the Borg scale to each of those swimming intensities. For example, for most swimmers, repeats at or near their present anaerobic thresholds should feel like an intensity of 14 to 16 on the Borg scale, 14 early in the set and 16 later. Overload endurance sets should probably begin at an intensity corresponding to 17 and progress to 18 throughout the set, and basic endurance sets should correspond to ratings of 10 and 13. Ratings of 6 and 9 should be associated with recovery training, and lactate tolerance and race-pace swimming should always be at an RPE between 18 and 20. After swimmers have become adept at associating each training intensity with its correct scale number, they will be able to use ratings of perceived exertion to monitor training intensity with a high degree of accuracy.

The Borg scale has the advantage of being a convenient and easy procedure for prescribing training intensity because it requires a minimal amount of training to use effectively. The scale has also been proved effective for increasing aerobic capacity because it has several advantages over other methods involving blood lactate testing and heart-rate counting. One advantage of prescribing training with ratings of perceived effort as opposed to other methods is that the ratings allow swimmers to compensate for periodic variations in their physiological capacity. They can swim slower or faster on "bad" or "good" training days when previous speeds feel as if they should be rated either higher or lower than before. Perhaps the most important advantage of the RPE method is that it allows motivated swimmers to progress at their own pace rather than according to some preselected test schedule. That is, they can increase their training pace when they feel capable of doing so, rather than waiting for new test results to tell them when it is time to increase their training speed.

When they use ratings of perceived exertion to monitor for overtraining, athletes should not become concerned when they perceive that they are using more effort to swim at their usual training speed unless that feeling persists over several days. If the feeling does continue for a few days, they should try to determine the cause immediately. The explanation could be failing adaptation due to overtraining, outside sources of stress, or impending illness.

Percent Efforts

The use of percent efforts refers to monitoring training intensity according to a percentage of a swimmer's best time, either lifetime or best time to date during a season. For example, a swimmer with a best time of 2:00 for a 200 m freestyle would be training at an 80% effort when he or she swims 200 m repeats at 2:24. The formula for making this determination is to the right. The calculations for an 80% effort over 200 m based on a swimmer's season-best time are also shown.

Formula for Determining Percent Efforts From Lifetime and Season-Best Times

Based on lifetime best of 2:00

80% effort = best time for 200 m × 0.20 = sec to be added to the swimmer's best time for 200 m

80% effort = 120 sec × 0.20 = 24 sec + 120 sec = 144 sec

80% effort = 2:24

Based on season-best time of 2:05

80% effort = 125 sec × 0.20 = 25 sec + 125 sec = 150 sec

80% effort = 2:30

The swimmer in this example has a lifetime best performance of 2:00 for 200 m and a season-best time of 2:05. Given these times an 80% effort based on the swimmer's lifetime best 200 m swim would be 2:24. An 80% effort based on the swimmer's season best 200 m swim would be 2:30.

Although in the first edition of this textbook I recommended percent effort for prescribing training speeds, the development of a number of better methods has rendered its use unnecessary. Even when I recommended this method, it was with reservations because of its imprecision. Several factors caused the lack of accuracy.

- The method never made clear whether lifetime best or season-best performances should be used to determine percent efforts. In addition, research by others and me (Maglischo, Maglischo, and Bishop 1982) showed that the percent effort corresponding to swimmers' anaerobic threshold speeds varied considerably from athlete to athlete.
- Athletes had to swim at progressively greater percent efforts to maintain threshold speeds as they improved their aerobic capacity during the season. This result should have been expected because athletes will be able to swim closer to their best times with less fatigue when their aerobic capacity improves.
- The percent effort associated with particular training intensity increased as the distance of the repeats increased. For example, a 70% effort might correspond to a particular athlete's anaerobic threshold speed for 100 repeats. But that athlete might have to swim at 85% effort for 400 repeats to reach anaerobic threshold speed. This circumstance occurs because longer repeats have a larger aerobic component; therefore, athletes could swim closer to their best times for longer repeats without upsetting the balance between lactate production and elimination.

Percent efforts cannot be used to predict training intensity with any reasonable degree of accuracy. Training speeds can only be prescribed in ranges so large that a sizable number of athletes will be swimming too slowly to produce a maximum improvement of their aerobic capacity. Others will be swimming so fast that they might be training well above threshold speed. Additionally, athletes cannot train at any standard percent effort and be assured that it represents the same training intensity during different phases of the season, nor can they be certain that any standard percent effort represents the same training intensity for a variety of repeat distances.

Tests for Anaerobic Power and Aerobic and Anaerobic Muscular Endurance

A large number of tests are used for monitoring and evaluating aerobic capacity. Few tests, however, can be used to evaluate changes in anaerobic metabolism. This is unfortunate because it is obvious that anaerobic metabolism plays a major role in most swimming events. A reduction in the rate of anaerobic metabolism can be devastating to swimmers in events of 400 m and less.

Some tests work well for evaluating changes in aerobic muscular endurance, particularly those that detect changes of velocity on the steep portion of the lactate-velocity curve. I described some of those earlier and will describe others here. Some of the tests of anaerobic power and aerobic and anaerobic muscular endurance have shown a high relationship with sprint performance, but others have not. I will discuss some tests that have been suggested for measuring anaerobic power, and then I will describe some tests for evaluating aerobic and anaerobic muscular endurance.

Tests of Anaerobic Power

Earlier in this chapter I suggested measures of peak blood lactates to measure anaerobic power. Although peak blood lactate measurements can be used for this purpose, coaches need noninvasive procedures that are safer, simpler, and less expensive to administer.

Many of the noninvasive tests developed for evaluating anaerobic power involve land activities. They include running, weight lifting, cycling, vertical jumping, running uphill, and arm cranking on a specially designed ergometer. None can tell us much about the anaerobic power of swimmers, however, because they lack specificity (Szogy 1988, Takahashi et al., 1992b). For that reason, some researchers have attempted to use the biokinetic swim bench to measure anaerobic power because swimmers can simulate their strokes while using it. Attempts to show a relationship between swim bench power and swimming speed have produced mixed results. Some researchers have reported a significant relationship between the two (Hawley and Williams 1991; Sharp, Troup, and Costill 1982), whereas others have not (Dopsaj et al. 1999; Johnson, Sharp, and Hedrick 1993). Similar results have been reported for comparisons of swimming speed with tests of strength involving weight-training activities.

The most accurate way to assess anaerobic power is with in-water swimming against resistance. For this reason, the Power Rack and swim wheel are excellent devices for measuring swimming power. They provide accurate ways to measure the amount of weight lifted, the distance it was lifted, and the time required to lift it. Once this information is known, the power generated by a swimmer can be calculated by using the standard formula force times distance divided by time. Figure 16.26 shows an example of how this formula can be used to quantify swimming power. Using a Power Rack, the swimmer lifted a weight of 20 kg over a distance of 2.0 m in 6.00 sec, resulting in a swimming power score of 6.67 kg/m/sec.

Example Calculations for Anaerobic Power

1. Weight lifted = 20 kg (44 lb)
2. Distance lifted = 2.0 m (6 ft, 6 in.)
3. Time required to lift weight = 6.0 sec

Anaerobic power = 6.67 kg/m/sec

$$\frac{20 \text{ kg} \times 2.0 \text{ m}}{6.00 \text{ sec}} = 6.67 \text{ kg/m/sec } (47.67 \text{ ft/lb/sec})$$

Figure 16.26 Sample calculations for anaerobic swimming power. The athlete swam 12 yd in 6.0 sec while attached to a Power Rack. He lifted 20 kg over a distance of 2.0 m during the swim.

Tests like those just described are good ways to quantify changes in swimming power. But the simplest and most direct method for evaluating changes in the anaerobic power of swimmers is simply to time them for very short sprints. Swimmers who improve their times for sprints of 10 to 50 yd or m have probably also improved their anaerobic power, whereas those who sprint slower have probably had their rates of anaerobic metabolism slowed by training or other factors, such as a detrimental change in stroke mechanics, injury, illness, excessive fatigue, or lack of effort. Careful structuring and administration of these sprints can reduce the possibility that these factors will influence the results. I will suggest some test sets for evaluating anaerobic power later in this chapter.

Tests of Aerobic and Anaerobic Muscular Endurance

The dV5-10 blood testing procedure described earlier in this chapter may be the single best test for evaluating changes in aerobic and anaerobic muscular endurance. A major advantage is that this test does not require an all-out effort. Most tests for this purpose require a maximum effort, and the results can be misleading if athletes fail to provide that effort.

Another procedure for evaluating aerobic and anaerobic muscular endurance that gets high marks involves calculating the oxygen deficit (O_2 deficit) (Green and Dawson 1993). In a study in which it was used to predict the sprinting ability of age-group swimmers, the O_2 deficit measured during swimming was strongly related to the swimmers' performance for 100 m events (Takahashi et al. 1992a). The procedure for calculating the oxygen deficit was described in chapter 9.

Several dry land tests of aerobic and anaerobic muscular endurance have also been developed over the years. One of the most popular is the Wingate test, but I do not recommend its use. Although a few studies have shown a relationship between scores on this test and sprint performance, most indicated that its validity was questionable for this purpose (Jacobs et al. 1983) or that it was not sufficiently specific to be used for measuring the anaerobic capacity of athletes in different sports (Ferris et al. 1989; Tamayo et al. 1984).

Stroke-simulated efforts on a biokinetic swim bench, however, may be used to evaluate aerobic and anaerobic muscular endurance. The relationship seems to be higher than relationships between scores on the biokinetic swim bench and sprint swimming speed. Takahashi and coworkers (1992b) tested the effectiveness of a 45 sec maximal effort on the biokinetic swim bench for this purpose. They found a high positive relationship, 0.83, between the work that swimmers could complete in that time and their oxygen deficit as measured in the water.

As with anaerobic power, the simplest and most direct method for evaluating changes in the aerobic and anaerobic muscular endurance of swimmers may be simply to measure their ability to maintain a near-maximum speed for a standardized set of swimming repeats. The next section will provide some suggestions for constructing and administering such a test.

Monitoring Training With Test Sets

The blood testing procedures I described in this chapter are only usable when specialized equipment is available, when the coaches and scientists are trained in their administration, and when only a small number of swimmers are tested. Some of the noninvasive tests are much more usable in the less-than-ideal environment of the typical large swim team, although even some of those tests require specialized equipment. For those reasons, the most direct and useful methods for evaluating changes in aerobic and anaerobic metabolism involve swimming standardized repeat sets designed to reflect a particular physiological capacity, be it aerobic capacity, anaerobic power, or aerobic and anaerobic muscular endurance. These standardized repeat sets have the advantage of requiring no special equipment. Coaches and swimmers rather than trained scientists can gather the data, and the results are relatively easy to interpret. In the following sections I will describe some ways that repeat sets can be constructed and administered for evaluating changes in aerobic capacity, aerobic and anaerobic muscular endurance, and anaerobic power. Coaches will find that monitoring training with these sets will provide valuable information about each athlete's response to the training program. At the same time, the test sets will not significantly detract from the athletes' training. Testing will not require the purchase of expensive equipment or the employment of scientists.

Test Sets for Aerobic Capacity

Changes of aerobic capacity can be monitored in two ways. The first is by swimming a set of repeats at submaximal speed while counting both exercise and recovery heart rates. The second method is by swimming a long set of repeats at threshold speed. That method was described earlier in this chapter under the heading "Standardized Repeat Sets." I will describe the method involving submaximal swims and heart-rate counting here.

When using this method, athletes should swim a set of repeats at a fairly intense but manageable speed. The length of a standardized repeat set designed for this purpose should be between 3,000 and 4,000 yd or m. The best repeat distances for this purpose are between 200 and 800 yd or m, and the send-off times for the set should provide between 10 and 20 sec of rest between repeats. The repeats should be fast enough to produce exercise heart rates above 140 bpm but below 180 bpm. Swimmers should pace each repeat evenly and swim all the repeats at similar speed. Examples of two repeat sets appropriate for this purpose are 15 × 200 and 8 × 500.

Swimmers should complete the test set selected to evaluate aerobic capacity once every 3 to 6 weeks during the training year. The results should be compared with previous tests to determine what, if any, training adaptations have taken place. For greater accuracy, the testing conditions should be nearly identical from one test to the next. Athletes should swim the same number of repeats in the same stroke, at approximately the same level of effort, and on the same send-off time. If possible, athletes should swim these sets on the same day of the week, following a day or two of easy training so that unusual fatigue or glycogen depletion will not affect the results.

The times for each of the repeats in the set should be averaged and recorded in a logbook. Exercise heart rates should be counted for 10 sec during the rest period after each repeat. Heart rates should also be averaged and recorded. The exercise heart rates may be recorded as 10 sec counts or multiplied by six and recorded as 1 min counts. The recovery heart rate should also be counted and recorded. A 15 sec count should begin exactly 45 sec after the end of the last repeat in the set. The information in table 16.7 will aid in interpreting the results of a test set of this type.

Sample results are presented from four identical test sets of 15 × 200 m on a send-off of 2:30 swum at approximately 4-week intervals. The average time for each set of re-

Table 16.7 Results of Four Test Sets Designed to Evaluate Changes in Aerobic Capacity

REPEAT SET	TEST DATE	AVERAGE TIME	WORKING HEART RATE	RECOVERY HEART RATE
15 × 200/2:30	1/22	2:18	162 (27)	120 (30)
15 × 200/2:30	2/21	2:16	162 (27)	112 (28)$^{+}$
15 × 200/2:30	3/17	2:15	168 (28)	104 (26)$^{\bullet}$
15 × 200/2:30	4/17	2:18	168 (28)	124 (31)$^{-}$

$^{+}$Probably better; $^{\bullet}$may be better; $^{-}$probably worse.

peats is listed together with the average exercise heart rate and the recovery heart rate it produced. Heart rates are presented in two ways. The converted minute rates for both exercise and recovery heart rates are shown without parentheses. The actual average count for the set and the actual recovery heart rate are in parentheses. When interpreting the data, actual heart-rate counts should be used. When counts are converted to minute values, the differences in counts appear to be much greater than they truly are. For example, a one beat decrease in a 10 sec count results in a six beat difference when it is converted to a minute rate, yet the one beat difference could easily be an error in measurement.

The results from these four test sets can be interpreted in the following manner. Results from the second test set, on February 21, show that the average time for the 200 repeats improved by 2 sec, from 2:18 on the first test to 2:16 on the second. The average working heart rate remained the same on the second test, but the recovery heart rate declined by two beats in 15 sec, or eight beats during 1 min, on the second test. These results indicate that the swimmer is obviously swimming faster with no increase in working heart rate and a faster recovery. Therefore, his aerobic capacity has probably improved. I say *probably* because that is the best judgment that can be made with heart rates.

The results of the third test set, on March 17, are more difficult to interpret. The athlete's average time has improved 1 sec, from 2:16 on the previous test to 2:15 on this test. But his working heart rate is one beat higher over 10 sec (six beats for 1 min) and his recovery heart rate is two beats lower over 15 sec (eight beats over 1 min). This swimmer may have improved his aerobic capacity. The difficulty in interpretation comes from the fact that although his average time has improved, his exercise heart rate indicates that he had to work harder to produce that increase in average swimming speed. His recovery time is the measure that indicates that an improvement has probably taken place. The fact that he recovered faster, even though he swam faster, suggests that his aerobic capacity has improved. My experience over several years of conducting tests like this is that the recovery heart rate is usually a better indicator of the severity of work than the exercise heart rate is.

The results of the fourth set of repeats, on March 17, indicate that this athlete is probably suffering from failing adaptation. His average time for the set of repeats is slower by 3 sec from the previous test. His exercise heart rate is the same, and his recovery heart rate indicates that he is recovering at a slower rate. This athlete may have lost some of his aerobic capacity from the first test, or he may be at the beginning of an illness, such as a cold or flu.

Including heart-rate counting adds to the complexity of administering test sets. Swimmers must be able to count their heart rates accurately, or the data will be misleading. The advantage in using heart rates is that athletes do not have to swim at maximum effort on these sets to test for changes in their aerobic capacity. Therefore, motivational factors play a smaller role in the interpretation of results. Weighing the advantages against the disadvantages, I would have to say that the addition of accurate heart-rate counting will improve the accuracy of interpreting changes in aerobic capacity, if athletes, for whatever reason, fail to provide an honest effort on subsequent repeat sets.

A final advantage in using standardized repeat sets like those suggested in this section is that the average speed for the set is probably close to each athlete's individual anaerobic threshold speed.

Athletes must understand the importance of providing honest effort on every test when this method is used. Less-than-honest effort will invalidate the results and eliminate assurance that aerobic capacity has improved.

Test Sets for Aerobic and Anaerobic Muscular Endurance

The reason for an aerobic and anaerobic muscular endurance test set is to get an estimate of changes taking place above the anaerobic threshold, principally changes in buffering capacity. This type of set provides the same information as a dV5-10 determination from a blood test, that is, it tells whether the slope of the lactate-velocity curve is flattening above the anaerobic threshold. This test may be the best measure of how well an athlete is maintaining the balance between aerobic and anaerobic training.

The repeat set should be 1,200 to 2,000 yd or m in length or take between 15 and 20 min to complete so that both aerobic and anaerobic metabolism are fully involved. The set should be done on a standardized send-off time that provides between 15 and 30 sec of rest after each repeat. The best repeat distances for this purpose are between 150 and 400 yd or m. Some examples of good repeat sets for monitoring changes of aerobic and anaerobic muscular endurance are 10 × 150 and 6 × 300.

The average repeat speed for the set is the principle statistic used to determine the nature of any changes in aerobic and anaerobic muscular endurance. When it improves, the athlete's aerobic and anaerobic muscular endurance has probably also improved. Exercise heart rates could be counted to ensure honest efforts, although they are not necessary for purposes of evaluation. The exercise heart rates should be near maximum on all sets of this type; therefore, they probably will not change much from one test to the next. Recovery heart rates, however, should be measured. Slow times with slower recovery almost certainly indicate failing adaptation, whereas slow times with rapid recovery signal lack of effort.

Test Sets for Anaerobic Power

The purpose of test sets for anaerobic power is to evaluate changes in an athlete's rate of anaerobic metabolism. A small number of very short repeats should be used so that acidosis and its slowing effect on anaerobic metabolism will not cause interpretation errors.

The best repeat distances are 25 and 50 yd or m. The repeat set should be 100 to 300 yd or m in length. The rest intervals should be long to allow for the elimination of much of the lactate that is produced during each swim. Send-off times of 2 to 3 min between 25s and 2 to 5 min between 50s are recommended for this purpose. Athletes should swim easy during the recovery periods between repeats to assist in clearing their muscles of lactic acid. Some examples of repeat sets for monitoring changes in anaerobic power are 6 × 25 yd or m on a send-off time of 3 min and 4 × 50 yd or m on a send-off of 4 min.

The average repeat speed for these sets is the best statistic to use for evaluating changes in anaerobic power. When the average time for the set of sprint repeats improves, the athlete's anaerobic power has probably improved.

Coaches and athletes may be tempted to use just one sprint to measure anaerobic power, but that is not recommended because too many factors, such as waves and timing errors, could affect the outcome. Averaging a swimmer's speed for several repeats will provide a more reliable estimate of changes in his or her anaerobic power.

The accuracy of evaluating changes of anaerobic power can be improved by stroke counting or by calculating stroke rates during these test sets. When athletes use fewer strokes or slower stroke rates, their swimming efficiency may have improved even when their times do not improve. At the same time, a lack of effort could be suspected on a previous test if they improve their times on the subsequent test by taking more strokes and using higher stroke rates. In this case, anaerobic power may not have improved even though they improved their average speed for the set of repeats.

Testing the Aerobic and Anaerobic Muscular Endurance of Sprinters

A test set used to evaluate the balance between aerobic and anaerobic training for 50 and 100 sprinters should be shorter than the sets used for this purpose with middle distance and distance swimmers. A longer set distance puts a greater premium on the aerobic portion of the measurement, and a shorter set distance emphasizes the changes in buffering capacity for sprinters. Therefore, for sprinters, a set of this type should be 600 to 800 yd or m in length. The best repeat distances for this set are between 50 and 200 m. The send-off time should allow approximately 30 sec to 1 min of rest between repeats. A rest of 30 to 45 sec between repeats is best for distances of 50 and 75 yd or m. The rest period should be between 30 sec and 1 min for the longer repeats to encourage faster and more efficient swimming by the sprinters.

Some examples of repeat sets for monitoring changes in the aerobic and anaerobic muscular endurance of sprinters are 12 × 50 on a send-off time of 1 min and 8 × 100 on a send-off time that allows approximately 1 min of rest between repeats. Rest intervals should be longer for age-group and masters swimmers who are not capable of repeating at the speed of senior swimmers. In those cases, send-off times of 1:00 to 1:30 are recommended for 50 repeats. For 100 repeats the send-off times could be 1:30 to 3:00.

Again, the average time for these repeat sets is the most important statistic for evaluating changes in aerobic and anaerobic muscular endurance. An improvement in average speed is a good indication that the athlete's buffering capacity and aerobic capacity have probably improved. Motivation, however, plays a large role in the results. Unless the athlete is highly motivated each time he or she completes one of these sets, the results could be invalid.

Stroke counts and stroke rates can be calculated during these sets as a measure of stroking efficiency and to allow more accurate interpretation of the results. Faster times with greatly increased stroke counts and rates on a subsequent test set could mean that the results were due more to greater motivation than to improvement in aerobic and anaerobic muscular endurance. In contrast, faster times with similar stroke counts and stroke rates are a good indication that the athlete's race performances will improve.

Administering Test Sets

As indicated, distance and middle distance swimmers should use test sets for aerobic capacity to evaluate improvement in aerobic metabolism. They should use test sets for aerobic and anaerobic muscular endurance to evaluate changes in the interaction of aerobic and anaerobic metabolism during races, as well as changes in their buffering capacity. They can safely continue with large volumes of endurance training as long as their results continue to improve on both types of test sets. Improvement in aerobic capacity not accompanied by improvement in aerobic and anaerobic muscular endurance usually signals a loss of anaerobic power and perhaps a loss of buffering capacity. This circumstance could mean that they are performing too much of their endurance training at too high an intensity. Conversely, it could mean that they are doing too little threshold and overload endurance training. If a logbook is maintained, a comparison of the relative volume of the three types of endurance training completed by the swimmer during the time between tests can help a coach determine which of the two opposing consequences needs to be corrected.

Middle distance and distance swimmers can use test sets that evaluate anaerobic power to ensure that their endurance training does not suppress their rates of anaerobic metabolism beyond repair. Sprinters should use them to evaluate improvements in anaerobic power, at least during the last half of a season.

Unfortunately, I cannot supply any estimates or even guesses about how much anaerobic power and buffering capacity swimmers can afford to lose during a season without affecting their ability to regain them by the end of the season. Time and experience with these tests will be needed to make accurate judgments of this type. In time, one may spot general trends for the group, or the response of anaerobic power to endurance training may be vastly different for each swimmer.

Sprinters should use test sets for aerobic capacity, test sets for aerobic and anaerobic muscular endurance, and test sets for anaerobic power to evaluate their progress during the season. They should expect to lose some aerobic and anaerobic muscular endurance and anaerobic power during the portion of the season when they emphasize aerobic endurance. Again, I cannot say how much they can allow their performance on these tests to deteriorate without hurting their potential at season's end. I can only say that, unlike distance and middle distance swimmers, sprinters want to leave time to improve their anaerobic power and buffering capacity, not simply regain them. Therefore, they should be more concerned about large decrements in performance on tests of aerobic and anaerobic muscular endurance and anaerobic power. They should allow more time in the season for improving their performance on these two types of test sets.

Evaluations with test sets should be conducted in a variety of ways. One method would be to set aside 1 week of each training cycle for testing, with the athletes performing a different test on each of 3 days. Alternatively, testing could be conducted in a way that does not interfere with training by administering them in 3-week cycles during the hard training periods. One test could be administered during each of 3 weeks until all three types of tests have been conducted. After that, athletes could start the process over again or wait for a few weeks before resuming testing.

17

Season Planning

New in this edition:

- Updated section on weekly planning
- Examples of season plans for the various categories of swimming events

Taking athletes to a peak for important competitions requires careful planning. That planning can and should extend over several years. Obviously, this gigantic task must be broken down into smaller, more manageable units. My purpose in this chapter is to discuss the structure and integration of those units. I will begin with multiyear planning. The second section will cover yearly planning. Later sections will describe season planning, weekly planning, and daily planning.

Multiyear Planning

Multiyear planning can encompass the entire career of a swimmer, from childhood to the adult years. Age-group coaches should have a general plan for regulating the nature, volume, and intensity of training throughout their swimmers' competitive careers with a goal of achieving peak performances sometime in their adult years.

Multiyear planning can also concern the preparation for major events like the World Championships and Olympic Games, which are conducted every 2 to 4 yr. For high school and college swimming coaches, multiyear plans should encompass the 3 to 4 yr that swimmers are in a coach's charge. Plans for these purposes are discussed in the next section.

Biquarterly and Quarterly Planning

Planning on a quarterly or biquarterly basis refers to programming a system of progression into 2 and 4 yr plans that coincide with the dates for the World Swimming Championships and the Olympic Games. Other multiyear plans can be constructed for the 3 or 4 yr span of an athlete's high school or college career. The purpose is to bring swimmers to a peak of performance at the proper times in their careers.

Many coaches and athletes do not prepare well-organized multiyear plans. Athletes are simply asked to train hard and improve as much as they can each year so that they will be fast when the time comes for their major competition, be it the Olympic Games, high school state championships, National Championships, or whatever. No system of planned progression is in place beyond attempting to swim faster in training each year. Although athletes can have success with a plan like this, their chances of achieving better performance increase with careful multiyear planning. Good planning involves focusing on improving each athlete's weaknesses during the early years of the multiyear plan and then concentrating on increasing endurance and speed during the year the major competition takes place.

An example of a biquarterly progression plan for a 200 swimmer with a goal of performing well at the World Championships and Olympic Games is displayed in figure 17.1 The training values in this figure are only approximations that illustrate how the volume and intensity of different types of training should change leading up to the Olympic year. The figures are not meant to symbolize ideal values.

The largest volume and greatest intensity of specific training occur during the years when the World Championships and the Olympic Games are held. Laying a foundation for endurance and speed receives greater emphasis during the other years. Training should focus more on developing aerobic capacity and anaerobic power during those years, whereas training during the competition years should emphasize improving aerobic and anaerobic muscular endurance. The "off" years are also a time when athletes can work hard on improving specific competition weaknesses, such as faulty stroke techniques, starts, turns, weaknesses in the strength and power of certain muscle groups, and poor flexibility in important joints.

Yearly Planning

Using the framework for multiyear planning as a guide, the next step is to plan each training year. Most coaches divide the training year into two or three seasons. The decision about whether to use two or three seasons is usually based more on the placement and importance of championship competitions than it is on physiological effectiveness. Coaches in the United States usually partition the training year into two seasons because of academic demands and because the two major meets of the year generally occur in the early spring and near the end of the summer. In other parts of the world, three major championship meets are commonly held each year, one in December, one in spring, and a third in late summer. Consequently, many coaches from those countries use three-season plans. Typical two-season and three-season yearly plans are described in the next two sections.

Planning for a Two-Season Year

Short-course season—September to March (30 weeks)
Long-course season—April to August (20 weeks)

Two-Season Yearly Plan

With this plan, the training year is generally separated into short-course and long-course seasons. The short-course, or winter, season culminates in a major national or international competition sometime in March or April. That meet is usually conducted in a

	Year 1	Year 2	Year 3	Year 4
Training days including competitions	250–270	280–290	280–290	300–320
Training sessions	400–420	460–500	460–500	520–540
Mileage	1,600–2,000 km	2,000–2,400 km	2,000–2,400 km	2,400–2,800 km
En-1	800–1,000 km	1,000–1,200 km	1,200–1,400 km	1,200–1,400 km
En-2	240–300 km	200–240 km	300–360 km	240–280 km
En-3, Spr-1, and R-P	80–100 km	140–160 km	100–120 km	170–190 km
Spr-2 and Spr-3	100–140 km	100–140 km	140–160 km	140–160 km
Recovery	300–400 km	330–350 km	320–340 km	340–360 km
Strength and flexibility on land	140–150 days	120–130 days	140–150 days	120–130 days
Power on land and in the water	80–100 days	120–130 days	80–100 days	120–130 days

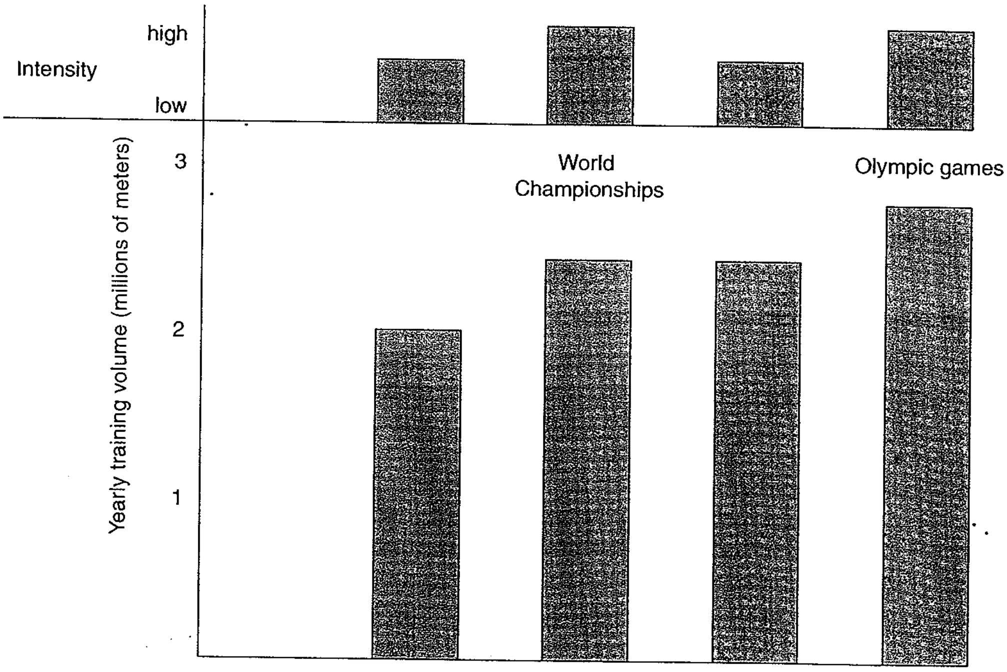


Figure 17.1 An example of a biquarterly plan for a 200 swimmer designed to produce peak performance at the World Championships and Olympic Games.

25 yd or 25 m course. The long-course, or summer, season ends with a meet of equal or greater importance in August or September, usually contested in a 50 m course. Swimmers usually have 1 or 2 weeks for rest and recuperation after each season.

Three-Season Yearly Plan

The three-season plan is used in parts of the world where there is a major international championship in late winter, followed by another important national or international

Planning for a Three-Season Year

Fall season—September to December (16 weeks)
Winter season—January to April (15 weeks)
Summer season—May to August (16 weeks)

championship in the spring and, another major championship meet in late summer. The first, or fall, season usually lasts from September to late December. The culminating championship meet for this season is usually conducted in short-course meters. The second, or winter, season is from January to April. The championship meet for this season may be contested in short-course or long-course pools, depending on the part of the world where it is held. The third, or summer, season extends from May to August and usually culminates with a major long-course championship. Again, swimmers generally have a break of 1 or 2 weeks after each season.

The placement and relative importance of major competitions during the year usually determines the number of seasons that coaches plan for each training year and the length of each season. Despite this, scientific data suggests that a season should encompass a minimum of 20 weeks when improving aerobic capacity is important (Denis et al. 1982).

Season Planning

In the past, a common practice has been to structure a season plan similar to the one illustrated in figure 17.2. With this plan, swimmers build to their maximum weekly mileage during the early weeks of the season and then remain at that level for 10 to 15 weeks. Following that stage, they reduce the mileage slightly and increase the intensity of their training for 4 to 6 weeks. A taper of 2 to 4 weeks follows, just before the major competition of the season. The effect of this plan on the performance of swimmers is also shown in figure 17.2. Race performance will generally improve rapidly during the first 4 to 6 weeks of each new season. After that, swimmers do not improve until the taper. In this case, the swimmers improved on their previous best performances at the season-ending meet following the taper.

Plans like the one in figure 17.2 have been used successfully over the years despite the fact that they have some major weaknesses. Perhaps the principal weakness is that the system of progression is based almost entirely on the motivation of individual athletes. Because of this, some athletes may work beyond their capability and become overtrained sometime in the middle of the season. Others may just go through the motions and never achieve an optimum level of conditioning by the end of the season. Another weakness is that the absence of a planned system of progression may cause some athletes to achieve their peak performance in midseason rather than during the important season-ending meets. For those reasons, many training experts advocate a different plan that includes a systematic pattern of progression that covers all aspects of the athlete's physical preparation and leads to a peak performance at the desired time of the season. They suggest separating a swim season into smaller, more manageable units that emphasize the development of certain physiological mechanisms in a systematic manner. A short period of recovery follows each of these units. The next unit is designed to overload the swimmer in some way so that the season plan is structured in a *staircase* manner. Figure 17.3 illustrates this method of planning.

The plan in figure 17.3 has been developed for swimmers who specialize in 200 yd or m races. The plan is presented not as an ideal model but to show how a plan like this could be superior to the traditional model shown in figure 17.2. This staircase procedure is considered superior because the workload increases systematically in concert with the swimmers' ability to perform the work. With careful planning, swimmers are often able to work at levels late in the season that they could not attain when using traditional planning. This, in turn, should make them capable of performing at a higher level at the culminating meet of the season. In the model presented in figure 17.3, the workloads for both volume and intensity surpass those shown in figure 17.2 at certain

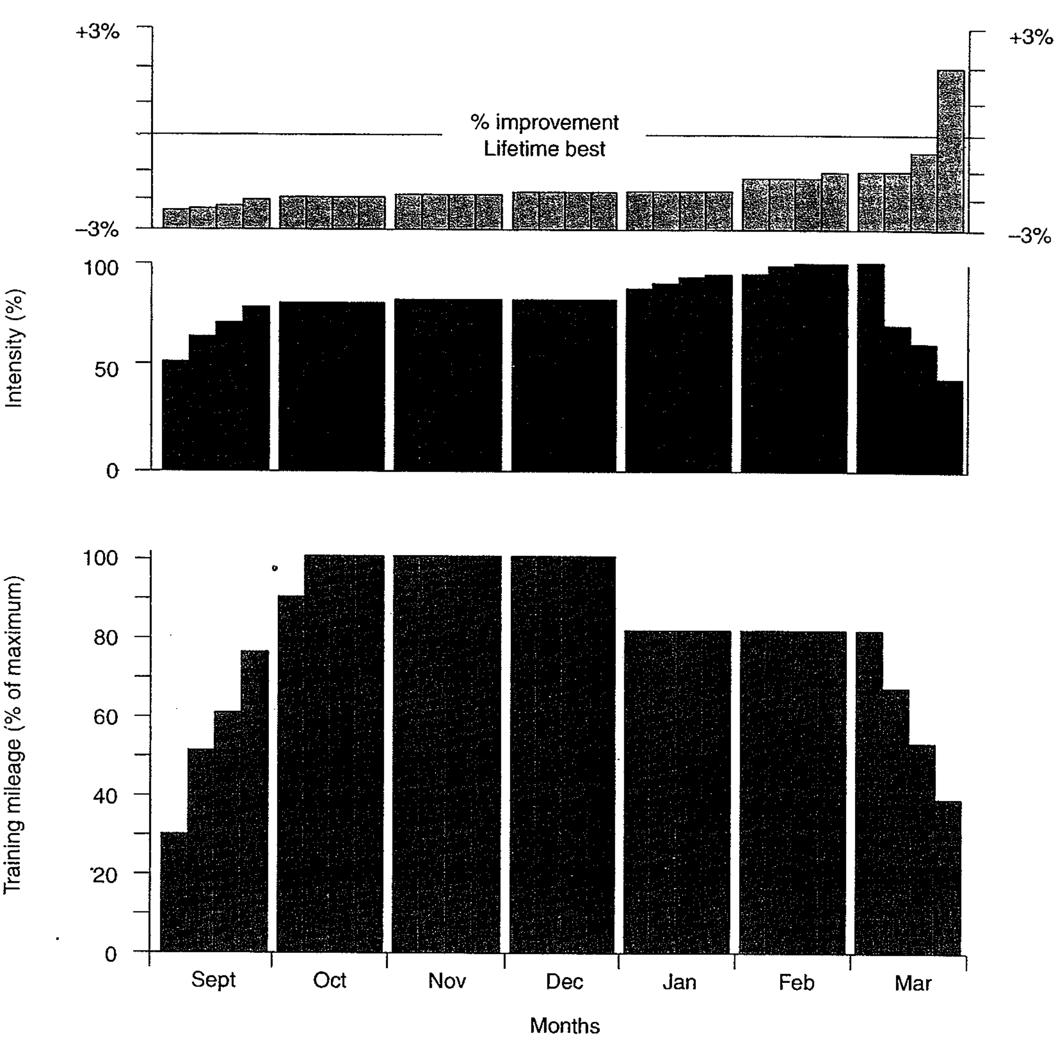


Figure 17.2 A typical season plan.

points of the season. Also, the amount of improvement at the end of the season is greater than that shown in figure 17.2. The athlete reaches a training volume of 110% in figure 17.3, which is 10% higher than the volume shown in figure 17.2. That increase in training volume is the result of a systematic buildup process that made it possible for the swimmer in figure 17.3 to perform and adapt to the additional work during the season.

A planned program of systematic progression is one of the best ways to ensure that swimmers reach their physiological peaks at the right time of the season. Systematic progression should also help them avoid plateaus and overtraining. Initial progress may be slower when seasons are constructed in this manner, but swimmers will ultimately reach higher levels of adaptation and, consequently, achieve better performances.

A plan like the one in figure 17.3 also allows coaches to compartmentalize the various types of training their athletes do into periods of emphasis and maintenance. When a season program like the one in figure 17.3 is planned correctly, all the levels of training described in the previous chapters can be incorporated in the proper proportions and administered at the appropriate times of the season. In addition, periodic changes in training emphasis make it less likely that the effect of one type of training will inhibit the effect of another.

The first step in the process of moving from theory to practice is determining the trainable components and their placement in the training year with regard to development and maintenance. Some of these components, such as aerobic capacity,

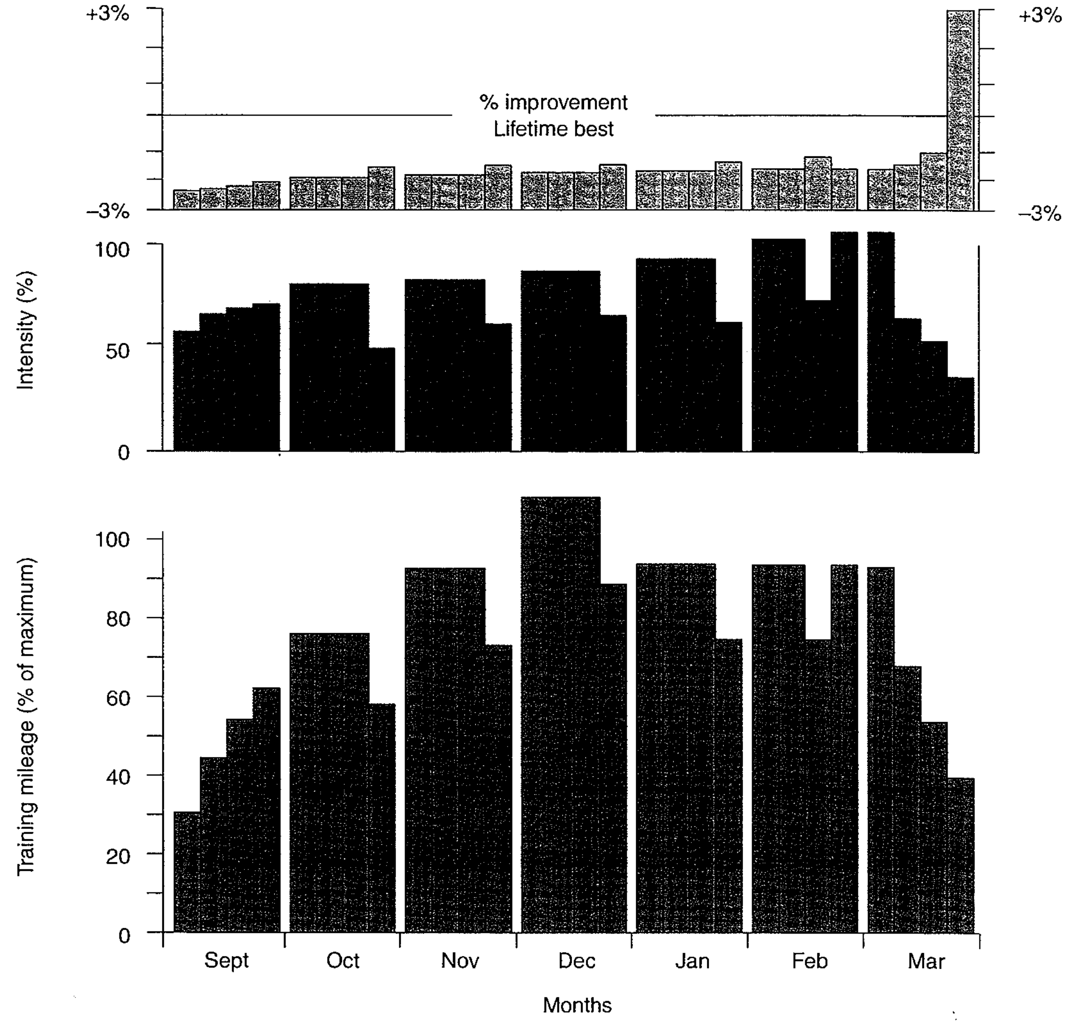


Figure 17.3 A more recent season plan in which various types of training are compartmentalized into development and maintenance phases. Improvement is systematically geared toward a peak performance at season's end.

will be primarily physical because they involve large amounts of training. Others, like stroke mechanics, will be both physical and instructional because a great deal of practice in the water is required to perfect them. Still other components, time management, for example, will be primarily instructional, requiring little or no water time. Coaches must encourage athletes to put the information from these lessons into everyday practice. I will now comment further on the selection of trainable components to be included in a season plan.

Trainable Components

First are the metabolic components of training, aerobic capacity, anaerobic power, and aerobic and anaerobic muscular endurance. These should be central to the structure of each macrocycle of every season throughout the year. Of equal importance is the improvement of stroke techniques. Strokes must be corrected and automatized early in each season so that athletes can use them in competition without much conscious thought. Athletes should also be drilled concerning the optimum combination of stroke rate and stroke length for each of their races. After athletes develop good stroke mechanics, they must, for want of a better term, become toughened so that they can remain reasonably effective in spite of fatigue and pain later in their races.

Strength, power, and flexibility training on land and power training in the water should also be part of the season plan. Starts and turns should receive attention because of their importance to performance. Athletes should learn about the pacing and strategy of racing. In addition, they should be instructed and drilled about preparing themselves emotionally and being mentally tough during races. Finally, they learn about proper nutrition and time management.

After the trainable components have been determined, the next step in planning a season is to separate it into parts with specific training and competition purposes. Following this, each season phase should be separated into even smaller units when the principle of progressive overload is applied from unit to unit. The process of structuring a season into smaller units with specific purposes and goals is called *cycle training*.

Trainable Components That Should Be Included in Every Season Plan

- Aerobic capacity
- Anaerobic power
- Aerobic and anaerobic endurance
- Stroke mechanics
- Optimum stroke rate and stroke length
- Strength and power training on land
- Flexibility training
- In-water power training
- Starts and turns
- Pacing and strategy
- Emotional preparation and mental toughness
- Nutrition
- Time management

Cycle Training

Training cycles fall into three recognized categories, popularly known as *macrocycles, mesocycles,* and *microcycles.*

Macrocycles, Mesocycles, and Microcycles

Macrocycle—a major season component lasting 4 to 12 weeks.

Mesocycles—shorter phases within a macrocycle in which stepwise increases in training volume, intensity, or focus take place. Mesocycles may last from 2 to 8 weeks.

Microcycle—weekly plans. Mesocycles are made up of microcycles.

Macrocycles

Macrocycles are major segments of a swimming season. Each of these segments is usually planned with the development of specific physiological aspects in mind, such as aerobic capacity, anaerobic power, or aerobic and anaerobic muscular endurance. They may also be planned to coincide with particular parts of the season, such as preseason, competitive season, and taper periods. They can also be planned around other competitive aspects, such as improving techniques, racing skills, strength, or flexibility.

Macrocycles can be anywhere from 4 to 12 weeks in length. Longer macrocycles usually occur early in the season when the emphasis is on development of aerobic capacity and basic skills. Macrocycles will usually be shorter during later parts of the season when training intensity is greater and when the nature of competitions is changing rapidly from minor to major contests.

The following is a typical pattern of macrocycle construction during a 26-week season. In this case, the season includes four parts—a general preparation period, a specific preparation period, a race preparation period, and a taper period—followed by a break.

Structure of a Typical Swimming Season

Macrocycle #1: General preparation period—4 to 12 weeks

Macrocycle #2: Specific preparation period—4 to 8 weeks

Macrocycle #3: Race preparation period—4 to 6 weeks

Macrocycle #4: Taper period—2 to 4 weeks

Macrocycle #5: Break—1 to 2 weeks

General Preparation Phase The principal purpose of the general preparation phase is to prepare athletes physically for intense training later in the season. Goals include improving overall endurance, speed, strength, and flexibility in a general manner. Ideally, this phase should last 8 to 12 weeks when athletes have not been in serious training for several weeks. The phase can be considerably shorter, however, for athletes who train year-round with short and infrequent breaks. Their aerobic capacity, strength, and speed should already be at a high level from the previous season.

Every athlete should focus on improving aerobic capacity. The primary emphasis of that training should be to produce central circulatory and respiratory adaptations that will improve the delivery of oxygen and nutrients to the muscles. Athletes can do this by performing lots of basic endurance training in a variety of strokes and by performing other endurance activities on land and in the water. The in-water basic endurance training will also improve the maximal oxygen consumption of their slow-twitch muscle fibers. This effect will be particularly valuable to sprinters because they will not be able to spend as much time on endurance training during later phases of the season. They do not want to risk losing muscle contraction speed and power in their fast-twitch muscle fibers by engaging in too much high-intensity endurance training.

Sprinters and stroke specialists should do a lot of endurance kicking during this phase. All swimmers should emphasize lactate production and power training during this time. In the case of distance swimmers, middle distance swimmers, and swimmers who specialize in 200 events, the purpose of lactate production training should be to prevent significant loss of speed while they are doing large volumes of endurance training. With sprinters, the purpose for lactate production and power training should be to improve swimming speed. Their volume of endurance training should never be so great that it dulls their speed during this phase of the season.

Training that improves aerobic and anaerobic endurance—overload endurance, race-pace, and lactate tolerance training—should be used sparingly during the general preparation phase. All these forms of training should be considered one category, and swimmers should do only one or two short sets of repeats from this category each week. That amount should be sufficient to prevent large declines of buffering capacity, lactate removal capability, and aerobic capacity in the fast-twitch muscle fibers while also preparing swimmers for intense endurance training later in the season. Descending sets are also useful for this purpose. Swimming a few repeats very fast near the end of basic endurance sets several times each week should help maintain buffering capacity, lactate removal capability, and aerobic capacity in the fast-twitch muscle fibers.

Goals and Procedures for the General Preparation Phase

Goals:

- Improve aerobic capacity, particularly circulatory and respiratory functions that will improve oxygen delivery to the muscles and both the oxygen consumption and lactate removal rates of slow-twitch muscle fibers.
- Improve the anaerobic power of sprinters and maintain it for other swimmers.
- Improve stroke mechanics, starts, and turns. Turn swimmers' technique weaknesses into strengths.
- Increase overall muscular strength.
- Increase specific joint flexibility.
- Maintain aerobic and anaerobic endurance.
- Correct nutritional deficiencies and errors in time management.

Suggested method for progressive overload: Increase volume.

Evaluate for changes of

- $\dot{V}O_2$max (if available),
- aerobic and anaerobic thresholds,
- peak blood lactate,
- speed,
- general muscular strength, and
- range of motion in specific joints.

Athletes should devote a great deal of time to improving stroke mechanics, starts, and turns during this phase. Swimmers in all strokes and events will be training intensely later in the season, so they will have difficulty changing their strokes at that time. They should make needed corrections during the general preparation phase and then try to use their improved techniques during racelike training efforts and competitions throughout the remainder of the season. They must work to automatize those techniques so that they can use them effectively in the major competitions at the end of the season.

The general preparation phase is the best time to turn swimmers' stroke weaknesses into strengths by emphasizing work on those weaknesses. For example, butterflyers with weak dolphin kicks should spend decidedly more time kicking than other butterfly swimmers. Backstrokers who are not able to kick fast underwater for 15 m of each pool length should do special drills to improve their ability to do so. An individual medley swimmer with a weak breaststroke should train with the breaststrokers often, particularly when they do stroke drills and endurance breaststroke swims. At the same time, that swimmer should spend more time doing race-pace breaststroke swimming than other individual medley swimmers during this period.

Swimmers should try to achieve specific performance goals in their weak stroke or strokes by the end of this phase. For a butterfly swimmer with a weak kick, it may be to kick 10 × 100 m dolphin kick on a 2 min send-off under 1:40. The goal for a backstroke swimmer with a weak underwater dolphin kick might be to kick 6 × 50 m backstroke underwater on a 2 min send-off with all times under 34:00. The goal for the individual medley swimmer in the previous example could be to swim 10 × 100 m breaststroke on a 2 min send-off with all times under his or her best breaststroke split in a 400 IM race. If that athlete competes in the 200 individual medley, the goal could be to swim 10 × 50 on a 1 min send-off with all times under his or her best breaststroke split in a 200 IM race.

Land training should focus on improving overall muscular strength. A basic weight-training program with a moderate number of sets and repetitions is ideal for this purpose. The program should include all major muscle groups. Distance swimmers may choose to forego weight training in favor of more swim training during the general preparation phase.

All swimmers should improve specific joint flexibility during this phase, but they need not risk injury by improving flexibility in joints where it is already adequate. Swimmers should perform specialized flexibility exercises only for those joints in which a limited range of motion interferes with efficient swimming.

This phase is also a good time to present lectures, perhaps by outside experts, on the importance of nutrition and time management. By learning about these aspects of training early in the season, athletes will have time to change their eating habits and prioritize their outside activities before training becomes more intense and time consuming later on.

Long mesocycles with a staircase configuration are usually the best choice for this phase of the season because athletes will be improving rapidly and striving to build a strong, stable, aerobic base. The best system of progressive overload is to increase the volume of training with sessions that gradually become longer and more frequent.

Specific Preparation Phase The general preparation period should be followed by a specific preparation phase. During this time, athletes should focus on improving their basic endurance, aerobic and anaerobic muscular endurance, muscular power, and speed. The optimum length for this phase is between 6 and 8 weeks. Longer periods can lead to overtraining because of the intensity of the training conducted during this phase. Because of its importance, the specific preparation phase should never be shortened to less than 4 weeks even when a season is very short.

The goals for this phase will depend largely on the events a particular swimmer is training for and the swimmer's physiological strengths and weaknesses. All swimmers should spend a greater amount of time training in their main stroke or strokes during this phase to improve the metabolic functions of the muscle fibers they will use in competition.

Distance and middle distance swimmers should increase the amount of threshold and overload endurance training they perform during this phase of the season so that

Goals and Procedures for the Specific Preparation Phase

Goals:

- Middle distance and distance swimmers should focus on improving the rates of oxygen consumption and lactate removal in their fast-twitch muscle fibers.
- All swimmers, particularly sprinters, should continue to improve the rates of oxygen consumption and lactate removal of their slow-twitch muscle fibers.
- Sprinters should continue to improve their speed. Middle distance and distance swimmers should continue their attempts to maintain speed.
- Swimmers should try to increase stroke length at race speeds without sacrificing stroke rate.
- Land training should be designed to increase the strength and flexibility of specific swimming muscles and joints.

Suggested methods for progressive overload:

- Increase volume
- Increase intensity (repeat speed)

Evaluate for changes of

- $\dot{V}O_2$max (if available),
- aerobic and anaerobic thresholds,
- peak blood lactate,
- sprint speed,
- improvements in stroke length at race speed,
- in-water swimming power,
- strength in specific muscle groups involved in swimming, and
- range of motion in specific joints.

they can increase oxygen consumption and lactate removal in their fast-twitch muscle fibers. Sprinters who specialize in 200 events should do the same.

Normal and fleet sprinters should continue to emphasize basic endurance training. They should descend many of their basic endurance sets to fast times, and they should schedule more short, fast endurance sets. Those procedures should help them improve the oxygen consumption and lactate removal rates of their fast-twitch muscle fibers without inhibiting the anaerobic power of those fibers. Sprinters should not do long, straight endurance sets at threshold paces or faster.

Sprinters who specialize in 50 and 100 races should also include slightly more lactate tolerance training in the weekly schedule, perhaps one additional set per week. This training will help prevent a loss of buffering capacity and prepare those swimmers for additional amounts of this training later in the season. Distance and middle distance swimmers do not need to schedule any lactate tolerance sets. Overload endurance training will accomplish the same purpose for them in a manner more specific to their events.

Sprinters should continue emphasizing lactate production to improve their sprint speed. They should also include some in-water power training in their weekly schedules. Distance and middle distance swimmers should also perform some lactate production training to prevent significant losses of anaerobic power while they are engaging in more fast endurance training.

With the exception of fleet sprinters, all swimmers should perform increasing volumes of basic endurance training. The goal should be to continue improving aerobic capacity by any means available. Sprinters and stroke specialists should continue to emphasize endurance kicking.

The need for recovery training will increase during the specific preparation phase because of the larger volume of high-intensity training that all swimmers will be doing. Consequently, the weekly schedule should include a few complete training sessions designed to enhance recovery, besides the recovery swimming that swimmers perform after each intense set and at the end of each training session.

The focus of technique training should shift toward improving the optimum balance between stroke rate and stroke length during this phase. Athletes should spend a considerable amount of time trying to improve their stroke length without significantly reducing their stroke rates.

The emphasis with land resistance training should shift from increasing general strength to increasing specific strength. Athletes should do heavy resistance training with more sets and fewer repetitions than they did during the previous phase. Land resistance training should become more specific by including more exercises designed to improve the strength of the swimming muscles. Exercises can even simulate swimming movements, although it is not necessary to train in that way.

Distance and middle distance swimmers may choose to forego land resistance training in favor of spending more time in the water. Even so, they should train at a maintenance level in the weight room. Distance and middle distance swimmers who feel a need for land resistance training can shift to a program that emphasizes muscular endurance. Swim benches, surgical tubing, and Vasa trainers are ideal for this purpose. As in the previous phase, swimmers should do specific flexibility training.

Shorter mesocycles are the best choice for this phase of the season because they provide more periods of both progression and recovery.

All swimmers can continue to use volume increases as their system of progressive overload. Distance, middle distance, and 200 swimmers may prefer to increase intensity or density, or they may choose to overload with all three methods. Sprinters should use volume and density increases as their system of progressive overload for endurance swimming. For lactate production and power training, increasing intensity is the system best suited for progressive overload for all swimmers.

Race Preparation Phase The principal goal of the race preparation phase is to improve aerobic and anaerobic muscular endurance so that athletes will be prepared to race in peak form when this phase ends. The optimum length for this period is between 4 and 8 weeks. Because training intensity is at its highest point of the season, continuing for longer than 8 weeks could lead to overtraining. Less than 4 weeks of training in this phase, however, will probably result in inadequate improvement.

During this phase, swimmers should zero in on the races they want to swim at the end of the season. They should swim the main sets of each training week at or near race pace and, of course, in their main stroke or stokes. The race-pace sets should be endurance oriented for all swimmers, especially distance and middle distance swimmers. Specifically, the race-pace sets for middle distance and distance swimmers should be longer than those that sprinters perform. Nevertheless, the goal for all swimmers is to increase their workload at race pace or to increase their average speed for those repeats from present to desired race pace.

All swimmers should discontinue overload endurance and lactate tolerance training because race-pace training will accomplish the same purposes. All swimmers should also reduce the

Goals and Procedures for the Race Preparation Phase

Goals:

- Improve aerobic and anaerobic endurance
- Increase swimmers' ability to swim longer at race pace or to move from present to desired race pace
- Increase speed of sprinters and optimize anaerobic power of middle distance and distance swimmers
- Increase ability to maintain good stroke mechanics when fatigued at the end of races
- Increase specific muscular power
- Increase in-water power of sprinters
- Increase specific joint flexibility
- Maintain aerobic capacity of all swimmers
- Refine pacing and racing skills

Suggested methods for progressive overload:

- Increase intensity (increase repeat speed)
- Increase density (reduce rest intervals)

Evaluate for changes of

- $\dot{V}O_2$max (if available),
- aerobic and anaerobic thresholds,
- peak blood lactate,
- positive changes in the relationship between stroke rate and stroke length at race speeds,
- speed,
- power on land,
- in-water power, and
- range of motion in specific joints.

volume of basic endurance training. During this phase of the season, the goal with basic endurance training should be to maintain aerobic capacity. The volume of threshold training should be reduced for distance and middle distance swimmers for the same reason. Sprinters should perform more of their basic endurance sets at moderate speed and descend to fast speed less often during the week. The race-pace training they perform should be adequate for maintaining the rate of oxygen consumption and lactate removal in their fast-twitch muscle fibers.

All swimmers should continue with lactate production training, although that training should be shorter and less frequent. Sprinters should continue their in-water power training, though with less frequency. The anaerobic nature of race-pace training will help all swimmers, particularly sprinters, maintain a high rate of anaerobic metabolism.

The volume and frequency of recovery training should increase for all swimmers during this phase. They will be swimming more intensely, more often. Consequently, they will need more recovery swimming to assist in tissue repair.

The emphasis for technique training should shift toward maintaining optimum combinations of stroke rate and stroke length when fatigued. Swimmers should be conscious of their stroke rate and stroke length during race-pace swimming, and they should try to maintain them at nearly the same level throughout the sets.

Land resistance training should focus on improving muscular power. Olympic lifts can be used for this purpose. Swim benches, surgical tubing, and Vasa trainers can also be used because actual stroking movements and rates can be partially simulated against time with these devices. Plyometrics and medicine ball training will also improve swimming power. If they have been lifting weights, distance and middle distance swimmers should discontinue heavy resistance training during this phase in favor of maintenance weight training and muscular endurance training with stroke-simulated devices. As in the previous phases, swimmers should strive to improve specific flexibility.

Instruction and practice on pacing races and race strategy should be emphasized during this period. Race-pace repeats are an ideal vehicle for teaching pace and strategy, as are competitions. Because the frequency of both generally increases during this phase, the race preparation phase is an ideal time to focus on these training components. This phase is also an ideal time to revisit and reinforce previous instruction and practice in the areas of emotional preparation and mental toughness.

Again, short mesocycles are the best choice for this phase because they provide more periods of both progression and recovery. To achieve progressive overload during this phase of the season, swimmers should either increase intensity (increase swimming speed) or increase density (reduce send-off time).

Taper Phase A taper period of 2 to 4 weeks should occur just before the most important meet or meets of the season, followed by a short break of 1 to 2 weeks. Training of all types should decrease to maintenance level during the taper period. During the break period, athletes should try to maintain a reasonable level of fitness. Because of its importance and complexity, the taper phase will be the topic of the next chapter.

Overlapping Season Phases Training of all types should be included in every phase. Only the degree of emphasis on each should change. Additionally, a transition between phases should be created by gradually increasing the type of training that will be emphasized in the next phase during the last 2 weeks of the current phase. This process prepares swimmers for the next phase. By beginning to adapt to the new training emphasis during the last weeks of the current season phase, they should be able to handle a greater volume or intensity of that training in the next phase.

Another Type of Season Plan Another type of season plan used successfully by many swimmers is shown in figure 17.4. In this plan, the entire training year has been divided into several macrocycles, each of which resembles a miniseason. That is, each macrocycle includes some combination of the phases just described. The example in figure 17.4 was the yearly plan used by the great Russian swimmer Vladimir Salnikov

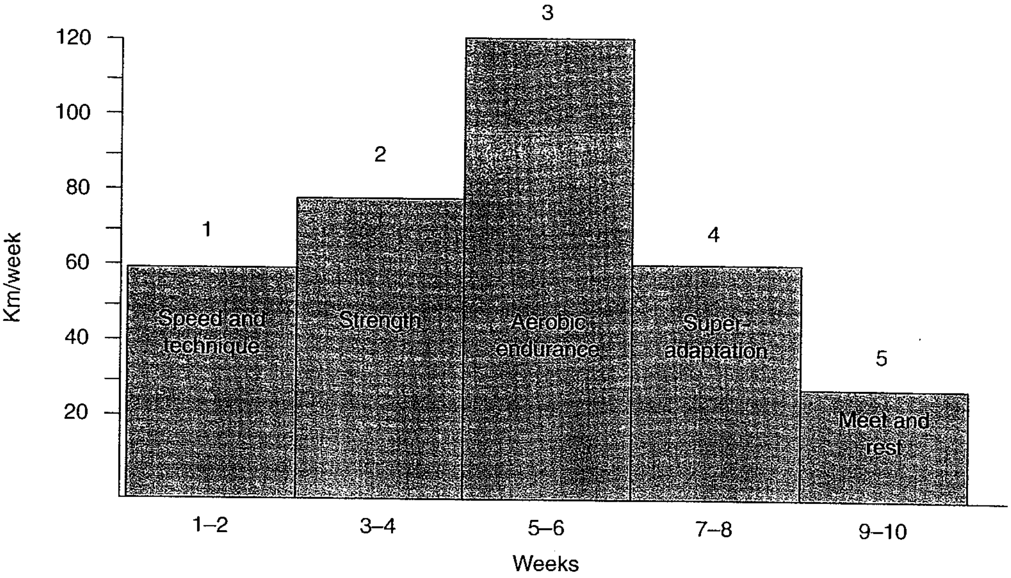


Figure 17.4 An alternate season plan in which each macrocycle includes biweekly periods of changing emphasis.

Adapted from Koshkin 1984.

during the training year in which he became the first man to break 15 min for the 1,500 m freestyle.

Salnikov's training year was divided into five 10-week macrocycles. Each new macrocycle began immediately after the preceding one ended. He took a break of 2 weeks at the end of each year.

Each macrocycle included five 2-week periods (mesocycles) of changing training emphasis. Speed and technique training, including evaluation of stroke mechanics and implementation of corrections, were emphasized during the first 2-week period. Weekly training mileage was approximately half of what it would be later during the peak training phase of each macrocycle. The intensity of training was low in the first period, with most of the swimming performed at what I would consider a basic endurance level. Swim training was not stroke specific, and all strokes were included in the training sessions. Dry land training was stressed during this period. Salnikov spent 2 hr per day, 4 days per week, doing exercises that included weight training, swim bench pulling, and flexibility training. This period was similar in purpose to the general preparation period described earlier.

Development of strength and power was emphasized during the second 2-week period of each macrocycle. This phase was termed the strength period, but the major focus was on improving specific muscular endurance. The phase was similar to the specific preparation period I described earlier except that the swimming was less intense. Salnikov performed a rigorous program of circuit training that included weights and swim bench pulling. The time devoted to dry land training was increased to approximately 2 hr per day for 6 days each week. Tethered swimming against surgical tubing was used to develop strength and power. Flexibility training also continued. Swim training mileage escalated to approximately 70% of the maximum weekly value that would be reached later in the most intense phase of each macrocycle. Intensity was not a major concern, and Salnikov performed most of the mileage at a basic endurance level, much of it with hand paddles and tubes. The mileage devoted to kicking increased during this mesocycle.

The third 2-week period was the most intense phase of each macrocycle. The goal was to produce a large increase in aerobic capacity. In this way, training during this period was similar to the specific preparation period I described earlier. Training mileage reached a peak of 88 to 120 km per week. The intensity of swimming also increased with training that included all levels of endurance training from basic to overload. Most of that training, however, occurred at an intensity slower than threshold speed. Dry land training decreased to the level performed in the first period.

The purpose of the fourth 2-week period was supercompensation. The mileage and intensity of training decreased to allow Salnikov to recover somewhat without losing conditioning. Weekly mileage dropped back to the level of the first period, but intensity stayed at a somewhat higher level. All levels of training were included in the weekly plan, although the repeat sets were considerably shorter than they had been during the previous phase. Dry land training decreased to approximately 1 hr per day. This period was most similar to the competition phase I described earlier.

The purpose of the fifth 2-week period was rest and recuperation. An important meet was usually scheduled near the end of this phase. This phase was similar in purpose to the taper period I described. Training mileage reached its lowest level, with most of the swimming done at slow speeds. Dry land training ended, although stretching remained part of the daily training. These 2 weeks also served as a rest period preceding the start of the next macrocycle.

Which Plan Is Best? The effectiveness of a yearly plan is probably determined more by the way it fits the schedule of a particular swimmer, team, or country than by anything inherent in its structure. An advantage of the traditional season plan (see figure 17.3) is that it allows the duration of each macrocycle to be in the optimum range for improvement of a particular metabolic system. The major disadvantage of this plan is that spending several weeks focusing on one type of training, either aerobic or anaerobic, can lead to inhibition of the other. If that inhibition becomes too great, the swimmer may not be able to return aerobic capacity or anaerobic power to an optimum level before major competitions.

The mixed macrocycle plan, Salnikov's plan in figure 17.4, also has distinct advantages and disadvantages. A major advantage is that it allows greater variety in training and more periods for rest and supercompensation throughout the training year. The constantly changing emphasis of training should permit greater adaptation with less danger of overtraining and less chance of inhibiting aerobic capacity or anaerobic power to the point where it cannot be optimized by season end.

On the negative side, the mixed macrocycle plan includes no period of sustained emphasis on certain aspects of metabolism. This circumstance allows for the possibility that less than optimum improvement may take place. This plan also requires that swimmers train conscientiously throughout the entire year. The total volume of aerobic training may not be sufficient to reach a peak performance if they decide to skip one or two macrocycles or if they train erratically during one or two of them.

I feel that the plan involving mixed macrocycles, like the one in figure 17.4, is well suited to the training of sprinters. They enjoy variety and are more prone to overtraining than distance-oriented athletes are. They may be less likely to lose their anaerobic power and speed by using such a plan. At the same time, they may be more motivated to train conscientiously and with a greater volume or intensity during each 2-week period precisely because it is short. The plan in figure 17.3 seems to be better suited for training middle distance and distance swimmers because it allows more time to improve aerobic endurance during the general and specific preparation periods and more time to improve aerobic and anaerobic muscular endurance during the specific preparation and race-pace phases.

Notwithstanding what I just stated, with careful planning either system could be used effectively in training for any kind of event. Careful planning means that all types of training will be included during each week of the training year, some at development levels and others at maintenance levels. If a mixed macrocycle plan does this, there will be little chance of reducing the development of a particular physiological mechanism if sufficient time is provided for that type of training throughout the macrocycle. Similarly, there will be small chance of inhibiting either speed or endurance with a traditional plan if sufficient time is provided for maintenance training of one type when another type of training is being emphasized.

Mesocycles

Macrocycles should be made up of mesocycles, shorter phases devoted to the progressive improvement of the major training components of a particular macrocycle. Mesocycles provide the primary building blocks for progressive overload. An increase in training intensity, volume, or focus should occur with each new mesocycle. Mesocycles can be from 2 to 8 weeks in length. Training for a longer period without a significant change in emphasis may cause saturation. The potential for improvement may decrease when training continues too long at the same level. At the same time, the possibility of boredom and overtraining may increase when swimmers continue a particular mesocycle too long without a change.

Mesocycles should be constructed carefully to coincide not only with the goals of the season but also with family, educational, and social commitments the athletes may have. The goals of each mesocycle with regard to type of training, volume, and intensity should be determined by the purposes of the macrocycle. The length of the mesocycle will be determined in part, by the same factors. The placement of competitions and the timing of possible distracting activities such as examinations, vacations, and other events must also be considered when planning the length of each mesocycle. For that reason, macrocycles may contain mesocycles with different lengths, even if they are not the optimum length for physiological development. The system of progression that will be used and the extent of that progression from mesocycle to mesocycle should also be determined. Finally, the tests that will be used to evaluate the effectiveness of each mesocycle and macrocycle should also be resolved.

The advantage of cycling training with mesocycles is that athletes can improve in manageable steps during the season rather than all at once during the taper at the end of the season. The short recovery period at the end of each mesocycle provides a time when the process of physiological adaptation can catch up so that athletes approach the next mesocycle with a greater ability to do work. The theory is that adapting periodically throughout the season results in overall greater improvement by the time of the major competitions with less chance of overtraining. Periods of recovery scheduled periodically throughout the season allow adaptations to take place, permitting athletes to train with greater volume and intensity, particularly during the second half of the season. That increase in workload should in turn allow them to attain higher levels of conditioning and consequently better performances by the end of the season.

Mesocycles generally include a *working* phase and a *recovery* phase. The stepwise increase in training intensity, volume, or focus takes place in the working phase, which may last from 1 1/2 to 6 weeks. The working phase of mesocycles can be constructed in one of two ways, in a *staircase* pattern or a *constant* pattern, as illustrated in figure 17.5. The recovery phase is included at the end of each mesocycle pattern.

With the staircase pattern, the working phase, in this case 3 weeks in length, is characterized by small but steady increases in the workload from week to week. Figure 17.5 shows that in a constant mesocycle, the workload remains the same from week to week during the working phase. The workload does not increase until after the recovery phase ends and the next mesocycle begins.

Staircase mesocycles are best suited for early periods in each new season when athletes are improving rapidly. Their capacity for work will be increasing quickly during this time, so a staircase pattern of progression will be needed to maintain an overload. Constant mesocycles work best during the middle and particularly the latter portions of a season when the rate of improvement is not as rapid. They provide more time for development and stabilization of the desired training effects, and they reduce the chance that athletes will become overtrained by trying to progress too quickly.

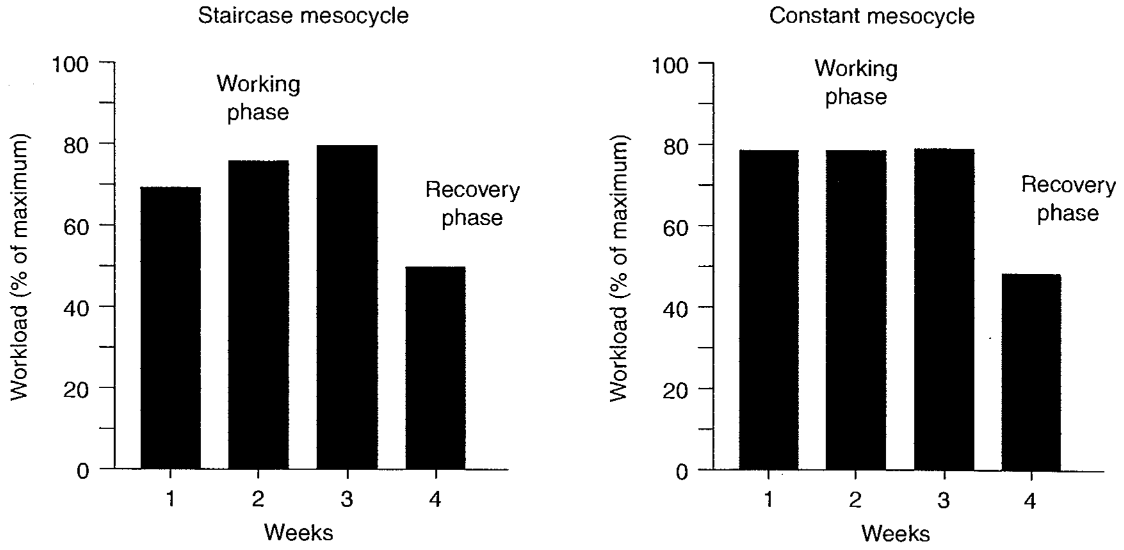


Figure 17.5 Staircase and constant mesocycle configurations.

During the recovery phase of a mesocycle, which may be 1/2 to 2 weeks long, swimmers have time to recover somewhat from the previous working phase. But the recovery period should not be a time of complete rest. The intensity and volume of training should be designed to maintain the level of performance reached during the present mesocycle, without causing further fatigue. The recovery period is a good time to conduct evaluations, hold special events, and offer presentations on other aspects of training such as nutrition, racing, and motivation.

Most experts believe that the major adaptations to training that occur within a particular mesocycle take place during the recovery phase. This belief is based on a widely accepted theory of supercompensation proposed by Yakolev (1967), depicted in figure 17.6. A mesocycle with a 3-week working phase and 1 week for recovery has been used to illustrate Yakolev's supercompensation theory. The training volume and intensity are indicated by the bar graphs in the lower portion of figure 17.6. The cycle of fatigue and supercompensation is indicated by the solid line at the top of the figure.

According to this theory, the cumulative effects of training cause progressive fatigue and loss of performance during the working phase, indicated by the drop of the line representing the athlete's level of training. Recovery will be incomplete because of the large volume and intensity of daily training; therefore, the athlete's performance may decline during this time. This accumulation of fatigue is believed to provide the stimulus for needed physiological adaptations of both aerobic and anaerobic nature because energy sources are depleted and tissues are damaged during this phase. Those adaptations are not fully realized until a reduction in training volume and intensity during the recovery period allows the replacement and repair processes to catch up. According to the principle of training specificity, most of those adaptations should occur in the phase of the metabolic process targeted by the earlier training.

Construction of mesocycles can occur in thousands of ways. They may vary from having a working period of 1 to 1 1/2 weeks with a recovery period of 1/2 week all the way up to having a working period of 5 weeks combined with a recovery period of 2 weeks. Several studies have suggested that 2 to 7 weeks is the optimum length of time for a mesocycle.

Mesocycles that encourage adaptation can be constructed in a great number of ways. They generally fall into three categories, however, which I have named *long mesocycles, short mesocycles*, and *mixed mesocycles*..

Long Mesocycles Mesocycles of this type are 4 to 7 weeks in length. The volume, intensity, and frequency of training that have been determined to provide an overload should remain constant during the working phase of a long mesocycle. A recovery phase of 1 to 2 weeks should follow the working period. The fast adaptations and many of the stabilizing adaptations will take place during the working period. A phase of supercompensation that allows these adaptations to occur follows during the recovery period. A similar mesocycle should be planned to take place immediately following the recovery phase of the previous mesocycle. A substantial increase in the workload should take place during that mesocycle, accomplished by increasing the volume, intensity, or frequency of training.

Evaluative tests conducted during the recovery period will be helpful in establishing an increase in workload for the next mesocycle that provides sufficient but not excessive overload.

Generally, the workload increase for the next mesocycle can be greater when the working phase of the previous mesocycle was longer (3 to 5 weeks). Increases of 3% to 6% are recommended with each mesocycle for athletes who train year-round. This increment provides for long-lasting improvement with small chance of overtraining. Increases of 3% to 6% may seem insignificant, but over a year they add up to substantial improvements in work performance. At the same time, the modest change at each stage reduces the risk of injury and failing adaptation. The workload increase should be even smaller when the working phase of the previous mesocycle is short (1 1/2 to 2 weeks) or when athletes are not training year-round. In these circumstances athletes have not had the opportunity to stabilize their adaptations. An example of progression during two successive mesocycles with 4 + 2 configurations is shown in figure 17.7. Notice that the workload increases during the second mesocycle.

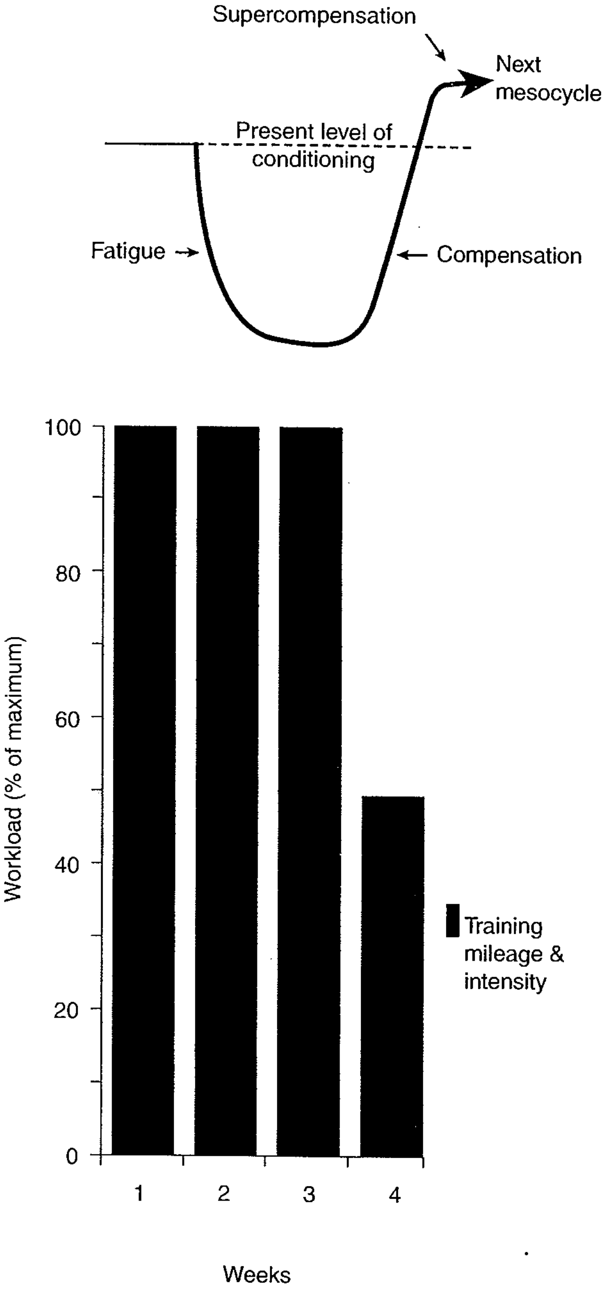


Figure 17.6 Yakolev's theory of supercompensation.

Adapted from Bompa 1999.

Short Mesocycles With this method the working period should be 1 1/2 to 3 weeks in length, followed by a recovery period of 3 to 7 days. As indicated previously, the increase in workload should be smaller from mesocycle to mesocycle when the working period is short. The total increase in workload for the season should be similar to that of longer mesocycles; the increases simply occur more frequently. Three consecutive short mesocycles with a 2 + 1 configuration are shown in figure 17.8. Notice that the increase in workload from one mesocycle to the next is smaller than it was in figure 17.7.

Mixed Mesocycles Mesocycle configurations that fall into the mixed category are similar to the plan for Salnikov shown in figure 17.4. A large macrocycle is structured from several small mesocycles. For middle distance and distance swimmers the macrocycles

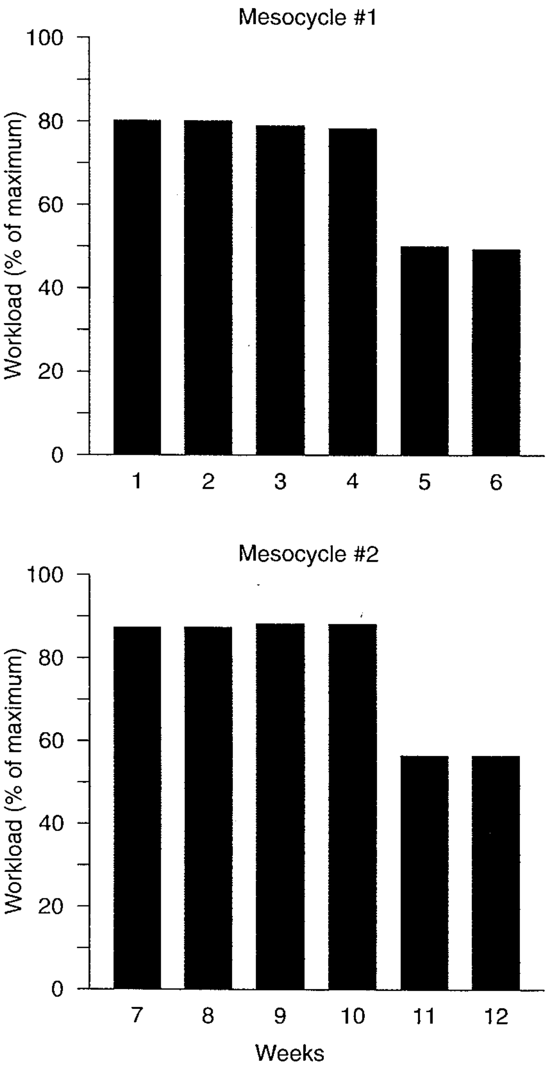


Figure 17.7 Two consecutive mesocycles with a 4 + 2 configuration.

start with a general endurance and speed phase and progress to a more intense and specific endurance phase. A race-pace phase should follow, which in turn should be followed by a recovery period.

The goal during the general endurance and speed phase is to improve aerobic capacity and maintain buffering capacity and swimming speed near normal levels. An emphasis on basic endurance, lactate production, and power training accomplishes this objective. The training should be general, including a mixture of the various competitive styles together with pulling and kicking drills. Most of the training should be completed at low intensity, or basic endurance speeds, during this phase. Therefore, swimmers can move on to the next mesocycle with no recovery period.

Additional threshold training and some overload endurance training should be provided during the specific endurance phase. Swimmers should complete much of their endurance mileage in their main stroke or strokes. A short recovery period of 3 to 7 days should occur at the end of the working phase of this mesocycle.

Overload endurance and race-pace training should be increased during the race-pace phase, with swimmers again completing much of the mileage in their main stroke or strokes. A recovery period of 2 weeks follows the race-pace mesocycle. This phase can double as a taper period if major competitions occur during it.

The plan for sprinters should also begin with a general endurance and speed phase. For them, however, the phase should include more emphasis on increasing speed. Most of the endurance training should be performed at basic endurance levels, with sets descended down to threshold and overload speeds on occasion. For sprinters the plan includes no specific

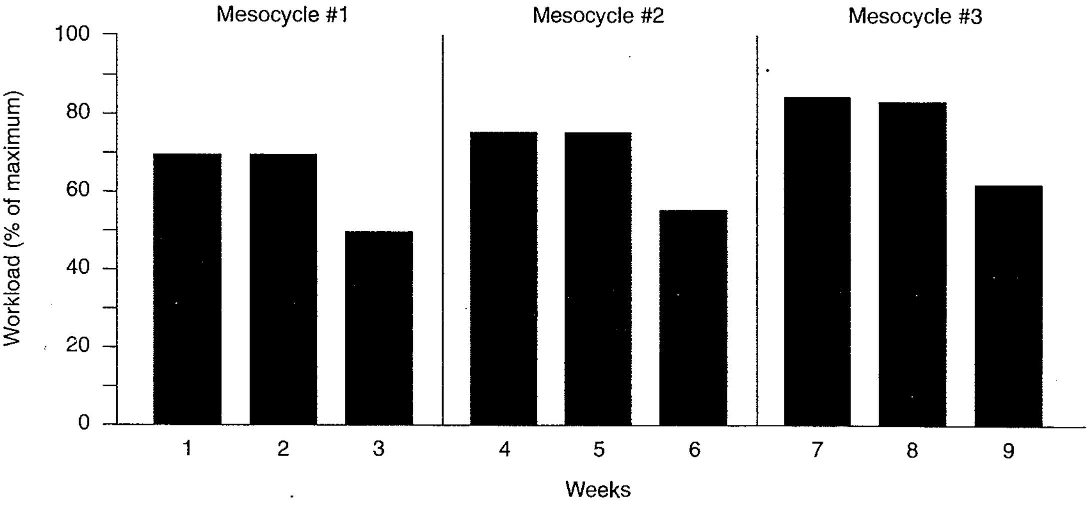
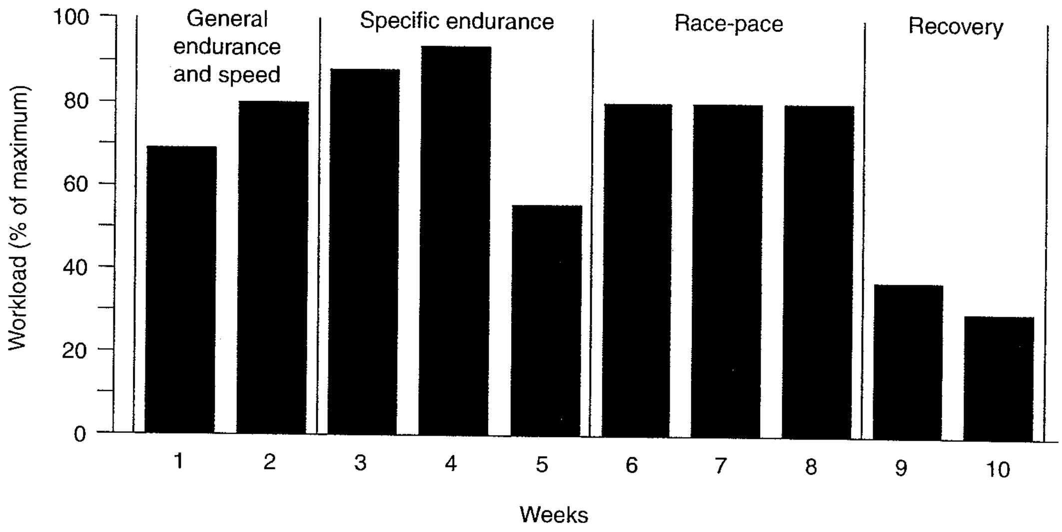


Figure 17.8 Three consecutive mesocycles with a 2 + 1 configuration.

endurance phase. The next mesocycle should be a race-pace phase that emphasizes improving aerobic and anaerobic muscular endurance with race-pace and lactate tolerance training. That training will also help improve speed. Sprinters should maintain their aerobic endurance with basic endurance training. The race-pace phase should be followed by a speed phase that emphasizes lactate production and power training and includes only enough endurance and race-pace training to maintain aerobic and buffering capacities. The final phase is for recovery. The bar graphs in figure 17.9 illustrate examples of mixed mesocycle configurations for distance swimmers and sprinters.

Which Kind of Mesocycle Is Best? The obvious advantage of longer mesocycles is that adaptations can be stabilized with less chance of overtraining. Workload increases are less frequent and therefore less likely to interfere with stabilizing adaptations. The major disadvantage is that the rate of improvement may be slower during each particular

Mixed mesocycles for a distance swimmer



Mixed mesocycle for sprinters

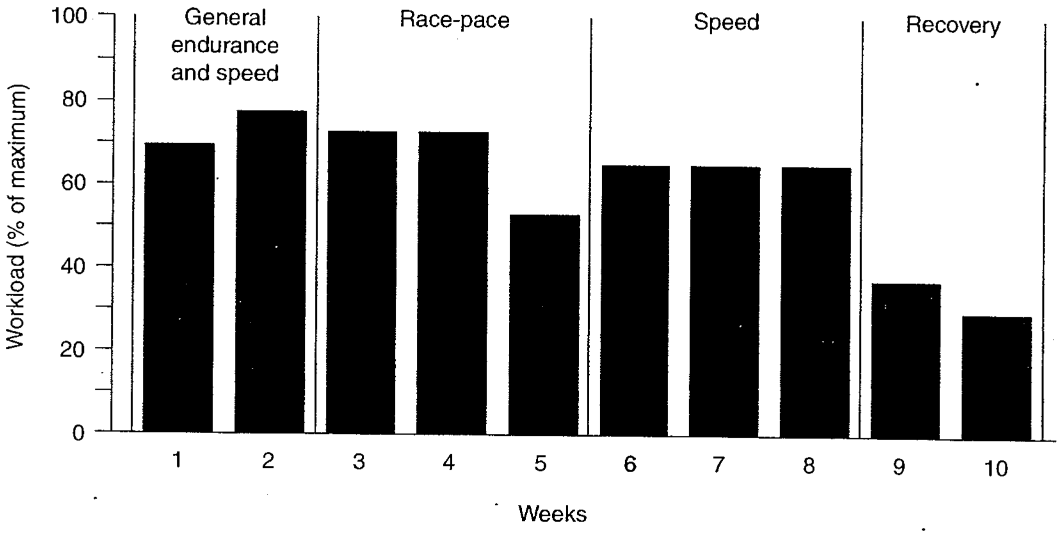


Figure 17.9 Mixed mesocycle configurations for distance and sprint swimmers.

season, although the overall improvement may ultimately be greater over the course of several training years.

Shorter mesocycles have two advantages. The first is that the rate of improvement may be greater within each season because the workload will increase more frequently. The second is that the chance of mistraining (losing either speed or endurance as a result of training that emphasizes the other quality) will be lower because the recovery periods will be more frequent. The primary disadvantage of short mesocycles is that frequent increases in the workload, if excessive, may cause failing adaptation.

The strong point for mixed mesocycles is that they reduce the chance of mistraining because they provide variety. The obvious disadvantage is that for distance swimmers the time devoted to improving aerobic capacity is short.

Based on these observations, long mesocycles are probably best suited for improving endurance because they provide greater opportunity for stabilization of various aerobic adaptations. At the same time, shorter mesocycles are probably best suited for improving speed and aerobic and anaerobic muscular endurance because they provide more frequent periods of recovery. Mixed mesocycles are also well suited for improving speed for the same reason. They are also popular with many swimmers because the frequent change in emphasis reduces boredom.

Other Considerations for Planning Mesocycles When planning a season, consideration of the physiological responses to various types of mesocycles is important. But even the most careful scientific planning will not be effective if swimmers are missing training. Therefore, coaches must consider other aspects of the swimmers' lives during the planning process. Family, social, and academic commitments must receive equal or even greater weight. A plan that schedules the working phase of a mesocycle for a time when absenteeism will be high because of vacations or exams is flawed. For this reason, mesocycles should be planned so that the working phase coincides with periods when the swimmers can be expected to attend practice regularly and when they are relatively free of distractions that could interfere with their training efforts. At the same time, recovery periods should be planned for times when absenteeism and distractions may be high. Unless coaches have complete control over the activities of their swimmers (and none of us do), considerations such as these are probably more important to the success of a training plan than those that are physiological in nature.

Another point to consider is the scheduling of competitions important enough to require a short rest, or minitaper. Mesocycles should be constructed so that recovery periods fall during the weeks when those competitions will be held. Planning in this way allows athletes the rest they need for those competitions without interfering with their working periods.

Sample Yearly Training Plans

The information on season planning that I have presented to this point has been highly theoretical. This section puts theory into practice and provides several examples of season plans. I have developed examples of two-season training plans for each of the following categories of competitors—middle distance and distance swimmers, 100 and 200 sprinters, and 50 and 100 sprinters. I also offer examples of three-season training plans for the three categories of competitors. Finally, I offer some examples of mixed macrocycle yearly plans for these three groups of competitors. I want to stress that these plans are only samples. They are not blueprints for yearly training. Although I have tried to make them representative of the quantity, intensity, and types of training that swimmers from each category should engage in throughout the year, readers will need to adjust general plans like these to fit individual training environments before they can use them effectively. I have included the reasoning I used in developing these plans so that coaches and athletes can adjust them to their particular training environments.

Steps in Framing Yearly Training Plans

Regardless of the type of yearly plan preferred, whether it be a two-season plan, a three-season plan, or a yearly plan with mixed macrocycles, taking a few general steps can help determine the length of each season and the placement of macrocycles and mesocycles within those seasons. The steps are listed in the order in which they should be considered:

1. Select the trainable components that should be included during the training year.

2. Determine the number of seasons preferred and the beginning and ending dates for each season. These primary considerations are the dates of major competitions and the ability of swimmers to tolerate large amounts of training without becoming overtrained. A season should extend from the end of the break following one major competition to the end of the next major competition.

   Obviously, scheduling fewer major competitions provides more time for training. This kind of schedule offers a decided advantage for swimmers who can handle a large amount of training. These swimmers tend to do best with two-season yearly plans. On the other hand, longer seasons increase the possibility that swimmers who do not tolerate training well will become overtrained. These swimmers often do best with three-season and mixed macrocycle yearly plans.

3. The next step is to determine the type, length, and placement of macrocycles within each season. This task is best done by counting backward. The length of the taper phase should be determined first. Its length will depend on the importance of the competition at the end of a particular season and the length of taper needed by the category of swimmers for which the plan is designed, that is, middle distance and distance swimmers, 100 and 200 sprinters, or 50 and 100 sprinters. The length of specific and race preparation macrocycles should be determined next. The length of each of these phases should be great enough to produce the desired training effects but not so great that they interfere with one another or reduce the general preparation phase to the point where it is largely ineffective. Suggested minimum and maximum lengths are 2 and 8 weeks for the race preparation phase and between 4 and 12 weeks for the specific preparation phase.

   The importance of the type of training stressed in each of these season phases must also be considered when selecting the length of that phase. A specific preparation phase of reasonable length is particularly important to the success of middle distance and distance swimmers. An adequate race preparation phase is equally important to 100 and 200 sprinters. The race preparation phase is important to the success of 50 and 100 sprinters, as is the general preparation phase. When necessary, the specific preparation phase can be shortened for sprint swimmers because improving the aerobic capacity of their fast-twitch muscle fibers is not nearly as important to their success as is improving their speed and increasing the rate of oxygen delivery to their muscles.

   The general preparation phase should make up the time that remains in each season. Except in extreme cases, this phase should not be less than 3 weeks in length. A period of 6 to 8 weeks is recommended for the best development of oxygen delivery. A general preparation phase of adequate length should be included in at least one of the seasons during each training year to develop a solid aerobic base of the circulatory and respiratory adaptations that are important to the delivery of oxygen and energy-containing chemicals to the muscles, as well as the protein substances needed for tissue repair to the muscles. This phase can be shorter during a later season or seasons once athletes have established that base.

4. The training goals for each macrocycle should be established next. All trainable components should be included during each macrocycle; only the degree of emphasis will differ. Therefore, coaches should decide which trainable components to emphasize within a particular training cycle and which to conduct at a maintenance level.

5. Once developed, each season phase, or macrocycle, should be subdivided into mesocycles that contain working and recovery periods. To allow for progression within each macrocycle, each macrocycle should include at least two mesocycles. As mentioned earlier, the length of macrocycles will depend on several factors, some of which may concern competition and many of which may not. The working phase of these mesocycles should be planned for periods when athletes are likely to be relatively free of outside influence so that they can attend training regularly and work conscientiously when they are there. The recovery periods should be scheduled during competitions when good performances are desired and during times when outside influences are likely to interfere with training.

6. The next step is to determine the training volume and training intensity goals for each mesocycle.

7. The next choices that need to be made concern the relative quantity of each type of training that will be conducted in each mesocycle. Those decisions will be determined by the goals for the macrocycle they make up.

8. Once the types and quantities of training have been chosen, a system or systems of progression for each mesocycle must be selected. Training should become progressively more difficult in some way from the beginning of the season to the taper period.

9. The final step in this process is to establish a system of evaluation for each mesocycle and for each macrocycle.

Two-Season Yearly Training Plans

Two-season yearly training plans for middle distance and distance swimmers, 100 and 200 sprinters, and 50 and 100 sprinters will be discussed in this section. Each of these plans includes short-course and long-course seasons. In these examples, the short-course season begins in mid-September and continues until late March, culminating with the major competition or competitions of the spring. In the United States the major competitions of the short-course season are usually the NCAA Championship, USA Swimming Championships, high school championships, or YMCA championships. In other countries, this final meet may be a national championship, a world regional championship, or a world championship. The major championship of the short-course season may be a conference, league, or regional meet for athletes who do not compete at national or international levels.

The long-course season extends from April to late August. For national and international level swimmers, the season usually ends with a major international championship involving a number of countries or a national championship. For other swimmers, the major competition of the long-course season may be another league or regional championship meet.

Two-Season Yearly Training Plan for Middle Distance and Distance Swimmers

An example of a yearly training plan for international level middle distance and distance swimmers is shown in figure 17.10. The short-course season was 26 weeks long and extended from September to April. A general preparation phase of 8 weeks from September to mid-November was selected to provide a good aerobic base. A staircase mesocycle plan was used for the first 4 weeks because athletes adjust to training rapidly during this time. A constant 3 + 1 mesocycle was used for the final 4 weeks of this phase. Volume increases were the preferred system of progressive overload for this phase. Weekly training mileage increased from 25% of the maximum for the year to approximately 80% of that maximum.

Training intensity was low at the start of the general preparation period and increased to moderate by the end of the phase. The increase in intensity was more or less unplanned. It happened simply because the swimmers' level of conditioning was improving rapidly. Weekly training volume was augmented during this period by in-

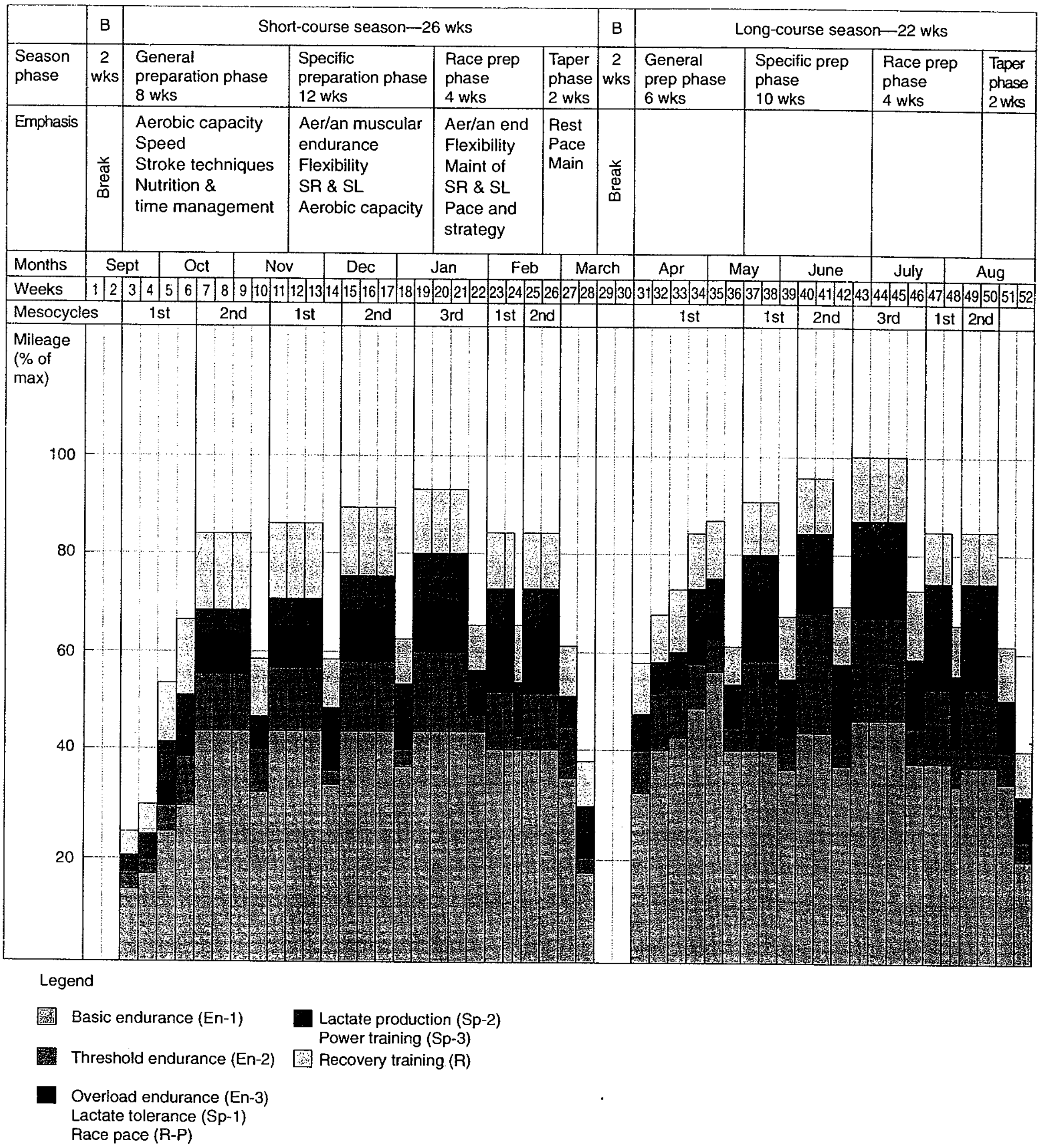


Figure 17.10 A two-season yearly training plan for middle distance and distance swimmers.

creasing the frequency of weekly training, from once per day to twice per day, and by increasing the mileage per training session.

Most of the mileage, between 60% and 70%, was swum at the basic endurance (En-1) level. Small amounts of threshold training (En-2) were included in the first 4 weeks. That amount was increased to approximately 10% of the total during the second 4 weeks of the general preparation phase. Some overload endurance training (En-3) was also included during the second mesocycle of the general preparation phase. Sprint training (lactate production and power training) was maintained at between 5% and 7% of the total throughout the general preparation phase; and recovery training was maintained at approximately 15% of the total throughout this period.

The aerobic and anaerobic thresholds of swimmers should have been evaluated approximately every 3 to 4 weeks, and their training speeds should have increased as their swimming velocity improved at those thresholds.

The specific preparation phase of the short-course season lasted for 12 weeks, from mid-November to February. Weekly mileage escalated with each new mesocycle until it was within 5% to 10% of the maximum planned for the year (assuming the most important meet of the year would occur during the summer season). A greater amount of the total swimming mileage was performed in the swimmer's main stroke or strokes during this period. Athletes swam most of the threshold (En-2), overload endurance (En-3), and sprint training in their main strokes so that all the muscle fibers they use in those strokes would receive adequate stimulation for both aerobic and anaerobic development.

Increases in both volume and intensity were the methods for progressive overload used during this phase. The specific preparation phase was constructed with three 3 + 1 constant mesocycles so that a large portion of the working phases of the latter two mesocycles would fall during vacation periods. The recovery weeks were planned to fall at Christmas time and at the beginning of the second term for most universities.

The percentages of each type of training during this period were based on an average weekly training mileage of 75 km. Basic endurance (En-1) training continued to be the staple, but the amount of threshold (En-2) and overload endurance (En-3) training increased considerably, making up approximately 30% of the total mileage. Sprint training (Sp-2 and Sp-3) continued at the volume of the previous phase. The volume of recovery training remained at approximately the same percentage of the total it occupied in the previous season phase. The actual volume of recovery training increased somewhat, however, because of the greater total volume of training being performed by the swimmers. Training volume should reach approximately 90% of the maximum weekly mileage for the training year during the second mesocycle of the short-course specific preparation period.

Evaluations of aerobic and anaerobic thresholds should have occurred at the end of each mesocycle of the specific preparation period, with training speeds increasing as the velocity at those thresholds increased. Some measure of aerobic and anaerobic endurance should have been used (that is, dV5-10 or a standardized repeat set) during the specific preparation phase. Training should continue at high intensity during this phase as long as the swimmers' aerobic and anaerobic endurance are improving, but they should be permitted some recovery if either of these should decline.

A race preparation phase of only 4 weeks was selected for the short-course season. Overload endurance (En-3) training and race-pace (R-P) training were nearly identical in the physiological adaptations they produced for middle distance and distance swimmers, so the primary purpose of the race preparation phase was simply to improve the swimmers' feel for race pace. Athletes should have improved their aerobic and anaerobic muscular endurance during the previous specific preparation phase and therefore should have been able to adapt quickly to race-pace training. The race preparation phase continued through February until the taper began for the major meet of the spring. Weekly mileage decreased between 10% and 15% to allow for greater training intensity during the race preparation period.

The race preparation phase consisted of two short, constant mesocycles. The first had a working phase of 1 1/2 weeks followed by a recovery phase of 1/2 week. One of the most important meets of the season was scheduled for the end of that week, so the recovery phase also provided a minitaper period. The second mesocycle had a working phase of 2 weeks, and the recovery week that followed served as the taper period phase.

Training intensity increased to its highest point of the season. The amounts of basic endurance (En-1) and threshold (En-2) training decreased to maintenance levels during this phase. Race-pace (R-P) training increased considerably, with the goal of swimming significant underdistance endurance sets at desired race-pace by the end of this phase. Overload endurance training (En-3) was not necessary because the adaptations produced by race-pace training were identical to those of the former type of training. Sprint training remained at the level of the previous phases, and the volume of recovery training increased somewhat because swimmers were training at high intensity more often. Increases in intensity or density are the best choices for progressive overload during this phase. The percentages for each type of training were based on an average weekly mileage of 60 km.

The anaerobic threshold and aerobic and anaerobic muscular endurance should have been evaluated during each mesocycle of the race preparation phase. The anaerobic threshold may decline somewhat, but this should not be a concern if aerobic and anaerobic muscular endurance is improving. The swimmers should have been provided with additional recovery time if their aerobic and anaerobic muscular endurance was not improving.

The 2-week taper that followed the race preparation phase was set aside to prepare for a major competition in late March, either the NCAA Championship, the national championship for a particular country, or a regional championship in some part of the world. Procedures for planning training during the taper phase will be covered in detail in chapter 18.

A break of 2 weeks followed the taper phase. A break period like this may be absent in the planning of many seasons because of the proliferation of major international meets in recent years. Athletes are often required to extend their tapers for 2 or more weeks to compete in those meets.

The 22-week long-course season began in April and ended with the most important competition of the training year. In this case, a period of 6 weeks, from April to mid-May, was selected for the general preparation phase. This phase was 2 weeks shorter than the corresponding phase in the previous season because the entire long-course season was shorter and because athletes should already have a strong aerobic base from the short-course season. The goals for this phase of the season were the same as those for the general preparation period of the short-course season.

The long-course general preparation phase was constructed as one staircase mesocycle with a 5-week working period and a recovery period of 1 week. The starting and ending weekly mileage were greater for this phase in the long-course season than they were in the short-course season because, as mentioned before, athletes should already have a strong aerobic base.

Weekly training mileage began at approximately 60% of the maximum for the training year and progressed beyond 80% of that maximum by the end of the phase. Volume increases were again used as the method for applying progressive overload. Swimmers were probably also overloading by increasing their swimming speed as they returned to good physical condition rapidly after their short break following the previous season.

The percentages of each type of training were the same as they had been for the general preparation phase of the short-course season. The weekly training mileage, however, was somewhat greater because the athletes were out of school and had more time to train and rest.

The specific preparation period was 10 weeks in length for the long-course season. Increases of volume and intensity were again the methods used for progressive overload. Due to its length, the long-course specific endurance phase was constructed of three mesocycles. The first two had 2 + 1 configurations, and the remaining mesocycle had a working phase of 3 weeks followed by recovery phases of 1 week (3 + 1).

Weekly training mileage increased gradually with each mesocycle of the long-course specific preparation phase until during the third mesocycle it was 100% of the maximum selected for the training year. The percentages of each type of training and the methods of evaluation were the same as those described for the short-course season.

The race-preparation phase was 4 weeks in length during the long-course season, just as it had been for the same phase during the short-course season. It contained two mesocycles. The first had a working phase of 1 1/2 weeks and a recovery period of 1/2 week, and the second had a working phase of 2 weeks with the taper serving as the recovery phase for this mesocycle. Weekly mileage decreased between 15% and 20% during the race preparation phase.

The types and percentages of training, the methods of progressive overload, and the weekly mileage were the same as those used in the short-course season. Swimming intensity, however, should be at its highest level for the training year during the long-course race preparation period. Athletes should be swimming their fastest repeats of the year at this time.

The taper period was 2 weeks in length, as it had been during the taper for the short-course season. The taper period culminated with the most important meet of the summer and of the entire training year. The taper was followed by a break period of 2 weeks before the start of the next school year and the next training year.

Two-Season Yearly Plan for 100 and 200 Sprinters

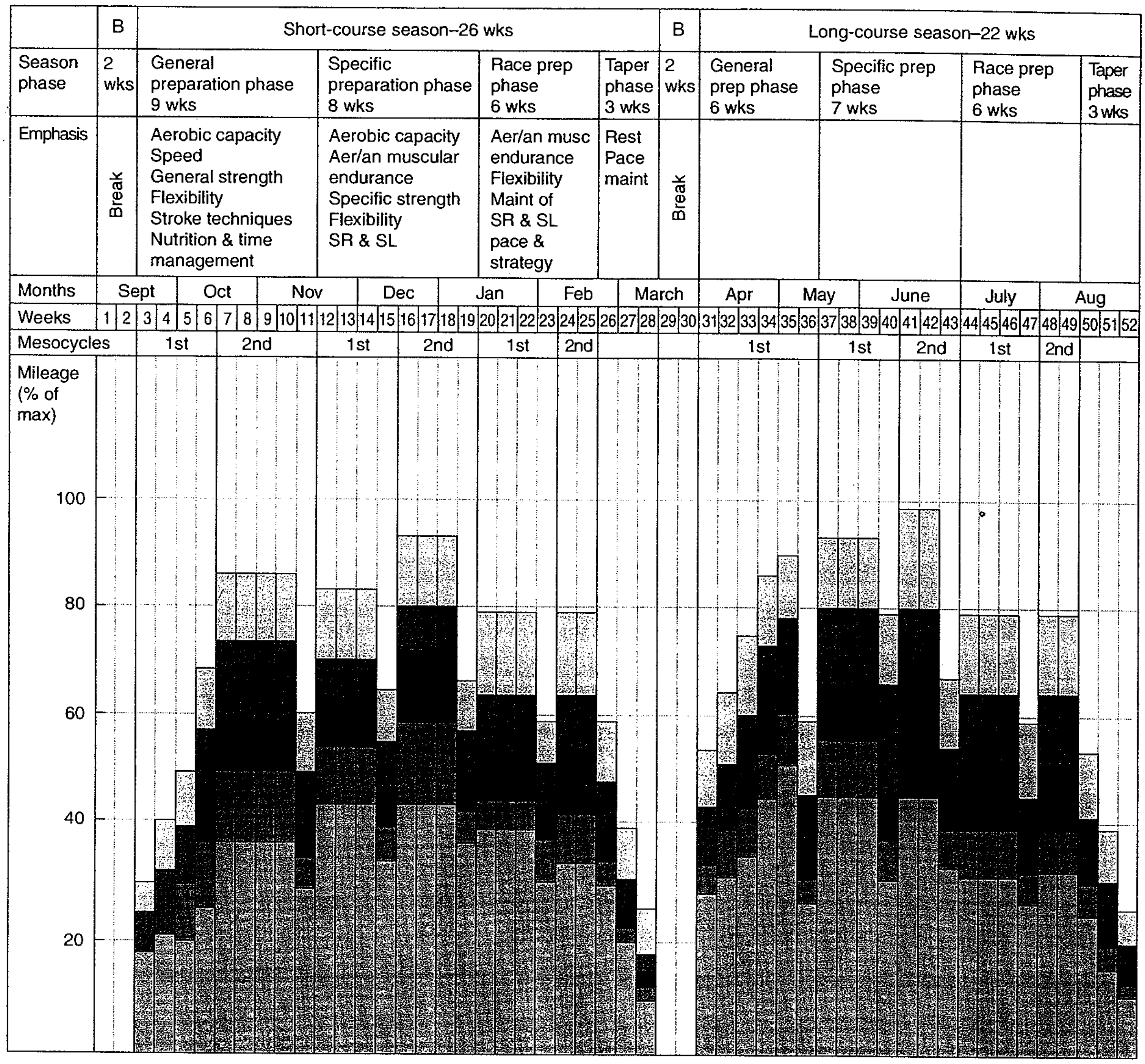
An example of a yearly training plan for 100 and 200 sprinters is illustrated in figure 17.11. This plan had several differences from the plan for middle distance and distance swimmers in figure 17.10, as well as some similarities to it. The first two differences concerned the length of the specific preparation and race preparation phases. The specific preparation phase was shorter, and the race preparation phase was longer. This scheduling provided the 100 and 200 sprinters with an opportunity to do more speed and buffer training. By shortening the specific preparation phase, sprinters were less likely to lose significant speed and power in their fast-twitch muscle fibers because the amount of threshold and overload endurance training they performed had not been increased dramatically.

A final difference in season planning for 100 and 200 swimmers was in the amount of lactate tolerance (Sp-1), lactate production (Sp-2), and power training (Sp-3) these swimmers performed. Sprinters swam more repeats of these types because speed and buffering capacity were much more important to success in their races.

As evident in figure 17.11, the general preparation period was 9 weeks in length during the short-course season. This was done to provide the swimmers with ample opportunity to improve the circulatory and respiratory mechanisms responsible for delivering oxygen to the muscles and to improve oxygen utilization by the swimmers' slow-twitch muscle fibers. Weekly training mileage began at approximately 30% of the maximum for the training year and increased to beyond 80% of the maximum during the short-course general preparation phase.

The general preparation phase was constructed with two mesocycles. The first was a staircase type, lasting 4 weeks. It had no recovery phase because of the gradual buildup that took place from the beginning of the season. The second mesocycle had a 4-week working phase followed by 1 week of recovery. Training mileage reached 80% of the maximum planned for the season during this mesocycle. A gradual shift toward doing more endurance training in each swimmer's main stroke or strokes occurred during this mesocycle to prepare them for more specific training during the next season phase.

Approximately 50% of the total weekly mileage was devoted to basic endurance (En-1) training during the general preparation phase. Lactate production and power training made up approximately 10% of the total. Recovery training made up approximately 15% of the total. Threshold training was introduced during the 3rd week of the general preparation phase and was increased to approximately 10% of the total mileage during the second mesocycle of this phase. Overload endurance (En-3) training was introduced during the 4th week and made up approximately 5% of the total mileage for the remainder of the general preparation phase. The percentages of training suggested for these swimmers during the general preparation phase were based on an



	B	Short-course season–26 wks				B	Long-course season–22 wks			
Season phase	2 wks	General preparation phase 9 wks	Specific preparation phase 8 wks	Race prep phase 6 wks	Taper phase 3 wks	2 wks	General prep phase 6 wks	Specific prep phase 7 wks	Race prep phase 6 wks	Taper phase 3 wks
Emphasis	Break	Aerobic capacity Speed General strength Flexibility Stroke techniques Nutrition & time management	Aerobic capacity Aer/an muscular endurance Specific strength Flexibility SR & SL	Aer/an musc endurance Flexibility Maint of SR & SL pace & strategy	Rest Pace maint	Break				

Legend

▨ Basic endurance (En-1)

▩ Threshold endurance (En-2)

■ Overload endurance (En-3)
Lactate tolerance (Sp-1)
Race pace (R-P)

■ Lactate production (Sp-2)
Power training (Sp-3)

░ Recovery training (R)

Figure 17.11 A two-season yearly training plan for 100 and 200 sprinters.

average weekly mileage of 50 km. Volume increases were the preferred method for progressive overload during this phase of the season, although the athletes were also increasing their repeat speeds as they got into better physical condition.

At 8 weeks long, the specific preparation phase for 100 and 200 sprinters was shorter than the corresponding phase for middle distance and distance swimmers. This phase was shortened to reduce the volume of high-intensity endurance training and the inhibiting effect it could have on the swimmers' sprint speed. Athletes who swim 200 races, however, need to include a reasonable amount of high-intensity endurance training in their programs during this phase of the season because they must improve the rates of oxygen consumption and lactate removal by their fast-twitch muscle fibers to be successful. But they must do this without any significant, long-lasting effect on their speed and power. Swimmers should complete most of the high-intensity endurance training and sprint training in their main stroke or strokes during this season phase. Weekly training mileage should increase to between 90% and 95% of the yearly maximum during the second mesocycle of the short-course specific preparation period.

The specific preparation period was divided into two 4-week mesocycles, each with a 3 + 1 configuration. The maximum mileage planned for the season was reached during the second of these mesocycles. Increases of training volume and intensity were the methods for progressive overload used during this phase.

Notice that the volumes of threshold endurance (En-2), overload endurance (En-3), and lactate tolerance (Sp-1) training increased considerably during the second mesocycle of the specific preparation phase. Threshold and overload endurance training made up approximately 30% of the total weekly mileage at this time. Although emphasized, the volume of threshold (En-2) and overload (En-3) endurance was not as great as it was for middle distance and distance swimmers because 100 and 200 athletes were swimming fewer meters each week. Some of their threshold and overload endurance training was done in straight sets, but the sets were not as long as they were for middle distance and distance swimmers. The majority of their high-intensity endurance training, however, was completed at the end of descending sets.

Small amounts of lactate tolerance training were also included for 100 and 200 sprinters during this phase because that training emphasizes buffering capacity. As in the previous phase, additional amounts of sprint training were included for this category of competitors. The amount of power training increased. The percentage of sprint training remained at approximately 10% of the total during the specific preparation phase, but the total volume of sprint training was greater because the weekly mileage increased during this phase of the season.

Basic endurance training remained at approximately 50% of the weekly total, and the percentage of recovery training remained at approximately 15% of the total. The percentages of each type of training during the specific preparation phase were based on an average weekly training mileage of 60 km.

The race preparation phase was set at 6 weeks for 100 and 200 swimmers to provide more time for improving their aerobic and anaerobic muscular endurance and buffering capacity under racelike conditions. The longer race preparation phase was scheduled because sprint swimmers generally have greater innate anaerobic power that requires more time for development. In this regard, much of the race-pace training that swimmers did during this period also contributed to improving their anaerobic power because it was done at fast speeds over short distances. Thus, the percentages of lactate production (Sp-2) training that swimmers performed decreased to between 5% and 7% of the total during the race preparation phase because of the overlap with lactate tolerance and race-pace training. The amount of power training (Sp-3), however, increased. The decrease in lactate production (Sp-2) training was not reflected by the percentages in figure 17.11 because the percentages were based on a total weekly mileage that was 20% to 25% below the season maximum.

The percentage of basic endurance training decreased to approximately 40% of the total weekly mileage, and the percentage of threshold training decreased to maintenance levels during the race preparation phase. The percentage of recovery training increased to approximately 20% of the total because the athletes were swimming at high intensity more often. Therefore, they needed more time for repair of muscle tissue and replacement of muscle glycogen.

The race preparation period for these swimmers was divided into two mesocycles. The first mesocycle had a working phase of 3 weeks and a recovery phase of 1 week. The second had a working phase of 2 weeks, and the recovery period was the 1st week of the taper phase that followed. Progressive overload was applied by increasing training intensity or density during the race preparation phase of the short-course season.

Evaluations of aerobic and anaerobic thresholds should have been conducted during the general and specific preparation periods of the short-course season, with training speeds increased as the velocities at those thresholds increased. Some measure of aerobic and anaerobic muscular endurance should also have been used during the specific preparation period and the race preparation phase that followed to evaluate changes in this physiological mechanism. Aerobic and anaerobic endurance should improve markedly during both season phases. If it did not, the swimmers may have been swimming too intensely, too often. In that case, the amounts of threshold endurance (En-2), overload endurance (En-3), and lactate tolerance training (Sp-1) should be reduced and replaced with more basic endurance and recovery training.

Sprinting speed and, if possible, peak blood lactates should be evaluated during the specific preparation period of the short-course season to determine whether improvements in the swimmers' aerobic and anaerobic thresholds were due to an increase in aerobic capacity or were instead caused by a decrease of anaerobic power. The amounts of threshold (En-2) and overload (En-3) endurance training should be reduced if the latter effect was suspected.

Evaluations of sprinting speed and swimming power should also be made during the general preparation phases of the season but only to be certain that muscular power and the athletes' rates of anaerobic metabolism have not declined too much.

Evaluations of sprinting speed and swimming power should continue during the race preparation phase, and both should improve dramatically at this time. If they do not, the reason could be that swimmers are doing too much lactate tolerance swimming or too much high-intensity endurance training.

The taper for the short-course season has been extended to 3 weeks for 100 and 200 swimmers because they usually need a longer recovery period to perform at their best. The taper may be followed by a break or by an extended taper period of 2 weeks when additional meets are contested before the start of the long-course season.

The long-course season for 100 and 200 swimmers was 22 weeks in length. The general preparation phase was shortened to 6 weeks because the athletes should have retained a reasonable aerobic base from the previous short-course season. At 7 weeks in length, the specific preparation phase was also shorter than it had been during the short-course season. The race preparation phase was 6 weeks long, as it had been during the short-course season.

The starting and ending mileages were somewhat greater for the general and specific preparation periods during the long-course season than they were during the previous short-course season. The athletes were not in school during the summer months, so they had more time for training and rest. Training mileage began at approximately 50% of the weekly maximum for the season and progressed to 90% of the yearly maximum by the end of the long-course general preparation period. Weekly training mileage increased to 100% of the yearly maximum during the second mesocycle of the long-course specific preparation period. Training mileage decreased to approximately 80% of the season maximum during the race preparation phase of the long-course season, just as it had during the same phase of the short-course season.

One long staircase mesocycle, with a working period of 5 weeks and a recovery period of 1 week, was selected for the general preparation period of the long-course season to ensure a return of aerobic capacity. The specific preparation period was constructed with two mesocycles. The first had a 3 + 1 configuration, and the second had a working phase of 2 weeks followed by a recovery period of 1 week. The race preparation phase was also constructed with two mesocycles. The first had a 3 + 1 configuration, and the second had a working phase of 2 weeks with the 1st week of the taper period serving as the recovery period for that mesocycle.

The taper period was 3 weeks in length, as it had been during the short-course season. A break of 2 weeks followed it before the start of the next training year.

The percentages of each type of training, the systems of progressive overload, and the methods of evaluation should be the same for the long-course season as those that were described for the short-course season. As mentioned, the weekly training mileage should be somewhat greater during the long-course season if the meet at the end of the summer is the major competition of the year. Swimming intensity should also be at its highest level for the training year during the long-course season, for the same reason.

Two-Season Yearly Training Plan for 50 and 100 Sprinters

An example of a yearly training plan for sprinters who specialize in the 50 and 100 race distances is shown in figure 17.12. The major difference between this plan and the previous two is that speed training was a major priority during every phase of each season. Another difference was that the weekly quantity of endurance mileage should decrease compared with that of swimmers who compete in longer events to reduce the effect of that training on sprinting speed.

Perhaps the biggest difference in the plan for 50 and 100 sprinters compared with the other two plans was that the mesocycles in the specific preparation phase were constructed to improve aerobic capacity and aerobic and anaerobic muscular endurance without causing a significant reduction in sprinting speed.

Sprinters who specialize in 50 and 100 events do need to improve their aerobic capacity but not at the expense of their sprinting speed. Most of that improvement can be accomplished with basic endurance swimming, which should not affect the contraction speed and power of their slow-twitch muscle fibers. But they must also spend some time swimming at threshold speeds and faster to improve both the oxygen consumption and lactate removal rates of their fast-twitch muscle fibers. An increase in the aerobic capacity of fast-twitch fibers is essential for them to swim well for distances of 100 yd and 100 m, particularly when the latter events are contested in long-course pools. At the same time, however, they cannot afford simply to maintain their speed and anaerobic power; they must increase them. For those reasons, the mesocycles for the specific preparation period have been planned to emphasize aerobic capacity and aerobic and anaerobic muscular endurance for 2 weeks and then to emphasize sprinting speed for 2 weeks so that endurance can be improved with less chance of losing sprinting speed. To accomplish this purpose, the specific preparation phase has been made considerably longer than the other season phases.

As with the plans for other categories of swimmers, the length of each season has been planned to coincide with the major competitions of the spring and summer. The general preparation period has been set at 7 weeks during the short-course season. Only 4 weeks was allotted to this phase during the long-course season, however, so sufficient time would be available for the specific preparation and race preparation phases.

During the short-course season the general preparation phase was constructed of one 7-week staircase mesocycle. Weekly training mileage progressed from approximately 30% to beyond 80% of the season maximum during this season phase. Between 50% and 60% of the training mileage was devoted to basic endurance training. Small amounts of threshold and overload training were added to this total during the final 4 weeks of this phase. Approximately 10% of the mileage was devoted to lactate production and power training during each of these weeks, and recovery training made up approximately 20% of the total weekly mileage. Approximately 8% of the weekly mileage was completed as lactate tolerance training during the final 4 weeks of this mesocycle. The percentages of each type of training were based on a weekly average mileage of 40 km. Volume increases were used for progressive overload.

The specific preparation period, as indicated, was the longest phase during both the short-course and long-course seasons. A length of 9 weeks during both seasons provided time for the dual purposes of improving endurance and speed. The specific preparation period was divided into two mixed mesocycles during both the short-course

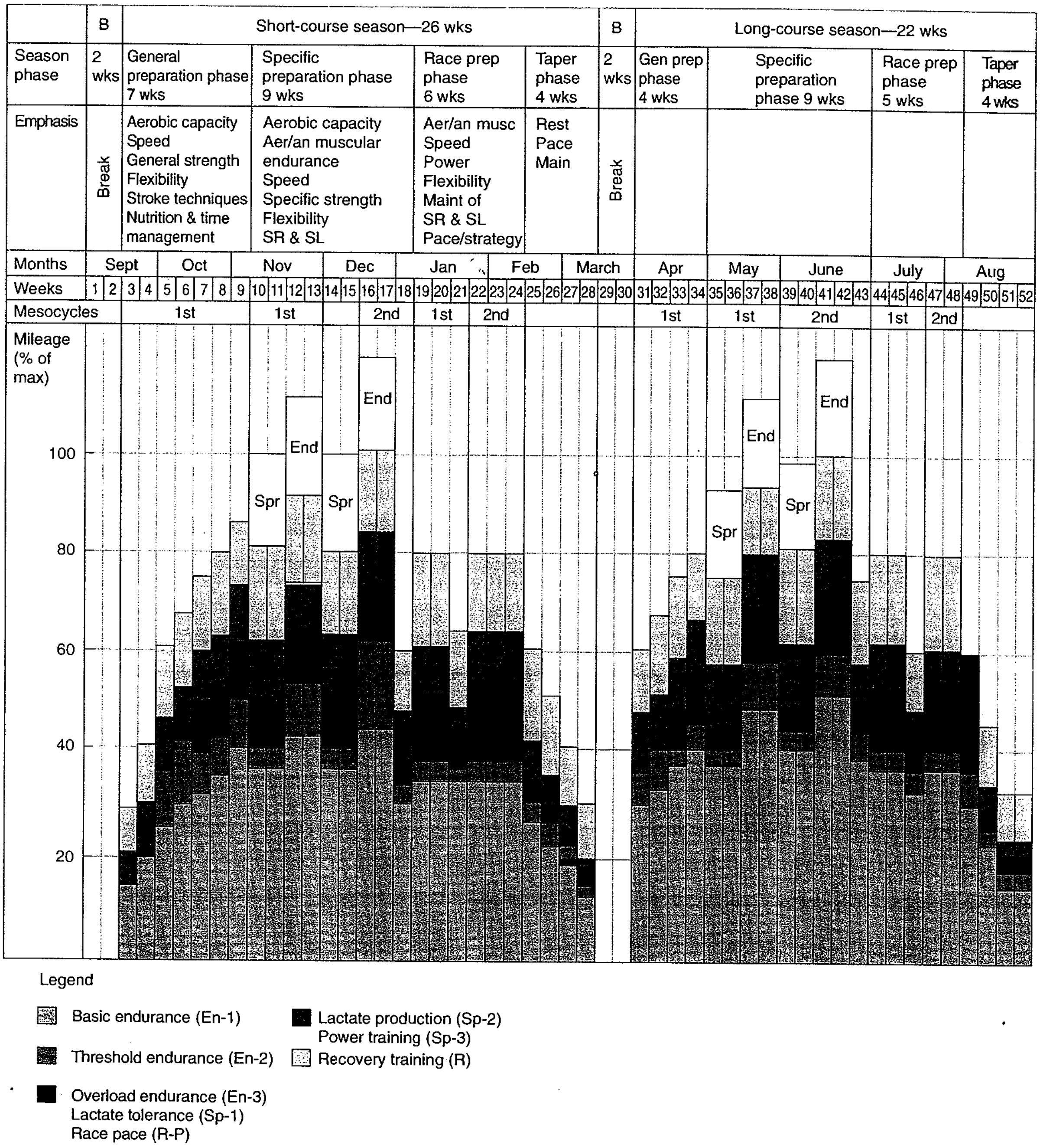


Figure 17.12 A two-season yearly training plan for 50 and 100 sprinters.

and long-course seasons. Each mesocycle was 4 weeks long. The first 2-week period was devoted to sprint training. In particular, the mileage devoted to lactate production (Sp-2), lactate tolerance (Sp-1), and power training (Sp-3) increased to approximately 12% of the total at this time. The increase in total sprint mileage was greater than that indicated by the percentage increase because the weekly mileage also increased during the specific preparation phase. Weekly training mileage was approximately 80% of the season maximum during the sprint phase of each mixed mesocycle.

The percentage of basic endurance training remained at approximately 45% of the total, and the percentage of recovery training remained at approximately 20% of the total during this sprint mesocycle. The amount of threshold training decreased during these

2 weeks to diminish its inhibiting effect on anaerobic power. Intensity was the system of progressive overload used during the sprint portion of these mixed mesocycles.

The second 2-week period of each mixed mesocycle of the specific preparation period was devoted to improving aerobic capacity and lactate removal in the fast-twitch muscle fibers. This was done to prepare the swimmers to compete well in their 100 events and to expand the amount of high-intensity sprint work they would be able to do during the race preparation phase that followed. But to achieve this purpose, the swimmers did not use straight sets of threshold or overload endurance training. They accomplished it by increasing the number and length of their basic endurance sets and by descending the last one-third to one-half of those sets down to threshold (En-2) and overload (En-3) endurance speed and occasionally to lactate tolerance (Sp-1) speed. The combined percentage of lactate tolerance (Sp-1), threshold endurance (En-2), and overload endurance (En-3) training increased to approximately 20% during this phase.

The percentages of basic endurance and sprint training did not change during the endurance phase of this mixed mesocycle, but the percentage of recovery training increased to approximately 25% because the greater quantities of high-intensity endurance and sprint training required more recovery time.

The maximum weekly mileage intended for each season should be reached during the endurance phase of the second endurance mesocycle during the specific preparation phase. During both seasons, the specific preparation period ended with a recovery week before moving into the race preparation phase. An increase of training volume was the principal system of progressive overload used during the endurance phase of each mixed mesocycle of the specific preparation phase.

The race preparation period was 6 weeks in length during the short-course season and only 5 weeks long during the long-course season. The time devoted to each type of training, however, was almost identical in the two seasons.

The race preparation phase was made up of two mesocycles during both seasons. In the short-course season, the first mesocycle had a 2 + 1 configuration, and the second mesocycle was 3 weeks in length with the taper serving as the recovery period for that mesocycle. The first mesocycle also had a working period of 2 weeks and a recovery period of 1 week during the long-course season. The second mesocycle was only 2 weeks in length. The taper phase served as the recovery period for the second long-course mesocycle of the race preparation phase.

The emphasis during the race preparation phase was on improving aerobic and anaerobic muscular endurance and sprinting speed. Lactate tolerance (Sp-1) training rather than overload endurance training (En-3) was used to improve aerobic and anaerobic muscular endurance because the former type of training was more effective for improving buffering capacity. For that reason, lactate tolerance training increased to its greatest volume, approximately 20% of the total mileage. Sprint training remained at 8% to 10% of the total, and threshold training decreased dramatically. The percentage of basic endurance training also decreased, but only slightly. The volume of basic endurance training decreased considerably, however, because the athletes were training with less weekly mileage during this phase of the season. The percentage of each type of training during this period was based on an average weekly training mileage between 40 and 45 km. Weekly training mileage decreased to approximately 80% of the season maximum during the race preparation phase of both the short-course and long-course seasons. Increases in training intensity and density were the systems of progressive overload used during this season phase.

Evaluations of aerobic capacity, aerobic and anaerobic muscular endurance, and sprinting speed should have been conducted approximately every 3 weeks during the general and specific preparation periods. Swimmers should have improved their aerobic capacity with little loss of speed and power. Swimmers' paces for endurance training should have been based on the results of their tests for aerobic capacity. Aerobic and anaerobic muscular endurance may have declined somewhat during the general preparation phase, but it should increase during the specific preparation period.

Measures of aerobic and anaerobic muscular endurance, sprinting speed, and muscular power should be conducted approximately every 3 weeks during the race preparation phase. Aerobic and anaerobic muscular endurance should improve markedly. If it did not, swimmers may have been swimming too intensely, too often. In that case, the amount of lactate tolerance training should decrease and basic endurance training should increase. Evaluations of aerobic capacity, aerobic and anaerobic muscular endurance, and sprinting speed should have been conducted at the end of each 4-week mesocycle. Aerobic capacity and sprinting speed may have declined somewhat during this phase, but aerobic and anaerobic muscular endurance should have increased.

Evaluations of sprinting speed and swimming power should indicate dramatic improvement during the race preparation phase. If they do not, swimmers may be doing too much lactate tolerance swimming, too much high-intensity endurance training, or both. The cause must be identified and the correction made.

The taper phase was extended to 4 weeks during both the short-course and long-course seasons of the year because sprint swimmers who specialize in the shortest events usually need a longer recovery period to perform at their best. The taper phase was followed by a break or extended taper period of 2 weeks following each season.

Three-Season Yearly Training Plans

Three-season yearly plans are generally subdivided into winter, spring, and summer seasons. The winter season begins in September and usually ends with a major regional, national, or international meet in early to mid-December that is conducted in short-course yard or short-course meter pools. The spring season begins in January and ends with another major regional, national, or international meet held sometime between late March and early April. The summer season begins in April and ends with a major competition usually held in mid to late August.

The phases for each season should be the same as they were for two-season yearly plans, except that each phase will usually be shorter. Consequently, these phases must overlap. To accomplish that, the type of training that will be emphasized in the coming season phase should be increased somewhat during the last 2 weeks of the preceding phase to provide adequate time to produce the desired training effects. The types of training that should be emphasized during each season phase, the percentages of each type of training, and the methods for evaluation are the same as those described for the two-season yearly plans, so they will not be discussed in this section. The following discussion will be concerned with the duration of the three seasons and with the length of each training phase within a particular season. I will also discuss the manner in which mesocycles can be constructed for each phase of a three-season year.

Three-Season Yearly Training Plan for Middle Distance and Distance Swimmers

A three-season plan for distance and middle distance swimmers is illustrated in figure 17.13. The winter season was 16 weeks in length, from September to mid-December. This was followed by a 1-week break for the Christmas holidays. The spring season was 13 weeks long. It began in January and continued until late March, when swimmers had a 1-week break. The summer season, the longest of the three, began in April and continued until late August. The swimmers then took another break of 1 week, after which they began their new training year.

Three-Season Yearly Training Plan for 100 and 200 Sprinters

An example of a three-season yearly plan for sprinters who specialize in 100 and 200 events is shown in figure 17.14. The major difference between this plan and the three-season plan for middle distance and distance swimmers was that more time was given to race preparation in the spring and summer seasons when the most important

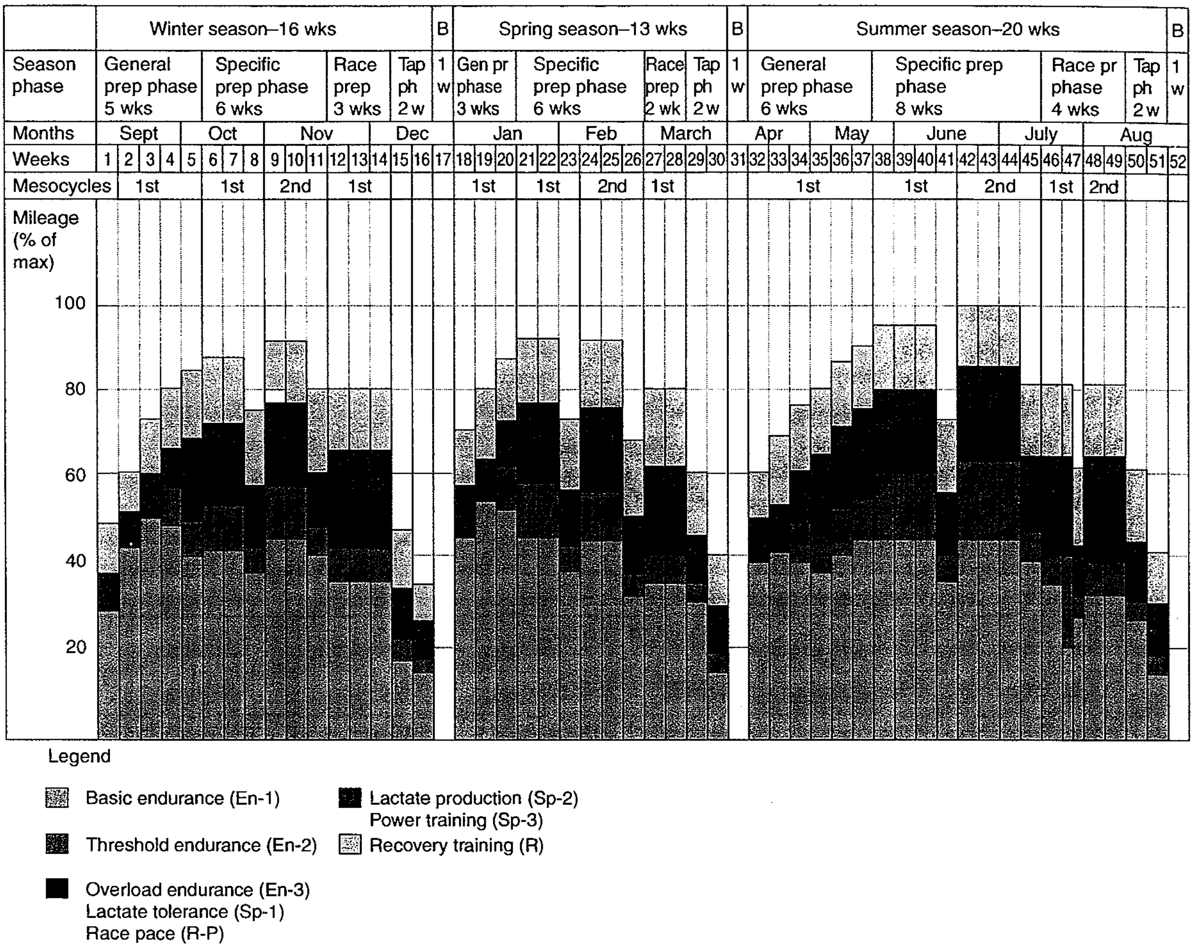


Figure 17.13 A three-season yearly training plan for middle distance and distance swimmers.

competitions were held. Race-pace training of sprinters is substantially less aerobic and more anaerobic than it is for middle distance and distance swimmers, so sprinters needed more time to improve their buffering capacity. Shortening the general and specific preparation periods made more time available for a longer race preparation phase.

Three-Season Yearly Training Plan for 50 and 100 Sprinters

An example of a yearly training plan for sprinters in the short events is shown in figure 17.15. As was the case with the two-season plan for this category of sprinters, the mesocycles during the specific preparation periods have been separated into weeks that emphasize sprint training and weeks that emphasize endurance training. This arrangement reduces the possibility that athletes will lose speed and power while building endurance. The general preparation periods have been shortened somewhat to make room for longer specific preparation phases throughout the training year.

Mixed Macrocycle Yearly Training Plans

With plans of this type, the entire training year is structured into several macrocycles. In turn, each macrocycle is constructed from several mesocycles, each with a different training emphasis. Scheduling would be easy if these plans could be constructed of macrocycles and mesocycles as was the plan for Salnikov described earlier in this chapter. In most circumstances, however, it is almost impossible to develop plans in which the macrocycles and mesocycles are of equal duration because of the scheduling of major competitions throughout the training year. Consequently, the plans described in this

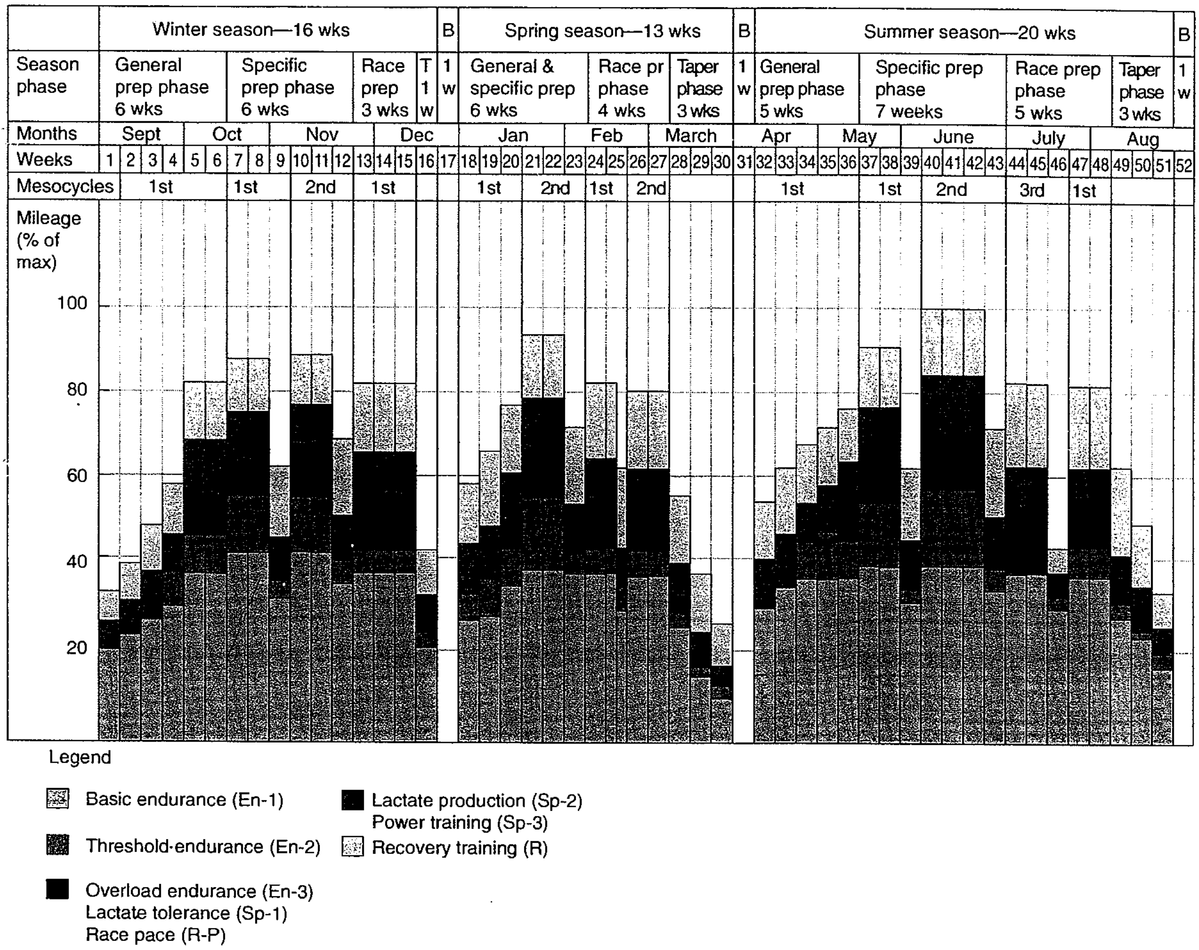


Figure 17.14 A three-season yearly training plan for 100 and 200 sprinters.

section will often have macrocycles of different lengths. Mesocycles within them also vary in length. But each macrocycle will include four mesocycles that encompass the four season phases: the general preparation phase, the specific preparation phase, the race preparation phase, and the taper or recovery period. The purposes for each of these phases or mesocycles, the percentage of each type of training, the progression systems used, and the evaluation methods will be similar to those described for two- and three-season training years.

Mixed Macrocycle Yearly Training Plan for Middle Distance and Distance Swimmers

The specifics of a mixed macrocycle plan for middle distance and distance swimmers are illustrated in figure 17.16. The yearly plan consists of four macrocycles. The mesocycles within each of these macrocycles were generally 4 weeks in length or longer during the general and specific preparation periods. That duration was used to provide time for development of aerobic capacity. Recovery weeks were also provided at the end of the specific and race preparation mesocycles to encourage superadaptation.

Mixed Macrocycle Yearly Training Plan for 100 and 200 Sprinters

A yearly training plan for swimmers in the longer sprint events is shown in figure 17.17. The plan consists of four macrocycles. The first was 14 weeks in length, beginning in mid-September and ending in late December. The second macrocycle was 12 weeks long, extending from January to April. The third macrocycle was 11 weeks in

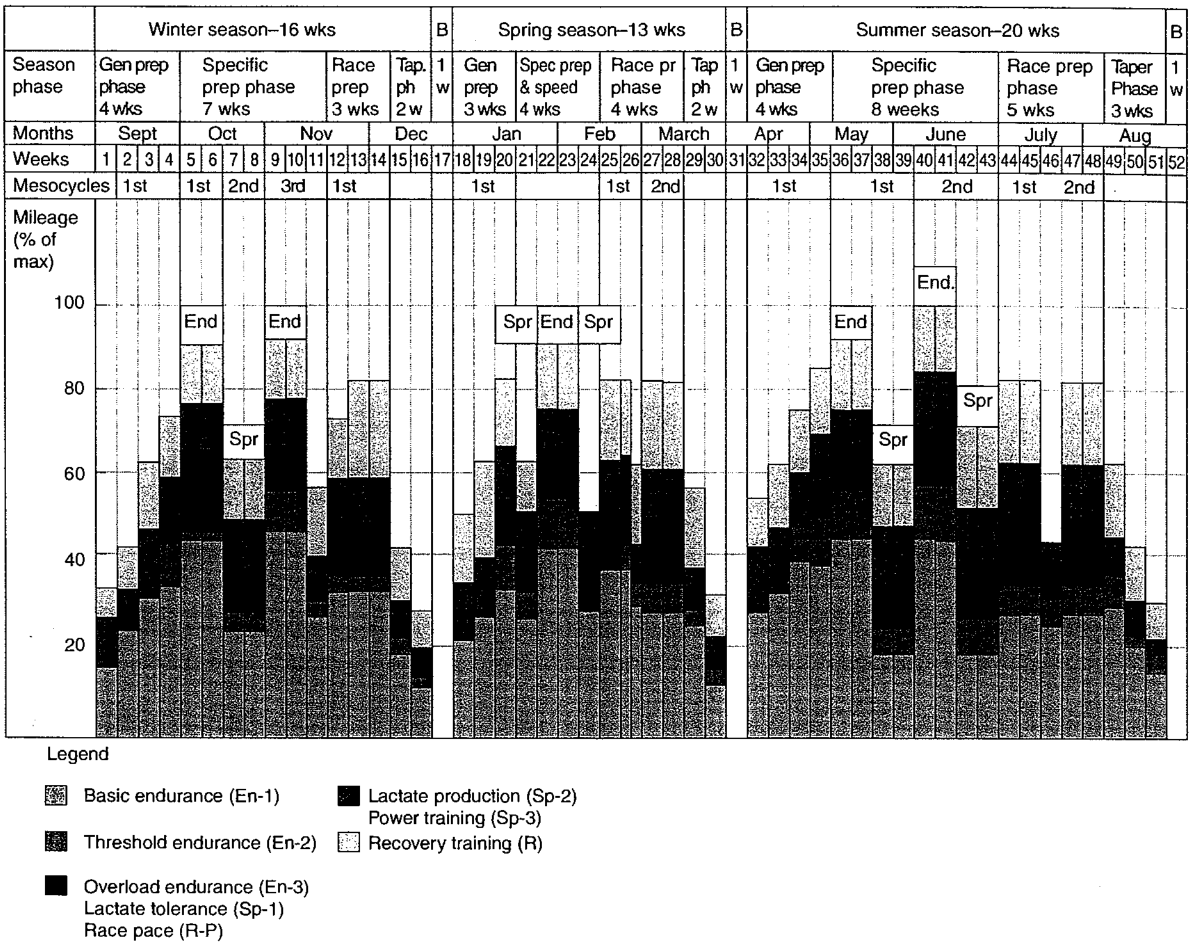


Figure 17.15 A three-season yearly training plan for 50 and 100 sprinters.

length, beginning in April and ending in mid-June. The final macrocycle, also 11 weeks long, was from mid-June to September.

Mixed Macrocycle Yearly Training Plan for 50 and 100 Sprinters

The template in figure 17.18 is an example of a yearly training program that could be used for swimmers in the shortest sprint events. Like the mixed macrocycle plan for 100 and 200 sprinters, it includes four macrocycles. The major difference between the two is that the plan for the 50 and 100 sprinters has within each macrocycle a speed mesocycle that is 2 weeks long. This arrangement put greater emphasis on the development of sprint speed.

The first macrocycle was 14 weeks in length and went from mid-September to late December. The second was 13 weeks long, extending from January to April. The third macrocycle was 11 weeks in length, beginning in April and ending in mid-June. The final macrocycle encompassed the period from mid-June to September and was 10 weeks long.

Planning Very Short Seasons

Coaches of U.S. high school swim teams and those who coach recreational and summer league swim teams usually deal with very short seasons and with athletes who do not compete for more than a few months of each year. They often ask how they can structure a season of only 8 to 12 weeks to provide some benefit to their swimmers. To offer some suggestions for planning short seasons, I will use an example of a season

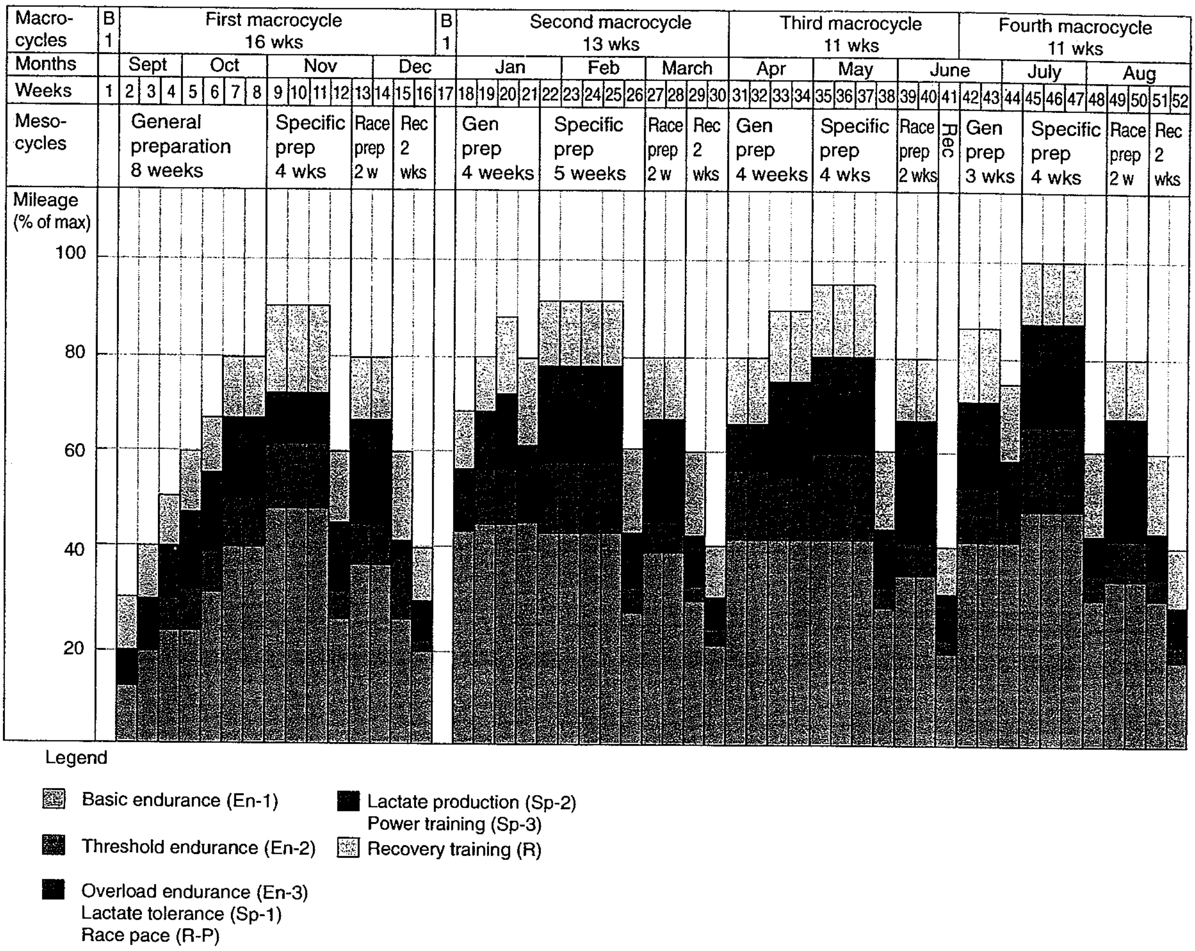


Figure 17.16 A mixed macrocycle yearly training plan for middle distance and distance swimmers.

that is 12 weeks long. The plan illustrated in figure 17.19 was designed for swimmers who specialize at race distances of 100 and 200 yd or m.

The first step in the planning process, determining the season length, has already been decided. The second step is to determine the length of the taper. When the entire season is short, the taper can be short, probably 1 or 2 weeks. The next step is to establish race preparation and specific preparation phases of reasonable length. If a 2-week taper was selected, 10 weeks remain. Three weeks can be set aside for race preparation and 4 weeks for specific preparation. That leaves 3 weeks for general preparation, an adequate period if the swimmers have been training elsewhere before joining the team. But if they have not been training, the general and specific preparation periods will need to overlap. This should be accomplished by combining the two periods into one phase that is 7 weeks long. The reason for combining these two phases is to provide more time for swimmers to master the techniques of competitive swimming. Three weeks is simply too short a time for inexperienced swimmers to do this. For that reason, the goals of the general preparation phase should be extended throughout this combined phase so that swimmers can spend more time learning strokes, starts, turns, and other competitive techniques. The general and specific preparation phases overlap in the plan shown in figure 17.19.

Personalizing Season Plans

Coaches must always be willing to make adjustments to any plan when the situation and the legitimate needs of certain swimmers require such changes. For example,

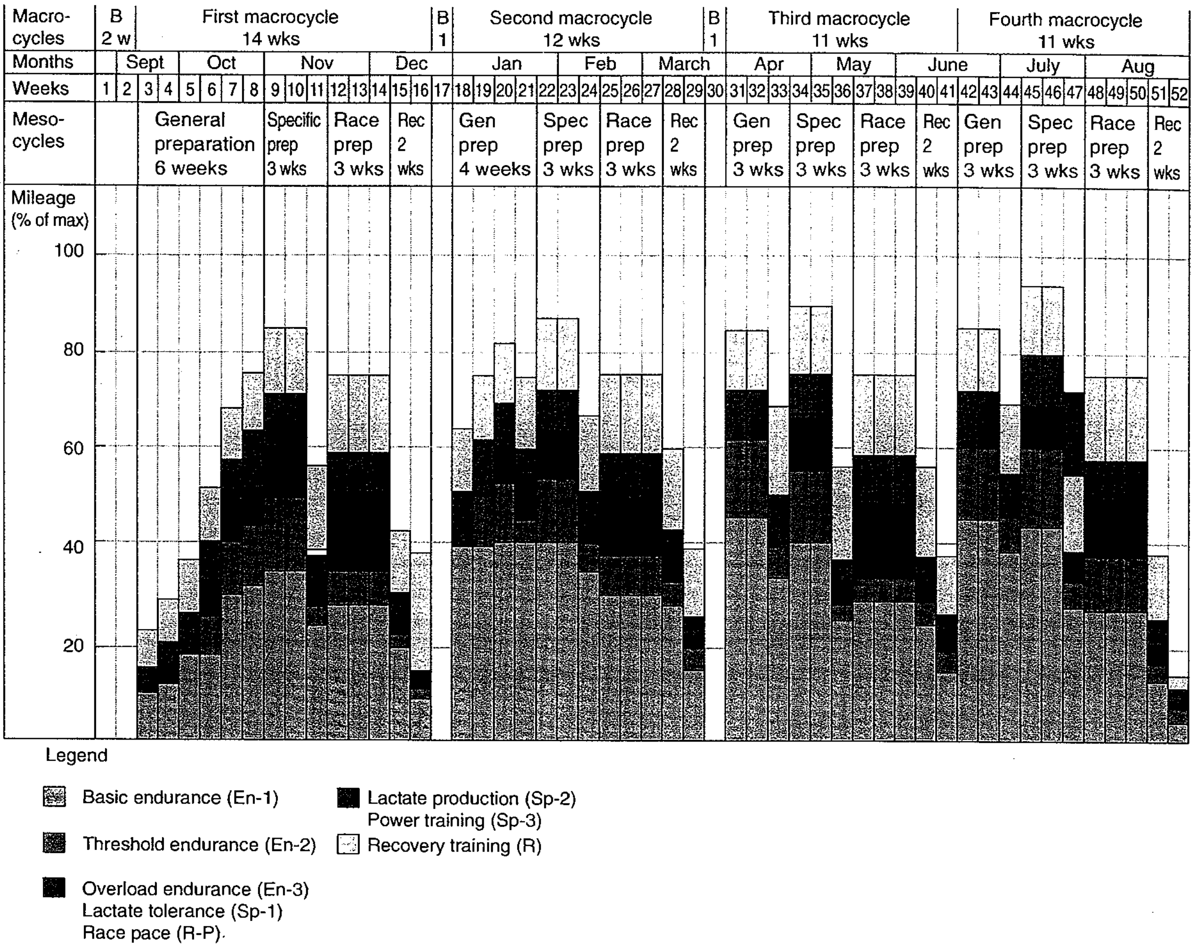


Figure 17.17 A mixed macrocycle yearly training plan for 100 and 200 sprinters.

individual differences in the ways that certain swimmers respond to training will often necessitate a change in emphasis from the one planned for a certain phase of the season. Family vacations, academic and other commitments, illnesses, or injuries may also cause swimmers to be absent at times when important training overloads occur. As a result, their plans will need to be adjusted to make up for the important training they missed.

Evaluating Progress

The motivation of swimmers will increase if they have goals for each mesocycle of the season and if their progress toward those goals is evaluated. The following list contains some tests that can be used within each category of evaluation. A more complete description of many of these tests can be found in chapter 16.

- *Strength.* One-repetition maximum lifts and stroke-simulated pulls on a swim bench are excellent for evaluating changes in strength. Progress on standard strength training exercises can also be used for this purpose.
- *Power.* Simulated arm pulls on a swim bench, swimming against resistance in the water, and times for sprints of 10 to 25 yd or m can be used for this purpose. Sprints of 10 to 12.5 yd or m should be done between the flags to give swimmers a chance to accelerate to top speed before they are timed.

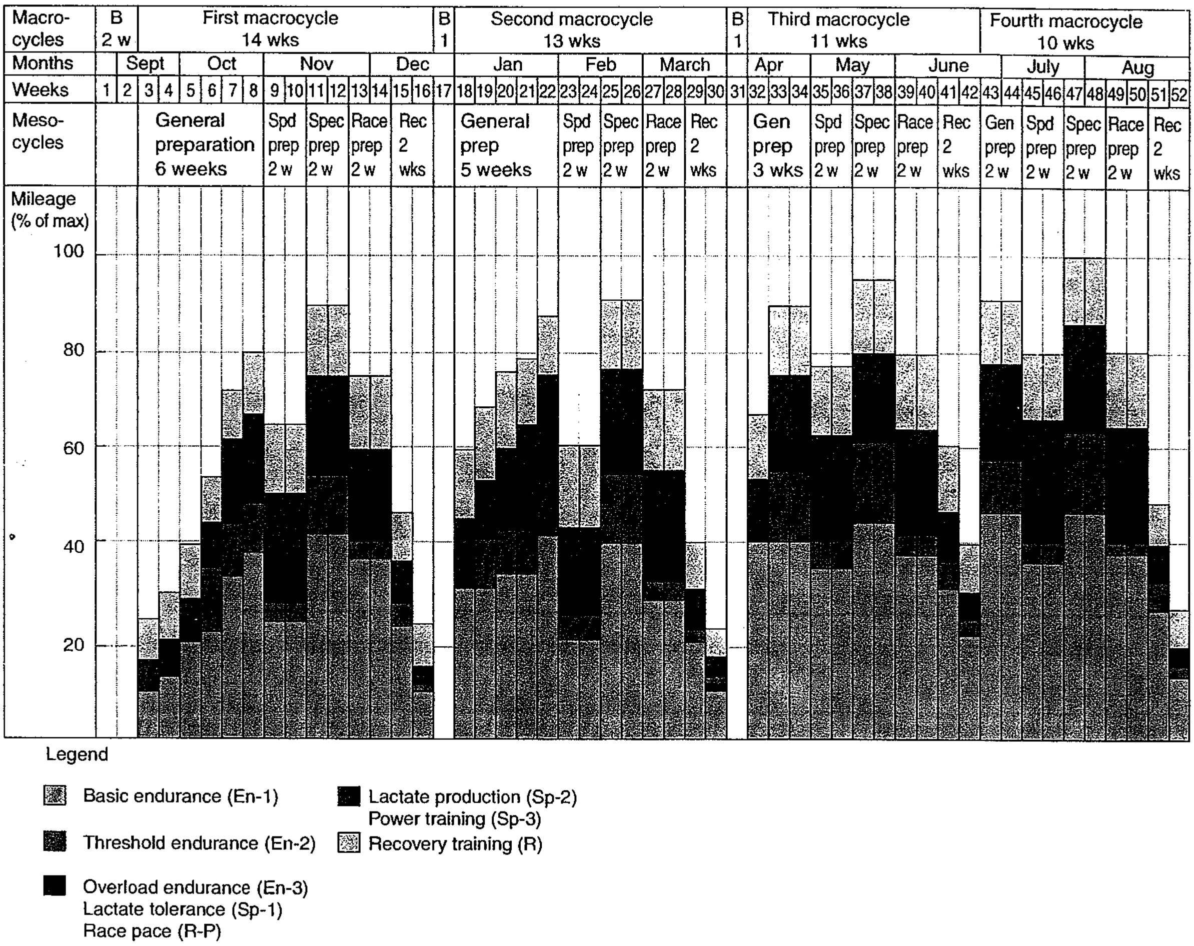
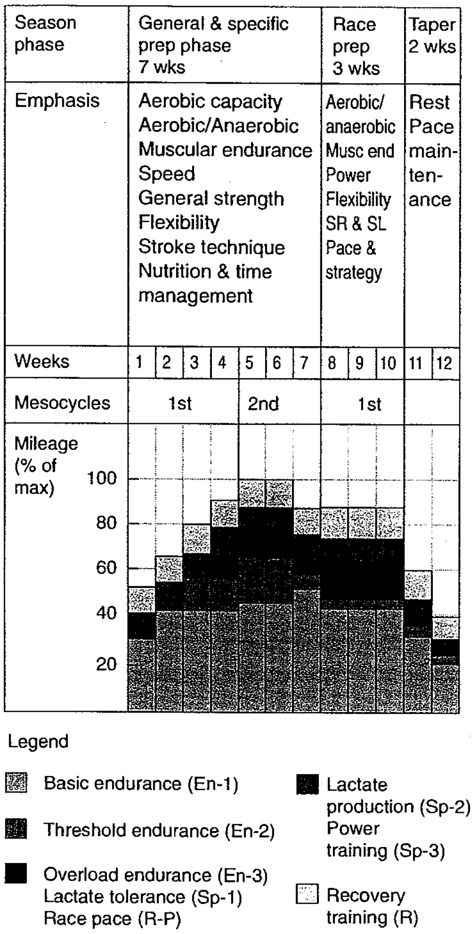


Figure 17.18 A mixed macrocycle yearly training plan for 50 and 100 sprinters.

- *Body composition and flexibility.* Body composition measurements should be used to evaluate changes in muscle tissue. They should not be used to measure body fat.
- *Aerobic capacity.* Blood tests or any of the other noninvasive methods described in chapter 16 can be used to evaluate aerobic capacity. Average times on standardized endurance repeat sets can also be used. Chapter 16 provided examples of these sets.
- *Aerobic and anaerobic muscular endurance.* Shifts in the lactate-velocity curves that occur above 5 mmol/L are excellent for evaluating changes in endurance at this high level of intensity. Average times on standardized repeat sets that reflect this type of endurance are also excellent for this purpose. Some sample sets of this type were described in chapter 16.
- *Anaerobic Power.* Measures of peak blood lactate are excellent for evaluating changes in the rate of anaerobic metabolism.
- *Speed.* Sprints of 25 to 50 yd or m are the most direct means for evaluating sprinting speed.
- *Stroke mechanics.* Repeated videotaping is a good way to evaluate stroke changes. Another good method is to chart changes in stroke length at competition stroke rates. Chapter 20 will describe procedures for measuring stroke rates and stroke lengths.



Season phase	General & specific prep phase 7 wks	Race prep 3 wks	Taper 2 wks
Emphasis	Aerobic capacity Aerobic/Anaerobic Muscular endurance Speed General strength Flexibility Stroke technique Nutrition & time management	Aerobic/ anaerobic Musc end Power Flexibility SR & SL Pace & strategy	Rest Pace maintenance
Weeks	1 2 3 4 5 6 7	8 9 10	11 12
Mesocycles	1st 2nd	1st	

Figure 17.19 An example of a plan for a swimming season that was 12 weeks long.

- *Starts and turns.* Swimmers' starting and turning techniques can be evaluated through videotaping. Their speed for starting and turning can be evaluated by timing various aspects of these techniques, such as time from a starting signal to a distance of 5 m from the starting end.
- *Pacing.* Swimmers can complete broken swims or underdistance repeats at various speeds to test their sense of pace.

Evaluation of all these components after each mesocycle is not necessary. Only those being stressed or the ones considered extremely important at a particular time of the season should be measured.

Breaks From Training

Breaks from training provide time for swimmers to rest and recover from the demands of the previous season. These breaks are often more important to swimmers' emotional well-being than they are to their physical status. Swimmers generally feel drained emotionally after the major competitions of the season, and they look forward to time away from training to rest, pursue other interests, and reenergize for the coming season. A break of 1 to 2 weeks is long enough to recover physically and emotionally yet not so long that swimmers will lose a significant amount of conditioning.

Problems arise when swimmers take training breaks that last 4 weeks to 9 months. Such long breaks are not uncommon for summer recreation swimmers and for some high school and college athletes. Swimmers who are serious about performing at their best cannot afford to take such long breaks from training because all the training adaptations they gained during the previous season will dissipate by the beginning of the next season. As a result, they will have to spend most of their time regaining those adaptations rather than building their various physiological capacities.

Swimmers should understand the time frame involved in the loss of certain physiological mechanisms so that they can avoid losing what they have gained. Several researchers have measured the length of the period during which athletes lose and regain various physiological mechanisms. The results of some of those studies are listed in table 17.1.

Competitive swimmers should never stop swimming entirely for more than 1 or 2 weeks at a time if they are serious about maintaining a high level of conditioning from season to season. They can reduce their training volume, intensity, and frequency for a short time, but they should not stop training altogether. Swimmers who take long breaks from training, through choice or circumstance, should do the following to reduce their training losses during those times. They should swim at least 3 or 4 days per week, and the swimming must be adequate in duration and intensity. Studies by Houmard and associates (1989) and Hickson and coworkers (1982) indicate that daily training mileage should be maintained above 50% of usual training levels. Intensity of training must be maintained within 70% of normal season levels (Hickson et al. 1985). Swimmers would be wise to swim their major strokes during these periods of reduced training to help prevent losses of endurance in the muscle fibers that are most important to their performance. They should also engage in strength and flexibility training

Table 17.1 Effects of Detraining on Various Physiological Measures of Aerobic Capacity, Aerobic and Anaerobic Endurance, Anaerobic Power, and Muscular Power

MEASURE	% LOSS WITH DETRAINING	TIME FOR LOSS IN WEEKS	SOURCES
Aerobic capacity ($\dot{V}O_2$max)	7%	2	Coyle, Martin, and Holloszy 1983
	16%	12	Drinkwater and Horvath 1972
Anaerobic threshold	17%	12	Coyle et al. 1985
	8–10%	4	Costill et al. 1985
Buffering capacity	25%	3	Costill et al. 1985
Muscle glycogen	39%	4	Costill et al. 1985
Aerobic enzymes	10–50%	2–6	Wilmore and Costill 1988
	40%	8	Coyle et al. 1985
Muscle glycogen	40%	4	Costill et al. 1985
Stroke volume	12%	4	Coyle, Martin, and Holloszy 1983
Capillarization	14–25%	1–7	Klausen, Andersen, and Pelle 1981
Blood volume	9%	4	Coyle, Hemmert, and Coggan 1986
Aerobic/anaerobic endurance	50%	3	Troup 1989
Anaerobic enzymes	0	4	Costill et al. 1985
	0	12	Coyle et al. 1985
Strength and power	7–13%	1–4	Costill et al. 1985
Flexibility	100%	4	Maglischo, 1990
Performance	2–3 sec for 200 m	1	Troup 1989
	6–8 sec for 200 m	3	Troup 1989

on land during this time. Strength training will prevent loss of muscle tissue, and stretching exercises will prevent decrements in range and ease of motion.

The caloric needs of reduced training should be calculated, and swimmers should receive some nutritional counseling to help them reduce their caloric intake to their new levels of expenditure during breaks from regular training. Periodic checks of body composition will be useful in estimating the extent of muscle loss and fat gain.

Despite what I just said, some athletes will choose not to engage in swim training during their break periods. These athletes may substitute other vigorous endurance and power activities during this time, but they should understand that the degree to which nonswimming activities will prevent a loss of conditioning depends on the similarity in muscle use between those activities and competitive swimming. Glina and associates (1984) demonstrated how quickly training effects diminish when the activities during a break do not involve the same muscles used during regular training. In the first part of their study, they trained the legs of a group of subjects with cycling. After doing that, they assigned the subjects to either an arms-only group or a legs-only group for 4 weeks of continued training. The legs-only group continued cycling, while the arms-only group trained with an arm-cranking ergometer. As one might expect, the group that trained only their legs continued to improve the aerobic capacity of their leg muscles. The group that trained only their arms lost nearly 3% of the aerobic capacity in their legs during cycling tests. These results suggest that the reverse would probably occur with swimmers who used running and cycling or some other legs-dominant activity as their means of exercise during breaks from swim training. Those swimmers would lose endurance in the muscles of their arms, shoulders, and trunk.

The next best type of training for swimmers is water polo, an activity that will maintain many anaerobic and aerobic adaptations. Swimmers who do not wish to train in the water during breaks are advised to participate in mixed programs of exercise that include leg endurance activities such as running, cycling, or skiing, and arm endurance activities such as rowing or rope climbing. Additionally, they should participate in activities that require power and anaerobic capacity. Games like basketball, tennis, volleyball, handball, and racquetball are excellent for this purpose, as is circuit training. They should spend at least 3 days per week doing activities that are endurance oriented and an equal amount of time performing activities that involve power and speed. As mentioned earlier, these athletes should also continue both weight training and flexibility training.

Weekly Planning

Macrocycles (season phases) are composed of mesocycles. Each mesocycle, in turn, is composed of several microcycles, which are the weekly training plans. Once the macrocycles and mesocycles of a season plan have been constructed, the planning of weekly and daily training programs is the next order of business.

Weekly planning involves two major considerations. The first is to include all the necessary types of training in proper quantity within the training week. The second is to distribute those types of training throughout the week in a way that will most benefit the training process. The goals of the macrocycle and mesocycle in effect during a particular week will determine the weekly volume of each training type. The placement of the various types of training should be based largely on the time required for replacement of muscle glycogen and repair of tissue damage.

Importance of Energy Replacement and Tissue Repair

The rates of energy use and the time required to replace glycogen as well as the time frame for tissue repair are factors that affect the ability of athletes to both perform and adapt to training loads. Let me discuss the role of energy use and replacement first. The most important source of energy to consider is muscle glycogen.

Muscle Glycogen Use and Replacement

Glycogen is an important source of energy for training because it is readily available in the muscles and because it can be metabolized for energy through both anaerobic and aerobic processes. Several studies have demonstrated that the working capacity of athletes increases when they have an adequate supply of glycogen in their muscles and that their working capacity declines when muscle glycogen is completely or partially depleted (Bergstrom et al. 1967; Costill et al. 1971; Kirwan et al. 1988). This occurs because, as explained in an earlier chapter, swimmers must rely on fat and protein for energy when their glycogen supplies are low. The problem with using fat for this purpose is that energy can only be released aerobically, at a rate that is too slow to support fast swimming. The same problem occurs when protein is used for energy. Energy can only be released slowly from protein because of the additional steps required to convert it to substances that can be metabolized. An additional problem arises if too much protein is metabolized for energy. If that occurs, athletes will lose some of the protein building blocks in their muscles that provide them with strength and endurance. Consequently, for weekly planning, knowledge about two considerations is extremely important:

1. The extent to which glycogen will be depleted from the muscles by certain types of training
2. The time required to replace glycogen in those muscles

Armed with that information, coaches can plan weekly training cycles to ensure that athletes have a high level of muscle glycogen when they need it for major sets of intense aerobic and anaerobic training. The information provided in table 17.2 shows the results of several studies in which the rate of muscle glycogen depletion was measured during some common types of aerobic and anaerobic training.

These data show clearly that muscles can lose between 50% and 85% of their glycogen after 30 to 90 min of intense endurance exercise. They can also lose up to 40% of their glycogen after only 6 to 30 min of anaerobic training. These data also suggest that swimmers will generally lose 70% to 85% of their muscle glycogen during a typical 2 hr training session during which they complete 6,000 to 8,000 m at a range of swimming speeds from slow to fast.

What about the rate of glycogen replacement once it has been lost from the muscles during training? The graph in figure 17.20 provides an example of the time frame for muscle glycogen replacement after training. The data were taken from a study by Costill and associates (1988).

Muscle biopsies were used to measure the amount of muscle glycogen in the deltoid muscles of swimmers after a few days of rest. The average for the swimmers was

Table 17.2 Muscle Glycogen Depletion During Exercise of Different Duration, Type, and Intensity

EXERCISE TYPE	% MUSCLE GLYCOGEN DEPLETION	SOURCES
Anaerobic exercise		
1. 1 × 30 sec maximum effort on a bicycle ergometer	25%	Jacobs et al. 1983
2. 1 × 30 sec maximum run	25%	Cheetham et al. 1986
3. 6 × 1 min maximum efforts on a bicycle ergometer	40%*	Gollnick et al. 1973
4. 2,200 m high-intensity 25 and 100 m swimming repeats	35%**	Houston 1978
Aerobic exercise		
1. 6 × 500 yd swims with 1 min rest between swims	54%	Costill et al. 1988
2. 30 × 100 swims with 20 sec rest between swims	69%	Costill et al. 1988
3. 12 × 500 swims with 1 min rest between swims	62%	Costill et al. 1988
4. 60 × 100 swims with 20 sec rest between swims	85%	Costill et al. 1988
5. 9,000 m of short rest running repeats at distances from 50 to 400 m	62%	Houston 1978
6. 30 km run	60%***	Costill et al. 1973
7. 2 hr of cycling	75%	Boven, Keizer, and Kuipers 1985

*Approximately 50% of FOG and FG muscle fibers were completely depleted, and 20% were partially depleted. Only 25% of ST muscle fibers were depleted and 5% were partially depleted.

**Approximately 25% of FOG and FG muscle fibers were completely depleted, and 70% were partially depleted. 10% of ST muscle fibers were depleted and 85% were partially depleted.

***70% of ST muscle fibers were almost completely depleted, and 25% were partially depleted. 40% of FT muscle fibers were partially depleted.

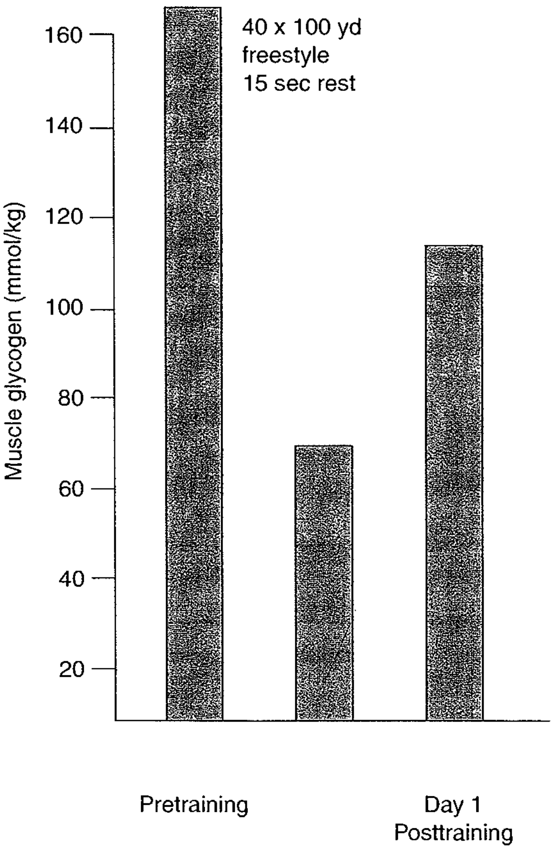


Figure 17.20 Glycogen use and replacement in the deltoid muscles of swimmers.

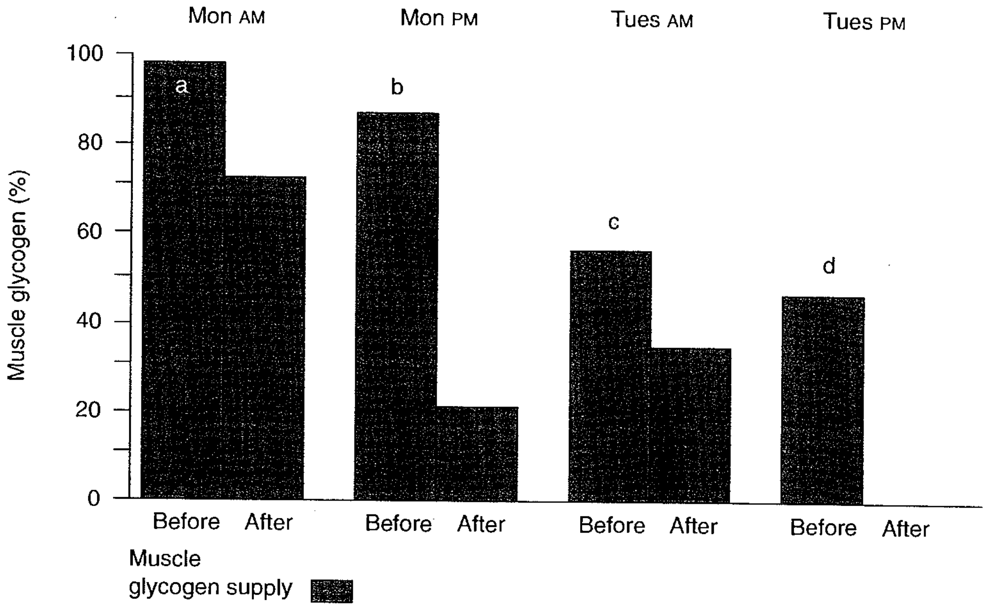
Adapted from Costill et al. 1988.

160 mmol per kg of wet muscle tissue, which is a very high level of glycogen storage. That value indicates that these swimmers were well trained. The swimmers were then asked to swim a set of 40 100 yd freestyles with 15 sec of rest between repeats. They were asked to swim these repeats at the fastest possible average speed for the entire set. Muscle biopsies were also taken after the swimmers completed the set. The results in figure 17.20 show that the swimmers lost on average more than half of their glycogen supply while swimming that set of repeats. Muscle biopsies were taken again after the swimmers had rested for 24 hr to determine the amount of muscle glycogen that had been replaced. As shown by the figure, the swimmers were able to replace only about half of the lost amount of glycogen in their muscles after that 24 hr rest period.

Because of results like those shown in figure 17.20, most experts believe it requires between 24 and 48 hr to replace the muscle glycogen that is usually lost during just one 2 hr training session. The replacement problem is exacerbated by the fact that most junior and senior national-level swimmers train twice daily. Therefore, they seldom have more than 12 hr between training sessions to replace muscle glycogen. The bar graphs in figure 17.21 illustrate the probable pattern of muscle glycogen use and replacement that swimmers go through over 2 days of training.

The swimmers represented by the graph are assumed to be training twice per day, in the morning and afternoon. The graph begins with the morning training session on Monday. Swimmers' muscle glycogen levels will usually be very high at this time because they have had 1 1/2 days of rest. Morning sessions are usually not intense, so I have shown only a 20% loss of muscle glycogen by the end of that 2 hr session. The swimmers have replaced approximately half that amount by the time the afternoon training session commences approximately 6 hr later on Monday. The data in table 17.2 suggests a reduction of 70% and 80% in muscle glycogen following a typical 2 hr training session. Consequently, in figure 17.21, I have shown a muscle glycogen reduction of 70% following the afternoon training session on Monday. The data in table 17.2 suggests a replacement rate of approximately 50% to 60% within 24 hr, of which approximately 35% will be replaced in the first 12 hr. Therefore, the graph shows the swimmers with approximately 60% of their muscle glycogen restored before training on Tuesday morning. Again, assuming a low-intensity training session, swimmers lose only 20% of that amount, of which 10% is replaced by the start of the Tuesday afternoon training session. This means that the swimmers begin the Tuesday afternoon training session with only half the amount of muscle glycogen they had on Monday. That amount is likely to be depleted before the training session is over if that session is as intense as the one on Monday afternoon was. The swimmers' ability to train at fast speeds will probably need to be curtailed on Tuesday afternoon and for at least 1 day.

The pattern illustrated in figure 17.21 is only an estimate of muscle glycogen use and replacement rates during typical training sessions. It makes the point that swimmers cannot perform large amounts of intense swimming day after day without depleting their muscle glycogen supplies. Actually, many factors other than training intensity determine the rates of muscle glycogen depletion and replacement among athletes.



Duration for intense training based on muscle glycogen supply
b = 120 min
c = 60 min
d = 30 min

Figure 17.21 An estimated pattern of muscle glycogen use and replacement over 2 days of training.

One of these is diet. Swimmers who eat high-carbohydrate diets will be able to replace muscle glycogen faster than those who are on high-fat or high-protein diets. Athletes will replace muscle glycogen faster if their diets contain at least 500 g of carbohydrates daily. They may be able to replace all the muscle glycogen that they used during one training session within 24 hr. On the other hand, the typical diet of athletes generally contains too much fat and too little carbohydrates. Consequently, most athletes need 36 to 48 hr to replace all the glycogen they used during one training session.

Another factor that influences the rates of glycogen use and replacement is the percentage of fast-twitch and slow-twitch muscle fibers in the major swimming muscles. Distance swimmers, because they generally have more slow-twitch muscle fibers, will generally use less muscle glycogen during training and replace it faster during the recovery period. On the other hand, sprinters, because they generally have more fast-twitch muscle fibers, will lose more muscle glycogen during training and replace it at a slower rate.

Once muscle glycogen has been largely depleted, training becomes ineffective for improving performance because the swimmers will of necessity slow to a training pace that can be supported principally by fat and protein metabolism. Training at such slow speeds is not only less effective for improving aerobic capacity but also largely ineffective for improving aerobic and anaerobic muscular endurance and absolutely ineffective for improving anaerobic power. For that reason, athletes must find ways to replace muscle glycogen while they are training. They can do this by cycling the types and intensity of training throughout the week. They intersperse sessions of very intense training that use muscle glycogen at a rapid rate with periods of less intensity that use only small amounts of muscle glycogen for energy.

Let me be clear that athletes cannot afford to rest long enough after a training session to restore their muscle glycogen completely. They would accomplish little training if they did that. What they must do instead is alternate the various types and styles of training throughout the week to allow partial restoration of muscle glycogen for times when they will need it in training.

Many coaches, through experience, have gravitated toward a system in which their swimmers perform most morning training sessions at low intensity to reduce the drain on muscle glycogen. The disparity between the rates of glycogen use and replacement is also the primary reason that many experts on training suggest that each training week should include only two or three sessions where the volume and intensity of training are very high (Bompa 1999). This kind of schedule allows 36 to 48 hr of low-intensity training after each high-intensity session for muscle glycogen replacement. The graph in figure 17.22 is an example of the probable pattern of muscle glycogen use and replacement over a week when a recovery period of 48 hr is included after each major training session.

The bar graph in this figure shows that swimmers can probably schedule no more than three major training sessions per week and still have time for adequate replacement of muscle glycogen. Figure 17.22 represents a schedule in which those major training sessions, referred to as *peak* training sessions, took place on Monday afternoon, Wednesday afternoon, and Saturday morning. The goal of the current mesocycle and macrocycle should be emphasized in those peak training sessions. For example, if improving aerobic capacity is the goal, the peak training sessions should include major sets of basic (En-1), threshold (En-2), or overload (En-3) endurance training. When the goal is to improve anaerobic power, the peak training sessions should include major lactate production sets. When the goal is to improve aerobic and anaerobic endurance, the peak training sessions should include a large amount of overload endurance (En-3), race-pace (R-P), or lactate tolerance (Sp-1) training, depending, of course, on the events for which the swimmer is preparing.

One purpose for the remaining training sessions during the week is to replace muscle glycogen lost during the peak sessions. These recovery days should be made up largely of basic endurance (En-1) and recovery (R) training. The amount of each will depend

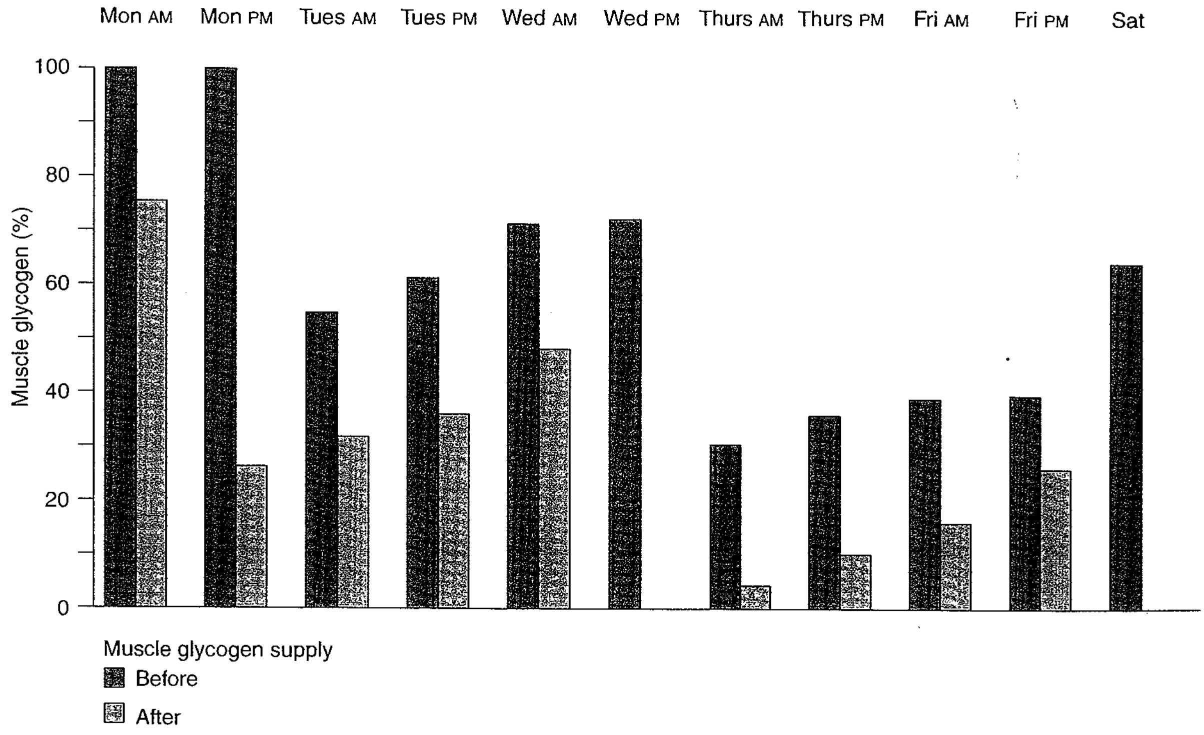


Figure 17.22 Muscle glycogen use and replacement with training intensity cycled throughout the week.

on the desired degree of glycogen replacement. Obviously, during recovery and low-intensity basic endurance swimming, fat will supply more energy and muscle glycogen will supply less. Consequently, athletes will replace more glycogen than they use, resulting in a net gain of muscle glycogen by the end of the day. That gain should be particularly noticeable in the swimmers' fast-twitch muscle fibers, which will not be used as much during recovery days.

What I just said does not mean that recovery sessions must consist only of low-intensity recovery training. Even on days marked for recovery, training can proceed in many ways that will be beneficial for improving performance. One way that swimmers can increase glycogen replacement while improving aerobic capacity is to swim some of the daily mileage in other styles during nonpeak training days. This will allow a greater rate of glycogen replacement in many of the fibers that swimmers use heavily in their main strokes but use less in other styles. Placing greater emphasis on kicking is another method that will increase muscle glycogen replacement in the arms and trunk muscles while still improving the mechanisms of oxygen delivery. Including more kicking during nonpeak training sessions will continue to stimulate the oxygen delivery mechanisms of the circulatory and respiratory systems while at the same time allowing a greater percentage of glycogen replacement in the muscles of the arms, shoulders, and trunk because they will be less active.

Swimmers can also perform short periods of threshold (En-2) and overload (En-3) endurance training, even in their main stroke or strokes, during some of the nonpeak training sessions of each week. Although these types of training require a greater rate of glycogen metabolism, the total amount of glycogen used can be kept to a minimum by limiting training volume. Performing a relatively small volume of work will not interfere with glycogen replacement if the net gain of this substance is well in excess of its use by the end of the day. Sets of lactate tolerance (Sp-1) and race-pace (R-P) training can be scheduled on nonpeak days if those sets are short (100 to 300 yd or m). The rate of glycogen use is high during these types of training, but glycogen use will be modest if the length of the sets is short. Lactate production (Sp-2) and power training (Sp-3) can be included as well. These types of training also involve a high rate of glycogen use, but the repeat distances are usually so short that the total amount of glycogen lost from muscles during such training will be small relative to the amount that will be replaced over the course of the day.

The types of muscle fibers used on peak and nonpeak days should also be considered when planning weekly training. For example, nonpeak sessions are an excellent time for middle distance and distance swimmers to do some sprint training. They rely more on their slow-twitch muscle fibers during peak sessions, so they can afford to deplete the fast-twitch fibers to a greater extent on nonpeak days.

The situation is reversed for sprinters when they are doing a great deal of race-pace and sprint training during their peak sessions. They will need to rest their fast-twitch muscle fibers more during nonpeak sessions. Therefore, they should sprint much less on those days and devote their time to recovery and low-intensity basic endurance training.

Examples of two-peak and three-peak weekly training schedules are shown in figure 17.23.

Two-peak training weeks, as the term indicates, have 2 peak training days each week. The peak training days are usually followed by a day when the volume or intensity is at its lowest level. These days include lots of recovery (R) and basic endurance (En-1) training with perhaps short periods of sprinting and more intense endurance training. The remaining 2 days are scheduled as intermediate training sessions in which the volume and intensity are moderate. More sprinting can be scheduled on those days. Somewhat greater volumes of intense endurance training can also be scheduled, particularly in strokes other than a particular swimmer's main styles.

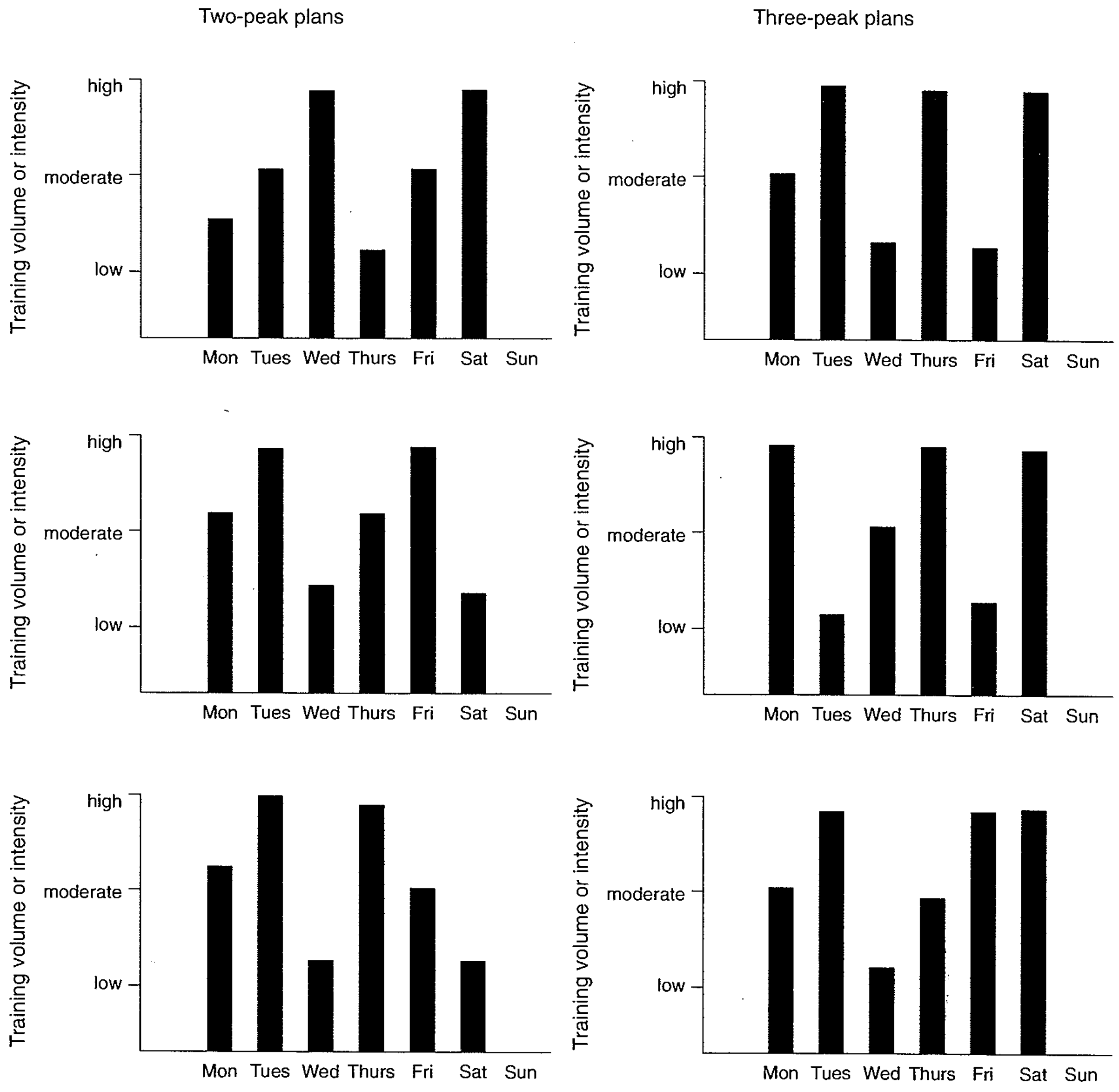


Figure 17.23 Examples of planning for two- and three-peak microcycles.

Low-volume and low-intensity recovery sessions are also appropriate following each peak session of a three-peak week. This schedule leaves only 1 day of the week for training with moderate volume or intensity.

Two- and three-peak plans in which the peak training days are scheduled for 2 of the days from Monday through Thursday are ideal for weeks when competitions are held on the weekend because a training session of lower intensity or volume can be scheduled for Friday.

Tissue Repair

Training, particularly intense training, causes some structural components of tissues to be metabolized or damaged. During recovery, nutrients are transported by the blood to these tissues and used for repair, replacement, and even enhancement during periods of recovery. Tissue enhancement, of course, is a major way that adaptation occurs and performance improves. Our knowledge concerning the time frame for tissue repair and enhancement is, unfortunately, limited. Nevertheless, this process must be given consideration if the physical condition of athletes is to improve rather than deteriorate because of training.

Several questions about this process are of great concern in the planning of training. What is the probable time frame for tissue repair, rebuilding, and enhancement? Should the process be completed after each training session? Or can the process of tissue repair lag behind its breakdown during the working phase of a mesocycle? If tissue repair can lag behind breakdown, the recovery period becomes the time when the repair process catches up and perhaps even supercompensates to enhance the structure and function of those tissues.

Regarding this first question, indications are that tissue repair may take several days, whereas the process of enhancement may take several weeks. A reasonable assumption, therefore, is that the process of tissue breakdown must necessarily exceed the rate of repair and rebuilding during training. This does not mean that athletes can train intensely day after day with no regard to providing time for partial tissue repair. If they do, the extent of the breakdown could become so severe that they would deteriorate back toward an untrained state. For that reason, it seems reasonable to schedule several days for recovery at the end of each major training period (mesocycle) to allow the processes of repair and enhancement to be completed. Several days of recovery may also encourage superadaptation (enhancement of those tissues).

Yakolev's theory of supercompensation, discussed earlier in this chapter, is based on the premise that allowing the breakdown process to exceed the rate of buildup for a short time results in adaptations of greater magnitude when an extended period of recovery is introduced. Although the theory remains unproved, some evidence supports it. Considerable scientific evidence indicates that supercompensation occurs after extended periods of deprivation with regard to carbohydrate and creatine loading. The procedure for creating carbohydrate and creatine loading is to produce a need for these nutrients over several days by depleting them without allowing adequate replacement. Then, when their rate of use decreases and an adequate supply is introduced, persons tend to accumulate in their muscles much more of these substances than they normally would. Perhaps, in a similar manner, when the supply of nutrients remains inadequate for a time, tissues will absorb more and when allowed to recover will go beyond simple repair and become larger, more numerous, and more effective than ever before.

Unfortunately, the available information does not allow me to make specific recommendations regarding the cycling of training for tissue repair. But I can make two general recommendations. The first is that athletes should allow 24 to 72 hr of recovery time whenever they complete one or two sets in which they have incurred a significant amount of acidosis and resultant tissue damage. The second is that some additional recovery time should be included in their training whenever signs of failing adaptation persist for several days. The common signs of failing adaptation are deteriorating performance, loss of weight, poor appetite, insomnia, irritability, and depression. The topic of failing adaptation or overtraining will be covered in detail in chapter 19.

Suggestions for Planning Weekly Training

My purpose in this section is to pull together all the assorted pieces of information about weekly planning presented thus far and present a set of concrete suggestions for planning microcycles.

- *All types of training—endurance, sprint, and recovery—should be included in each weekly plan.* The goal of the current macrocycle and mesocycle will determine the relative volumes of each.

- *Major sets of intense endurance or sprint training should be scheduled at least twice per week during mesocycles when they are not being emphasized and three to four times per week during mesocycles aimed at their maximum development.* These major sets should be placed throughout the week so that adequate time is available for replacement of muscle glycogen and repair of muscle tissue.

The intent of this suggestion could easily be misunderstood, so I want to explain it more fully. What I have said does not mean that two or more sets of each of the eight types of endurance and sprint training should be included in each training week. Including that many sets would be unwise and practically impossible—unwise because several of these types of training produce similar training effects and impossible because the time for energy replacement and tissue repair would be inadequate.

The various types of intense training should be considered in only four categories for purposes of weekly planning. The first category is aerobic capacity training, which includes basic endurance (En-1) sets of repeats, for example, 6 to 10 × 400, and sets of threshold endurance (En-2) training. The second category refers to training that is designed to improve aerobic and anaerobic muscular endurance. This category includes overload endurance (En-3) training, lactate tolerance (Sp-1) training, and race-pace (R-P) training. The third category is training designed to improve anaerobic power. Lactate production (Sp-2) and power (Sp-3) training are the two types in this group. The fourth category is recovery (R) training. These categories were used in planning mesocycles earlier in this chapter.

- *Although a particular training session should emphasize only one or two of these categories of training, each session should include a short time in the remaining one or two categories.* This objective can be accomplished by scheduling short sets of a particular type of training on days when that type is not included in a major set or by descending lower intensity repeat sets so that they end with a few repeats from more intense categories of training. For example, a basic endurance set of 20 × 100 can be descended to threshold (En-2), overload (En-3), or lactate tolerance (Sp-1) speed during the last one to five repeats of the set. Another way to do this is to swim the basic endurance repeats as 4 sets × 5 × 100 with the last one or two repeats of each set at more intense speed.
- *Basic endurance training should be included in nearly every training session of the week.* This type of training will generally make up the highest volume of training during most sessions, even though it may not be the emphasis.
- *Short sets of recovery training should be included in the daily schedule following each major set of intense anaerobic swimming.* In addition, one or two training sessions should be devoted primarily to recovery training each week.

Examples of Weekly Training Plans

With the suggestions from the previous section in mind, the following steps are suggested for planning a weekly training microcycle.

1. Choose a two-peak or three-peak weekly cycle.
2. Determine the placement of peak training sessions throughout the week. They should be placed so that no more than two peak sessions occur on successive days. A peak session should be followed by 1 1/2 to 3 days of nonpeak training sessions. Peak sessions should be scheduled on successive days only when there is no other way to arrange them within the week. Consecutive peak sessions are sometimes necessitated by such factors as weekend competitions, vacations, and examinations. When possible, however, peak sessions should be separated by 24 to 72 hr of nonpeak training.
3. Determine the types of training that will be emphasized during those peak sessions.
4. Place emphasized types of training at times during the week when athletes are most likely to be motivated and physically ready to perform that training correctly.

5. Include some basic endurance (En-1) and recovery (R) training in nearly every training session.

Some examples of weekly training programs for middle distance and distance swimmers, 100 and 200 sprinters, and 50 and 100 sprinters will be described in the following sections. I have provided explanations for the placement of the various types of training throughout the week to provide coaches and athletes with ideas for structuring microcycles for their own training programs.

Weekly Training Plan for Middle Distance and Distance Swimmers

The template in figure 17.24 is one way in which a weekly training cycle could be planned for middle distance and distance swimmers. This weekly plan is for the specific preparation period.

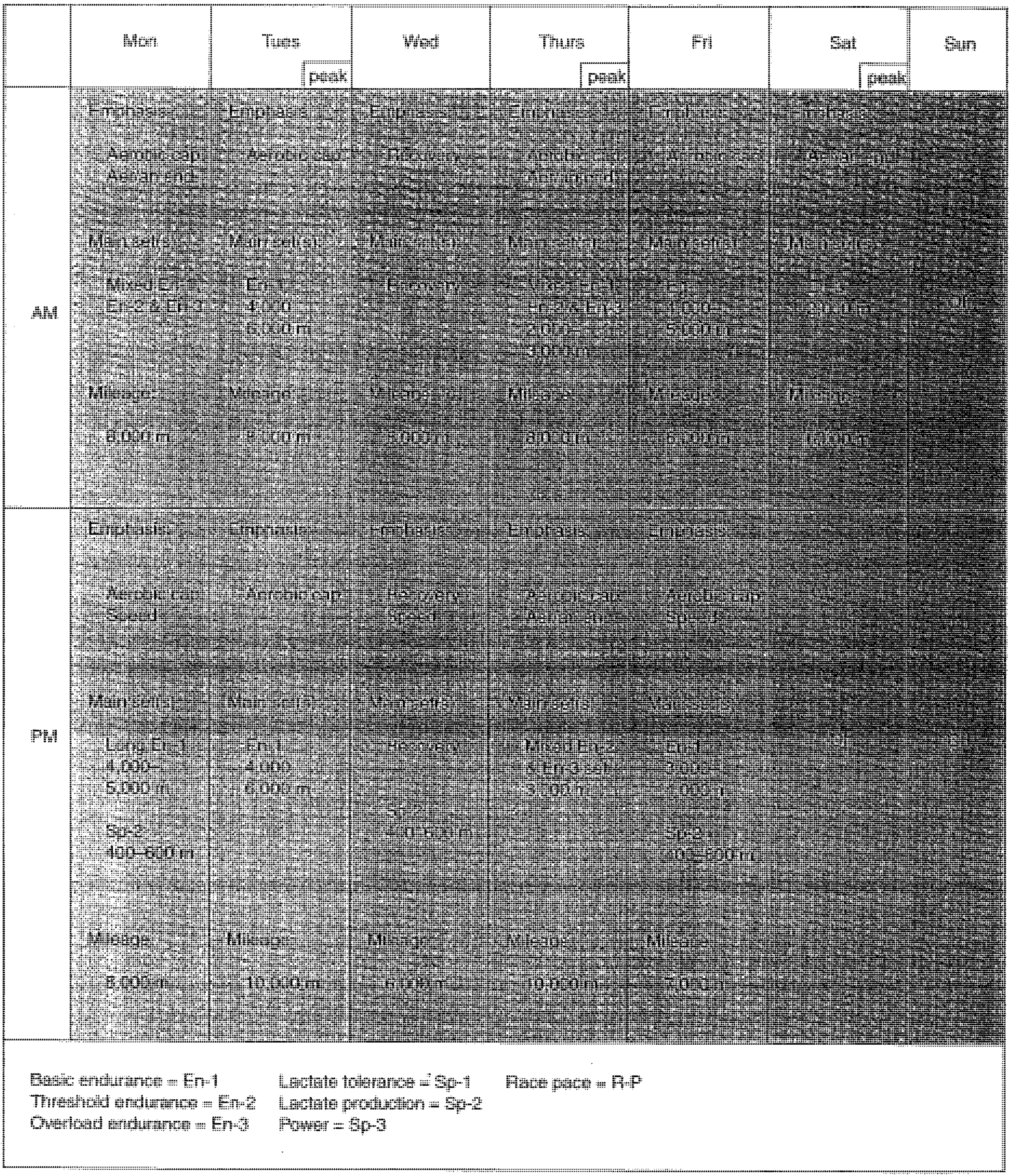
The week included three peak training sessions, scheduled for Tuesday afternoon, Thursday afternoon, and Saturday morning. An extra-long basic endurance (En-1) set was the major set for Tuesday. Its purpose was to overload aerobic capacity. Slow-twitch muscle fibers should have done most of the work that day, although some fast-twitch muscle fibers should also have been called into play because the set was so long that some slow-twitch muscle fibers should have become nearly depleted of glycogen.

The second major endurance set was planned for Thursday afternoon, thus providing 48 hr for replacing the muscle glycogen used on Tuesday. The major endurance swimming for Thursday was structured as a descending set that combined threshold (En-2) and overload (En-3) endurance training. The purposes were to improve the rate of oxygen consumption and lactate removal from both fast-twitch and slow-twitch muscle fibers and to improve aerobic and anaerobic muscular endurance in those fibers. The final major set of the week was scheduled 36 hr later on Saturday morning. That overload endurance (En-3) set was designed to improve aerobic capacity and aerobic and anaerobic muscular endurance, particularly in the fast-twitch muscle fibers. The overload endurance repeats were swum as a straight set in each swimmer's best stroke. Most of the remaining mileage during the peak training sessions was aimed at improving aerobic capacity, done as pulling, kicking, and swimming repeats at basic endurance (En-1) speed. Those sets were done in the athlete's main stroke or as mixed styles. The morning sessions on Tuesday and Thursday were made up of the same types of basic endurance (En-1) training.

Three sprint sets were also planned for the week to reduce the slowing effect of endurance training on the swimmers' rates of anaerobic metabolism. These lactate production (Sp-2) sets were scheduled for afternoon sessions on Monday, Wednesday, and Friday. The sprint sets were placed at these times for two reasons. The first reason was to reduce any interference they might have on muscle glycogen replacement by placing them at least 24 hr after major endurance sets. The second reason was to give athletes an opportunity to swim quality sprints on days when their endurance training was less voluminous and less intense.

A complete day of recovery training (R) was scheduled for Wednesday to allow for more replacement of muscle glycogen at midweek when it was likely to be low. Recovery training consisted of stroke drills, kicking, pulling, and mixed-stroke swimming, all at low intensity. A small amount of sprinting was also scheduled for Wednesday, but the small volume should not have interfered with the rate of muscle glycogen replacement on that day.

Two descending sets, combining basic (En-1), threshold (En-2), and overload (En-3) endurance training, were placed throughout the week to stress the oxygen consumption and lactate removal rates in the athletes' fast-twitch muscle fibers. Because these sets would reduce muscle glycogen in both fast- and slow-twitch muscle fibers, they were scheduled for Monday morning, after the athletes had been resting for 1 1/2 days,



	Mon	Tues peak	Wed	Thurs peak	Fri	Sat peak	Sun
AM	Emphasis: Aerobic cap. Aerobic end. Main sets: Mixed En-1, En-2 & En-3 Mileage: 6,000 m	Emphasis: Aerobic cap. Main sets: En-1 4,000– 6,000 m Mileage: 8,000 m	Emphasis: Recovery Main sets: Recovery Mileage: 5,000 m	Emphasis: Aerobic cap. Aerobic end. Main sets: Mixed En-1, En-2 & En-3 2,000– 3,000 m Mileage: 8,000 m	Emphasis: Aerobic cap. Main sets: En-1 4,000– 5,000 m Mileage: 6,000 m	Emphasis: [illegible] Main sets: 3,200 m Mileage: 10,000 m	[illegible]
PM	Emphasis: Aerobic cap. Speed Main sets: Long En-1 4,000– 5,000 m Sp-2 400–600 m Mileage: 8,000 m	Emphasis: Aerobic cap. Main sets: En-1 4,000– 6,000 m Mileage: 10,000 m	Emphasis: Recovery Speed Main sets: Recovery Sp-2 400–600 m Mileage: 6,000 m	Emphasis: Aerobic cap. Aerobic end. Main sets: Mixed En-2 & En-3 set 3,000 m Mileage: 10,000 m	Emphasis: Aerobic cap. Speed Main sets: En-1 3,000– 4,000 m Sp-2 400–600 m Mileage: 7,000 m	[illegible]	[illegible]

Basic endurance = En-1
Threshold endurance = En-2
Overload endurance = En-3
Lactate tolerance = Sp-1
Lactate production = Sp-2
Power = Sp-3
Race pace = R-P

Figure 17.24 An example of a weekly training plan for middle distance and distance swimmers. This plan is for the specific preparation period.

and for Thursday morning, following the day of recovery swimming on Wednesday. These descending sets should have been swum in the swimmers' main stroke or strokes.

Four additional basic endurance (En-1) training sets were scheduled for Tuesday morning and afternoon and for Friday morning and afternoon. These sets were to be completed at low intensity using a variety of strokes. They should also have included stroke drills and pulling and kicking repeats. This form of work would improve the delivery of oxygen to the muscles without excessively reducing muscle glycogen supply.

	Mon	Tues peak	Wed	Thurs	Fri	Sat peak	Sun
AM	Emphasis: Aerobic cap. Aerobic end. Main set(s): Mixed En-1, En-2 & En-3 2,000–3,000 m Mileage: 6,000 m	Emphasis: Aerobic cap. Main set(s): En-1 Mileage: 5,000 m	Emphasis: Recovery Main set(s): Recovery Mileage: 6,000 m	Emphasis: Aerobic cap. Aerobic end. Main set(s): Mixed En-1, En-2 & En-3 3,000–4,000 m Mileage: [illegible]	Emphasis: Recovery Main set(s): Recovery Mileage: 5,000 m	Emphasis: [illegible] Main set(s): Race pace 800–1,200 m Mileage: 6,000 m	[illegible]
PM	Emphasis: Aerobic cap. Aerobic end. Speed Main set(s): Sp-2 1,000–1,500 m Mixed En-1, En-2 & En-3 3,000–4,000 m Mileage: 5,000 m	Emphasis: Aerobic end. Main set(s): En-1 1,000 m Mileage: 6,000 m	Emphasis: Aerobic cap. Speed Main set(s): En-1 Sp-2 800–1,200 m Mileage: 6,000 m	Emphasis: Aerobic cap. Aerobic end. Main set(s): Mixed En-1 En-2 & [illegible] Mileage: 6,500 m	Emphasis: Aerobic cap. Speed Main set(s): En-1 Sp-2 1,000–1,500 m Mileage: 6,000 m	[illegible]	[illegible]

Basic endurance = En-1
Threshold endurance = En-2
Overload endurance = En-3
Lactate tolerance = Sp-1
Lactate production = Sp-2
Power = Sp-3
Race pace = R-P

Figure 17.25 An example of a weekly training plan for 100 and 200 sprinters during the specific preparation period.

Weekly Training Plan for 100 and 200 Sprinters

An example of a weekly training plan for 100 and 200 sprinters has been provided in figure 17.25. This plan is also for the specific preparation phase. Two peak training days occurred during the week, the first on Tuesday and the second on Saturday. Peak training sessions had not been defined in the same way for sprinters as they were for middle distance and distance swimmers; they were not the sessions that contained the greatest volume of endurance training. Instead, these sessions contained the largest volume of long anaerobic training, such as overload endurance (En-3), lactate tolerance (Sp-1), and race-pace (R-P) training. The mileage was lower during these sessions, but the degree of acidosis and muscle damage was greater. Training mileage may be greater during other training sessions, but those sessions will include less intense basic (En-1) and threshold (En-2) endurance training as well as lactate production (Sp-2) and power training (Sp-3).

The peak training session on Tuesday afternoon included an overload endurance (En-3) set that swimmers performed in their main stroke or strokes. This set was designed to improve the swimmers' aerobic and anaerobic muscular endurance, with more emphasis on the aerobic side of the equation. A major race-pace set was scheduled for the second peak session on Saturday morning. The purpose here was also to improve aerobic and anaerobic muscular endurance, emphasizing the anaerobic side of the equation. The placement of these sets provided the swimmers with 72 to 80 hr after each for repair of possible tissue damage.

Three lactate production (Sp-2) sets were also scheduled throughout the week, on Monday afternoon, on Wednesday afternoon, and on Friday afternoon. The major purpose for these sprint sets was, of course, to improve swimming speed.

Four sets of mixed endurance training, combining basic endurance (En-1), threshold endurance (En-2), and overload endurance (En-3) training, were scheduled for Monday morning and afternoon and Thursday morning and afternoon. These were not designed to be particularly long sets, and the major portion of the total distance was to be made up of basic endurance (En-1) swimming. The swimmers were instructed to descend to threshold (En-2), overload, and even race speeds for the final 400 to 800 m of these sets, and they were supposed to swim those fast repeats in their major stroke or strokes. The purpose for including these descending sets was to improve the aerobic capacity and lactate removal rates of all types of muscle fibers, particularly the swimmers' fast-twitch muscle fibers.

Two sessions were devoted to recovery training. The first was on Wednesday morning, and the second was on Friday morning. The first recovery training session followed the 2 days of training early in the week, and the second followed the intense Thursday training session.

Sets of basic endurance (En-1) training for the combined purpose of improving aerobic capacity and providing time for replacement of muscle glycogen and tissue repair were scheduled for Tuesday morning, Wednesday afternoon, and Friday afternoon. These sets provided some recovery time in preparation for the intense training that was scheduled for Tuesday afternoon, for both sessions on Thursday, and for Saturday morning. These sets were to be swum at the low end of the intensity range for basic endurance training in a variety of styles and drills.

Weekly Training Plan for 50 and 100 Sprinters

The weekly plan for 50 and 100 sprinters should include more sprinting and less high-intensity endurance training because, as indicated earlier, it is more important for them to improve their sprinting speed while gaining a reasonable amount of endurance than it is to gain a great deal of endurance at the expense of sprinting speed. An example of a training week for 50 and 100 sprinters is shown in figure 17.26. This training week was also designed for the specific preparation period.

Two peak training days were scheduled for the week. The first was on Wednesday afternoon, and the second was placed on Saturday morning so that the swimmers would have 60 to 72 hr after each for recovery and tissue repair. The emphasis on Wednesday afternoon was on improving aerobic and anaerobic muscular endurance. This was accomplished with a lactate tolerance (Sp-1) set. The set on Saturday morning was at race-pace speed. Athletes should have swum these sets in their main stroke or strokes. I might mention that the two major sets could have been interchanged in the weekly schedule without changing the training effect. Lactate tolerance sets could also have

	Mon	Tues	Wed peak	Thurs	Fri	Sat peak	Sun
AM	Emphasis Aerobic cap Aerobic end Main set Mixed En-1, En-2 & En-3 2,000–3,000 m Mileage 5,000 m	Emphasis Recovery Main set Recovery Mileage 4,000 m	Emphasis Aerobic cap Main set En-1 2,000–3,000 m Mileage [illegible]	Emphasis Recovery/Power Main set Recovery/Power Sp-3 400–600 m Mileage 4,200 m	Emphasis Recovery Main set Recovery Mileage 4,000 m	Emphasis [illegible] Main set Race pace R-P [illegible] m Mileage [illegible]	Off
PM	Emphasis Aerobic cap Speed Main sets Sp-2 1,000–1,500 m En-1 2,000–3,000 m Mileage 5,000 m	Emphasis Aerobic cap Power Main sets En-2 2,000–3,000 m Sp-3 300–600 m Mileage 6,000 m	Emphasis Aerobic cap Main set Sp-1 600–800 m Mileage 4,000 m	Emphasis Aerobic cap Aerobic end Main sets Mixed En-2 & Sp-1 2,000–3,000 m Mileage [illegible]	Emphasis Aerobic cap Speed Main set Sp-2 1,000–1,500 m En-1 Mileage 5,000 m	Off	[illegible]

Basic endurance = En-1
Threshold endurance = En-2
Overload endurance = En-3
Lactate tolerance = Sp-1
Lactate production = Sp-2
Power = Sp-3
Race pace = R-P

Figure 17.26 An example of a weekly training plan for 50 and 100 sprinters during the specific preparation period.

been scheduled for both Wednesday and Saturday at this time of the season with race-pace swimming saved for later in the season.

A major lactate production set (Sp-2) was placed on Monday afternoon and another on Friday afternoon. Two additional sprint sets of the power (Sp-3) type were also planned for the week. They were placed on Tuesday afternoon and Thursday morning. The Sp-2 and Sp-3 sets were scheduled for sessions in which the remainder of the training mileage was at a low intensity so that swimmers would be more likely to sprint at maximum effort. Athletes should have swum these sets in their main stroke or strokes.

Two descending endurance sets, combining basic endurance (En-1), threshold endurance (En-2), overload endurance (En-3,) and a few final repeats at lactate tolerance (Sp-1) training speed were scheduled throughout the week to provide some stimulation for improvement of oxygen consumption and lactate removal in the athletes' fast-twitch muscle fibers. These sets were placed on Monday morning and Thursday afternoon. Athletes should have swum the faster portions of these sets in their main stroke or strokes. The descending sets could just as easily have been scheduled elsewhere during the week without interfering with recovery. Placing them just before or after the major lactate tolerance or race-pace sets of the week, however, would not have been wise.

Recovery sessions were scheduled on Tuesday morning, Thursday morning, and Friday morning. Their placement at these times would aid in replacement of muscle glycogen and repair of tissue damage after the intense training that had taken place during the previous training sessions. The athletes had completed an intense descending set on Monday morning and a long sprint set on Monday afternoon. They swam an intense lactate tolerance (Sp-1) set on Wednesday afternoon and another intense descending set on Thursday afternoon.

Basic endurance training was combined with sprinting on Monday, Tuesday, and Friday afternoons, and it was the major form of training on Wednesday morning. These basic endurance sets should have been completed at the low end of the intensity range. They should have been nonspecific as well, including a variety of strokes, drills, and pulling and kicking repeats.

Exceptions to General Weekly Plans

Cyclic weekly training plans like those just presented should normally be used throughout the season because they are structured primarily with concern for energy replacement and tissue repair. On occasion, however, these plans should be altered to prepare athletes for multiday competitions and competitions in which the preliminary heats are followed by final events later in the same day. For example, middle distance and distance swimmers should on occasion swim two overload endurance (En-3) sets or race-pace (R-P) sets during successive workouts to prepare themselves to swim preliminaries and finals in the same day. They should also schedule two overload (En-3) or race-pace (R-P) sets on successive days to prepare for multiday competitions. Similarly, sprinters should swim two successive lactate tolerance (Sp-1) or race-pace (R-P) sets when they are preparing to swim in same-day preliminary and final races or multiday competitions.

Exceptions like these should be used infrequently because they are not the best way to train for physiological improvement. The mind-set, confidence, and mental toughness required to compete well in multiple races over several days can be developed quite rapidly. Therefore, the desired results can be achieved by scheduling sets in the manner described in the previous paragraph once every week during the last 3 or 4 weeks of the race preparation phase.

Weekly Planning for One Training Session per Day

Swimmers who train once per day are not as likely to become glycogen depleted because they get approximately 22 hr for recovery after each training session. The problem they will have is fitting all the various types of training into six sessions per week. The plan in figure 17.27 is an example of how the various types of training could be scheduled throughout the week when a swimmer is training once per day.

Daily Planning

The types of major training sets that should be included on a specific training day will be fairly well established once the weekly plan has been formulated, but each daily

	Mon	Tues peak	Wed	Thurs peak	Fri	Sat peak	Sun
PM	Emphasis: Aerobic cap Aer/an end Main set(s): Mixed En-1, En-2 & En-3 Mileage: 8,000 m	Emphasis: Aer/an end Speed Main set(s): Sp-2 600–800 m En-3 1,500 m Mileage: 8,000 m	Emphasis: Recovery Main set(s): Recovery Mileage: 6,000 m	Emphasis: Aer/an end Speed Main set(s): Sp-2 600–800 m En-3 1,500 m Mileage: 8,000 m	Emphasis: Aerobic cap Aer/an end Main set(s): Mixed En-1, En-2 & En-3 Mileage: 7,000 m	Emphasis: Aer/an end Speed Main set(s): Sp-2 400–600 m R-P 800–1,200 m Mileage: 6,000 m	Off

Basic endurance = En-1
Threshold endurance = En-2
Overload endurance = En-3
Lactate tolerance = Sp-1
Lactate production = Sp-2
Power = Sp-3
Race pace = R-P

Figure 17.27 An example of a weekly training plan for swimmers who are training once per day. This particular plan was designed for 100 and 200 sprinters during the specific preparation phase of the season.

training plan should also include minor sets and other training activities. A list of the types of training sets and activities that should be included in most training sessions follows.

- Land drills for improving muscular strength, endurance, flexibility, or skills
- An adequate swimming warm-up
- Instruction and drills
- A main set designed to improve aerobic capacity, aerobic and anaerobic muscular endurance, anaerobic power, or some combination of those three components of training
- Additional secondary sets designed to improve physiological or biomechanical weaknesses, that is, pulling and kicking
- Additional secondary sets designed to work on some important competitive skills, for example, dolphin kicking underwater
- Several secondary sets designed to improve aerobic capacity, aerobic and anaerobic muscular endurance, and anaerobic power
- Recovery training
- A swim-down

After the various sets and activities have been selected for a training day, their placement becomes the next task in daily planning. Although the placement of sets and activities should generally observe sound physiological principles, other factors must sometimes be considered when planning the training day. These exceptions serve the purpose of preparing athletes for competitive situations. Both the general rules for planning daily training as well as when and where exceptions should be made will be described in this section.

As a rule, morning training sessions should be less intense than afternoon sessions. The morning sessions should include basic endurance training, stroke drills, and kicking and pulling drills. Some fast endurance training and sprinting should be included in a few of the morning sessions of each training week, however, to prepare athletes for maximum efforts during preliminary sessions, which are usually held during the morning hours.

The warm-up, of course, should be the first item planned for any training session. The warm-up should be of sufficient length to stimulate oxygen delivery to the muscles, increase their elasticity and range of motion, and allow recovery from land training, if needed. At a minimum, the warm-up will require 10 to 15 min.

Instruction and swimming drills should most often occur early in the training session when athletes are not fatigued and when their motivation and concentration are high. The exception would be when the purpose of the instruction and drills is to help swimmers maintain their skill in the face of accumulating acidosis. In that case, the instruction and drills should occur later in training after the swimmers have become fatigued. Athletes should be encouraged to swim at race speed while concentrating on the use of correct technique.

The main set should usually occur near the end of the training session, particularly if it is long or intense. Normally, it should not be placed early in the training session. The effort required in a main set will usually produce acidosis, and it may deplete muscle glycogen substantially. Therefore, a long set of recovery training would be needed afterward before athletes would be ready for additional intense training. Long recovery swims in the middle of a training session use valuable time that can be put to better use when the main set occurs later in the training session.

Secondary sets designed to improve speed or power (that is, Sp-2 and Sp-3) should usually be placed early in the training session so that acidosis or muscle glycogen depletion will not interfere with athletes' efforts to swim fast. Many coaches and athletes, however, like to end their workouts with sprinting. An adequate amount of low-intensity basic endurance (En-1) or recovery training should precede sprint training scheduled near the end of a training session. An adequate amount would be 10 to 20 min of low-intensity swimming.

Secondary sets designed to improve aerobic and anaerobic muscular endurance, such as overload endurance (En-3) and lactate tolerance (Sp-1) training, should usually be placed late in a training session. The only exception would be when the training session has been designed to simulate and prepare athletes for a competitive situation in which they will swim several events during one competition. In that case, each overload or lactate tolerance set should be followed with 10 to 20 min of recovery training before another fast swimming set takes place.

Basic endurance training completed in other strokes or as kicking and pulling drills should be placed early in a training session if it is to be swum near the top of that range. This training can be placed in the middle or late portion of the session if it is to be done at the low end of the intensity range. Low-intensity basic endurance training will reduce acidosis in swimmers' muscle fibers, particularly their fast-twitch muscle fibers, while at the same time stimulating oxygen delivery by the circulatory and respiratory systems and oxygen consumption by the slow-twitch muscle fibers. For that reason, low-intensity basic endurance training performed near the aerobic threshold can be used for recovery and training.

Athletes can do recovery training between main sets and between intense secondary sets to relieve acidosis before they swim additional sets of an intense nature. Every training session should finish with a swim-down period of 10 min or more of recovery swimming to hasten the removal of lactic acid from muscles and the delivery of nutrients to them.

Land drills for improving flexibility and skills are best done before training in the water begins. Athletes should be fresh when learning skills so that they can concentrate better, and flexibility training will prepare them to perform their swimming with greater efficiency.

The placement of strength and endurance land drills is not so easily determined. An advantage to scheduling this training before in-water training is that swimmers will not be fatigued and will therefore be able to train more intensely. The major disadvantage to performing land endurance training before in-water training is that the former type of training tends to increase acidosis. Consequently, it can adversely affect the quality of the in-water training.

Performing land resistance training after the in-water portion of a training session presents a different problem. Athletes are usually not able to train at 100% during land training after an intense session of in-water swimming. The advantage, obviously, is that the land-resistance training will not interfere with the quality of the in-water training.

The disadvantages of performing land resistance training either before or after in-water training can be overcome simply by providing adequate recovery time. If on-land training is conducted before the in-water portion of the training session, athletes should be provided enough time to recover from acidosis. A good warm-up and some low-intensity basic endurance repeats early during the in-water training session can accomplish this objective. Similarly, the intensity of land-resistance training conducted afterward can be improved by providing a long recovery swim-down following in-water training so that most of the lactic acid will be removed from the athletes' muscles before they begin the land training. Equipment availability rather than physiological efficacy often determines the time when land resistance training is performed. Therefore, it is good to know that providing adequate recovery time can overcome the disadvantages of conducting that training either before or after in-water sessions.

An example of a typical daily training session is displayed in figure 17.28. This session is designed primarily to improve the aerobic and anaerobic endurance of middle distance and distance swimmers, with some basic endurance (En-1) and lactate production (Sp-2) included.

The session begins with a warm-up of 800 m done in segments, starting with two 300 repeats, one swimming, one pulling. These are followed by four 50 m repeats on a send-off time of 1 min. Swimming speed should progress to a basic endurance level during the 300 repeats so that the warm-up serves a training purpose as well. The 50s should be descended to a reasonably fast speed to prepare the swimmers' bodies for fast swimming later.

The next set consists of stroke drills completed at low-intensity basic endurance speed. The purpose of this set is to improve stroke mechanics and endurance without causing extreme fatigue. The set was placed early in the training session rather than later so that the athletes would concentrate on performing their strokes correctly and not swim the set at recovery speed. That might have happened if this set had been placed after one of the more intense repeat sets that came later.

A lactate production set was placed next so that the swimmers could sprint before they became too fatigued to swim at top speed. Basic endurance kicking for 1,200 m was scheduled next. The purpose was to improve leg endurance.

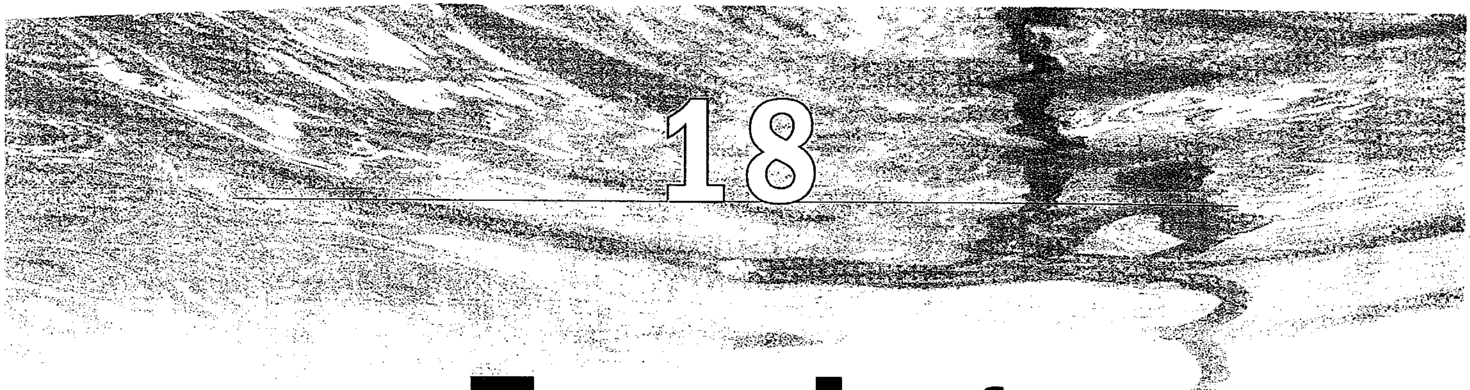
1. Warm-up:
    Swim 300 m
    Pull 300 m
    Swim 4 × 50 on 1 min
    800 m
2. Swim stroke drill:
    10 × 100 on 2 min
    25 right, 25 left, 100 both
    1,000 m of basic endurance swimming
3. Lactate production training:
    Swim 6 × 50 on 3 min
    Swim easy 150 m after each 50
    300 m of lactate production training
    750 m of recovery swimming
4. Kick at basic endurance speed:
    6 × 200 m on 4 min
    1,200 m
5. Pull a basic endurance set:
    2 × 1,000 on 12 min
    2,000 m
6. Swim overload endurance set:
    8 × 200 on 2:45
    1,600 m
7. Swim recovery set:
    4 × 200 m on 2:45
    Start at a basic endurance speed and swim each 200 slower until recovered
    800 m of recovery swimming

Total = 8,450 m

Figure 17.28 An example of a daily training session for middle distance and distance swimmers.

The next set was 2,000 m of basic endurance pulling. The purpose was to improve aerobic capacity without taxing the fast-twitch muscle fibers.

The main set for this session was eight 200 m swims at overload endurance (En-3) speed. This set was placed late in the session so that the acidosis and fatigue it produced would not interfere with correct performance in the earlier sets. The set could have been positioned earlier had it been followed by a recovery set. That arrangement would have allowed the swimmers to reduce their acidosis before they had to swim fast again. The final segment of the training session was 800 m of easy swimming to aid recovery.



18

Tapering

New in this edition:

- Interpretation of recent studies concerning taper length as well as intensity, frequency, and volume of training during the taper

Before 1960 the prevailing wisdom was that athletes should increase their training to its greatest volume and intensity just before their most important meet of the season. Coaches believed that such a procedure would bring athletes to their peak of physical performance for the meet. We realize now that this practice worked in reverse. It caused swimmers to enter those meets in a fatigued state in which peak performance was unlikely to occur. A different system has been used during the past three decades. Now swimmers finish their most intense training a few weeks before the major meet of the season and then go through a period of reduced training that supposedly allows them to recover and superadapt. That period of reduced training is known as the *taper*.

Presently, more mystique than fact surrounds tapering procedures. Only in the last decade have researchers conducted a significant number of studies on tapering. As a result we are beginning to know more about the physiological reactions associated with tapering. Still, the exact nature of the physiological changes that result in better performance after a taper continues to be a mystery. The purposes of this chapter are to articulate the results of some of the studies that have been conducted on tapering and to suggest some tapering procedures.

Types of Tapers

The various types of tapers used by competitive swimmers can be separated into three categories. First is the *major taper,* a procedure used to prepare swimmers for the most important meets when their best performances of the training year are desired. Commonly 2 to 4 weeks in length, the major taper is the longest of the three types.

The usual practice is to plan one major taper per season. Experts suggest that athletes should plan for only two to three major tapers for a single training year (Bompa 1999). This is logical advice. Tapering for 2 to 4 weeks several times per year can cause swimmers to lose valuable training time. For example, conducting five major tapers per year instead of three would reduce yearly training time by nearly 30%.

The second category is the *minor taper*, which is usually 1 week long or shorter and used when a good performance is desired in the middle of a particular season. Coaches have conflicting opinions about the advisability of minor tapers. Some feel that they interfere with training and prevent swimmers from reaching peak performances at the end of the season. Others believe that taking occasional breaks from training and swimming fast in the middle of the season is good for swimmers both physiologically and psychologically. Minor tapers provide an opportunity to recover and adapt physiologically. Psychologically, swimming fast in early and midseason can sometimes improve an athlete's confidence and motivation.

The third taper category is a *retaper.* This type of taper is used when two important meets are held within a period of 3 to 5 weeks. The ability to retaper and maintain or even improve upon performances after a major taper is becoming increasingly important to swimmers. The qualifying standards for major competitions have become so high that many athletes must go through a major taper for an early competition to qualify for a more important competition later. For example, many U.S. collegiate swimmers must go through a major taper at their conference championship to achieve the qualifying standard for the NCAA championship, which is usually scheduled 2 to 4 weeks later. Additionally, the number of major competitions held in a single season has increased considerably in recent years. Athletes often find themselves going from national, to world regional, and then on to major international championships within a period of 1 or 2 mo. At one time, coaches believed that athletes could maintain their ability to swim at a peak level for only a few weeks. The proliferation of major meets has shown that swimmers can maintain peak performance over a considerably longer time.

Researchers have suggested that the duration of a peak performance can be maintained for 7 to 10 days without additional training (Ozolin 1971 cited in Bompa 1999) and that two or three subsequent peaks can be achieved within the space of 1 to 2 consecutive mo if time is available for some training between each peak (Matveyev, Kalinin, and Ozolin 1974). Athletes should understand, however, that a solid background of training is essential to maintain peak levels of performances over a period of several weeks. Swimmers who train on a yearly basis will be able to maintain peak performance longer, and they will be able to peak more times in a short period than those who train for only part of the year.

Performance Improvement With Tapering

Typically, swimming times will improve 2% to 4% from earlier performances following a major taper. Certain athletes will improve considerably more. Average improvement for swimmers in a variety of events from 100 to 1,500 m have been reported at 2.8% (Anderson et al. 1992) and 3% (Costill et al. 1985) in separate studies. The swimmers in these studies also shaved down at the end of the taper; consequently, it is difficult to determine how much of the improvement resulted from the taper and how much resulted simply from shaving down. Houmard and associates (1994) tried to resolve this question by studying the effects of tapering on runners. They reported an average improvement of 3% for a group of runners who competed in a 5K race. D'Aquisto and coworkers (1992) used another approach. They tapered a group of swimmers who then competed without shaving down. The subjects in their study improved between 4% and 8% for distances of 100 and 400 m.

Physiological Changes During the Taper

Some experts have attributed a major portion of the taper effect to supercompensation of the muscles' glycogen supplies. This assessment is probably incorrect. The amount of glycogen stored in muscle will increase between 8% and 35% even in the absence of special carbohydrate loading procedures (Neary et al. 1992; Sheply et al. 1992), but it probably does not play a major role in performance improvements that accompany tapering in swimming. Although glycogen supercompensation has been shown to improve performance in endurance running events (Bergstrom et al. 1967), the same effect is not likely in our sport because competitive swimming events are considerably shorter. The amount of glycogen depleted from muscles would probably be in the neighborhood of only 30% to 40% during even the longest competitive swimming event, 1,500 m. Consequently, swimmers with only normal amounts of glycogen stored in their muscles would be able to supply enough energy for those events. Furthermore, muscle glycogen increases could not explain why swimmers require at least a week to produce a taper effect. Rest of 2 to 3 days is adequate for glycogen loading to take place in muscles.

Although glycogen supercompensation probably cannot explain the improved performance of swimmers after a taper, it may explain the heavy, sluggish feeling commonly reported by them during the 1st week of a taper. Three grams of water are stored with every gram of additional carbohydrate. Consequently, an increase of 30% in muscle glycogen, which could easily occur during the 1st week of a taper, could cause an additional 108 g of water storage, which in turn might be accompanied by an increase in weight and a heavy, bloated feeling.

Some experts have suggested that the taper effect may be due to supercompensating effects of other physiological mechanisms that are similar to those of glycogen loading. Although this explanation is vague, it may nevertheless be the best one currently available.

The supercompensation effect accompanying tapers that has been reported most often in the scientific literature has been an increase in muscular power. Costill and his associates (1985) reported an increase in muscular power of 24.6% after 14 days of tapering. Power was measured in the water with a tethered swimming apparatus. These researchers also reported an increase of power with stroke-simulated movements on land. Power measured on a biokinetic swim bench increased an average of 17.7%. Other studies conducted with stroke-simulated devices have reported increases in muscular power 5% to 19% after tapering (Anderson et al. 1992; Sheply et al. 1992).

A final physiological change reported during the taper period is a decrease in creatine kinase (Costill et al. 1985; Yamamoto, Mutoh, and Miyashita 1988). A large creatine kinase concentration in muscles is believed to indicate muscle damage; therefore, a reduction in the concentration of this enzyme could mean that damage was repaired and that muscle strength and power had increased during the taper.

A recent study by Trappe and associates (1998) sheds some light on the mechanisms that may be responsible for this increase of muscular strength and power. They found that muscle contraction speed, force, and power all increased after a taper period of 21 days. Muscle contraction speed increased by 37% in slow-twitch muscle fibers and by 55% in fast-twitch fibers. Force and power did not change in slow-twitch muscle fibers, but muscular force increased by 15% in fast-twitch muscle fibers, and power increased by 114%. The swimmers' performance times in their events improved an average of 4% after tapering.

Research results have been contradictory concerning changes during the taper that might improve aerobic capacity and aerobic and anaerobic muscular endurance. Maximum oxygen uptake apparently does not increase during the taper (Anderson et al. 1992; Houmard et al. 1994; Sheply et al. 1992; Van Handel et al. 1988). Muscle buffering capacity does not increase during the taper either (Costill et al. 1985), but that particular measurement has been reported in only one study with swimmers. The result cannot be considered conclusive until verified by additional research.

The recent scientific literature has reported two additional physiological changes that occur following a taper: an increase of blood volume and an increase of red blood cells (Burke et al. 1982; Rushall and Busch 1980; Sheply et al. 1992; Yamamoto, Mutoh, and Miyashita 1988). Both of these increases should improve oxygen delivery to the muscles. They are, therefore, in conflict with the finding that maximal oxygen consumption does not increase following a taper.

Results have been contradictory concerning the effect of tapering on the anaerobic threshold. Blood lactate levels for standardized submaximal efforts did not change during the taper in two studies (Anderson et al. 1992; Van Handel et al. 1988). Costill and his associates (1985), however, reported a 13% reduction in blood lactate for a standardized submaximal 200 yd swim after tapering. Likewise, D'Acquisto and his coworkers (1992) reported reductions in blood lactate of 25% and 32% at two different swimming velocities after tapering. The group of researchers led by D'Acquisto (1992) also reported that swimming economy improved by 7% to 15% and heart rates decreased by 8% to 26% at standardized submaximal swimming speeds. The swimmers were not shaved in the study by D'Acquisto and associates (1992); therefore, those results did not occur because of reduced drag. Their results suggest that the energy cost for swimming at submaximal speeds decreases during the taper. This effect may in turn provide greater endurance for maximum efforts.

Let me summarize the results of the investigations just mentioned. Currently, it appears that tapering will increase the strength and power of muscle fibers. This effect is most pronounced in the fast-twitch muscle fibers. Maximal oxygen consumption does not increase by tapering. Nevertheless, indications are that aerobic endurance improves, perhaps because swimming efficiency improves after resting so that the oxygen requirement of swimming at a particular speed decreases. Still to be determined are the effects of tapering on lactate removal during exercise and on buffering capacity. Any improvements in either should improve performance.

Tapering Procedures

The essence of a good taper is to have enough of a break for restoration to take place, and perhaps for supercompensation of certain physiological mechanisms to occur, while at the same time not resting so long that valuable adaptations to training are lost. Several questions arise. How long can a taper be continued without losing adaptations? How much can weekly and daily training volumes be reduced without losing adaptations? How much can training intensity and frequency be reduced without losing adaptations? I will discuss these questions in the next five sections.

Taper Duration

Taper durations ranging from 1 to 4 weeks have been reported to produce good results with swimmers. Yamamoto, Mutoh, and Miyashita (1988) reported that the positive physiological changes in blood volume, red blood cells, and creatine kinase that take place during a taper occur in the first 7 days of a 14-day taper. D'Acquisto and coworkers (1992) reported no difference in the amount of performance improvement and no significant loss of certain physiological measures for two groups of swimmers who tapered 2 weeks and 4 weeks respectively. In contrast, Costill and associates (1985) reported that $\dot{V}O_2$max, the anaerobic threshold, and muscle power all deteriorated after a group of swimmers tapered for 4 weeks. In agreement with those results, Neufer and his coworkers (1988) reported a significant increase in blood lactate of 1.8 mmol/L following a standardized 200 yd swim after 4 weeks of reduced training. Training mileage was reduced by approximately 80% for 4 weeks in that study, and training frequency was cut in half. The normal weekly total of 54,000 yd for the swimmers (9,000 yd per day, 6 days per week) was reduced to 9,000 yd (3,000 yd per day, 3 days per week). Disagreeing with those results, Mujika and his associates (1996) studied the effect of tapering periods of 3, 4, and 6 weeks on swimming performance. The swimmers improved their performance significantly with the 3- and 4-week tapers but experienced decrements in performance after 6 weeks of tapering.

From these results, it appears that a taper effect can be achieved within 7 to 14 days and maintained for an additional 14 days. These generalizations do not take into account individual reactions of athletes. Athletes who recover fast and athletes who have maintained a good training balance can probably achieve a taper effect within 7 to 14 days. Athletes, particularly sprinters, who do not recover as quickly and athletes who have experienced severe reductions in anaerobic power may require longer taper periods to achieve maximum performance. Indeed, in the study cited earlier (Mujika et al. 1996) the optimum taper duration for various athletes was between 12 and 32 days.

Training Balance and Tapering

In my experience, training imbalances that occurred during the regular season caused some athletes to require longer tapers than others did. Specifically, swimmers may do too much intense endurance training or too much intense sprinting during the season. Either of these training imbalances can result in one or the other of the following reactions. Those athletes who do too much intense endurance and sprint training may reduce their anaerobic power to the point where they do not possess the speed to swim the early portions of their races at competitive speeds. The second reaction is the reverse of the first. Swimmers who do too little endurance training may increase their anaerobic power so much that they tend to produce high levels of lactic acid at slow speeds. When that happens they will incur severe acidosis at slower speeds.

We have all known athletes who swam much faster several days or even several weeks after a major competition. Usually these athletes had experienced one of the two training imbalances just mentioned. In the first case, their anaerobic power may have been depressed so much that it could not recover to a normal level by the time of the first major meet. Consequently, these swimmers were not able to produce a season-best performance at that meet. After a few additional weeks, however, anaerobic power returned to normal, and they were able to swim considerably faster. This result most often occurs when athletes who were mistrained engaged in some basic endurance training for a few weeks after their major competition. The basic endurance training probably maintained their aerobic capacity with reduced intensity so that they were able to achieve a season-best performance after they regained their anaerobic power.

The same situation can occur when too much intense endurance training has suppressed aerobic and anaerobic muscular endurance. An overabundance of high-intensity endurance training may cause some swimmers to enter their first major competition with such a high rate of anaerobic metabolism that they accumulate large amounts of lactic acid in their muscles at slow swimming speeds. In their case, a few additional weeks of basic endurance training may reduce their rate of anaerobic metabolism to the point where they are able to swim the early portions of their race at the same speed with less acidosis. As a result, they will be able to swim the later portions at a faster average speed.

When the delicate balance between endurance and sprint training has been managed well during the regular season, swimmers have a good chance of tapering well within 1 to 3 weeks. When it has not, they may need an additional 1 or 2 weeks of taper before they can produce good times.

Training Intensity, Volume, and Frequency During the Taper

During the taper, volume, frequency, and intensity should decrease to permit athletes to recover from the weeks and months of training. Athletes cannot rest completely, however, or they will lose their training adaptations. Coaches and athletes must decide how much and how long to reduce each of these three factors.

Training Intensity

Maintaining training intensity at or near pretaper levels seems to be the most important factor in achieving peak performances at the end of the taper. In other words, athletes cannot simply swim easy during a taper. They must spend some time training at normal season speed if they wish to maintain their training adaptations. Sheply and associates (1992) put three groups of cross country and distance runners through three tapering procedures. All groups tapered for 7 days. Runners in the first group, the high-intensity taper group, reduced their training volume by 90% during this time but ran a short series of 500 m runs every day at 120% of $\dot{V}O_2max$. The second group, the high-volume taper group, reduced their training volume by only 65% and did no fast running. Instead, they completed their reduced training mileage at an intensity of approximately 60% of their rates of maximum oxygen consumption. The third group rested completely, doing no running during the taper period. All groups were tested with runs to exhaustion before and after the taper. The high-intensity group improved 22% after tapering. The other groups showed no improvement despite the fact that they increased their muscle glycogen and muscular power as much as the high-intensity group did. The high-intensity group increased their blood volume and red blood cells, whereas the other two groups did not. These changes may have accounted in part for the improvement of the high-intensity group.

The results of several other studies support the finding that athletes must maintain a certain minimum level of training intensity during a taper. In other studies with runners and swimmers, athletes improved their performances after tapering only when they maintained the intensity of their endurance training above 90% of $\dot{V}O_2max$. This would be at anaerobic threshold speeds or higher (Anderson et al. 1992; Costill et al. 1985; Houmard 1991; Houmard et al. 1994; Sheply et al. 1992.). In a series of studies by Hickson and associates (Hickson and Rosenkoetter 1981; Hickson et al. 1982; Hickson et al. 1985), performance deteriorated for groups of subjects who reduced their training speeds by one-third and two-thirds. The group that reduced training speed by one-third showed a 21% reduction in running and cycling times to exhaustion (184 min before versus 145 min after). The group that reduced training speed by two-thirds was 30% worse (202 min before versus 141 min after), although that effect did not occur until the group had been tapering for 5 weeks.

Keeping training intensity near the anaerobic threshold (greater than 70% $\dot{V}O_2max$) can apparently maintain endurance for up to 5 weeks. Of course, the goal is to improve performance, so it is probably better to continue some endurance training intensity above the anaerobic threshold (greater than 90% of $\dot{V}O_2max$) because doing so seems to result in improved performance following a taper. Troup (1989) suggests that swimmers should perform between 12% and 15% of the daily training volume in excess of anaerobic threshold speed during a taper.

Weekly Training Volume

Coaches have intuitively used reductions of as little as 30% and as much as 90% during tapers. In studies in which the performance of swimmers improved after a taper, reductions in training volume were between 60% and 90% of season maximums (Costill et al. 1985; D'Acquisto et al. 1992). The research suggests that training volumes should decrease 80% to 90% during short tapers (less than 10 days) and be maintained at 60% to 70% of normal during longer tapers. In one study a 62% reduction in weekly training volume did not improve performance after a 7-day taper. In contrast, performance improved by 22% in a run to exhaustion when training volume was reduced by 90% over the same period (Sheply et al. 1992). In another study, a reduction in training volume of 85% for 7 days improved performance by 3% on a 5K run (Houmard et al.

1994). In contrast to those results, the performance of swimmers improved in several studies in which training volume was reduced by 65% to 80% for tapers that were 2 to 4 weeks long (Anderson et al. 1992; Costill et al. 1985; D'Acquisto et al. 1992; Mujika et al. 1996).

Daily Training Volume

Troup (1989) reported that performance could be maintained for up to 5 weeks even when the duration of daily training was reduced from 3 hr per day to 1 hr per day if training frequency remained at 6 days per week and a portion of the training was performed faster than anaerobic threshold speed. The results of a study by Hickson and coworkers (1982) support this finding. They showed that endurance could be maintained with a 35% reduction in daily training duration if weekly training frequency was maintained at 6 days per week. Endurance was also maintained for events lasting 2 min or less when training duration was reduced by 68%, but performance in longer events was 10% worse. Hickson and his coworkers also reported that athletes could maintain their performance for up to 15 weeks as long as they maintained training at 60 min per day for 4 days of each week.

Training Frequency

Research findings about training frequency and tapering are more ambiguous than the results of studies about the other two factors. The results of several studies show that endurance training adaptations can be maintained for several weeks if training frequency is maintained at 3 days per week or more (Bryntesson and Sinning 1973; Hickson and Rosenkoetter 1981; Houmard et al. 1989; Neufer et al. 1987). Muscular strength and anaerobic power, however, can apparently be maintained with lower training frequency. Muscular strength on land can be maintained for several weeks with only one training session per week (Graves et al. 1988), and anaerobic capacity has been maintained for up to 15 weeks when training frequency was reduced to two sessions per week (Hickson and Rosenkoetter 1981).

Despite those findings, Neufer and associates (1987) found that swimming power in the water declined when training frequency dropped below 3 days per week. The researchers reduced training frequency from 6 days per week to 3 days per week for one group of swimmers and to 1 day per week for another group. After 4 weeks, swimming power and distance per stroke were significantly lower in the group that trained only 1 day per week, but the group that trained 3 days per week maintained power and distance per stroke at pretaper levels. The authors felt that swimmers may lose their feel for the water when training frequency decreases too drastically.

Although the available research indicates that swimmers can maintain training adaptations with training frequency at 3 days per week, I suggest a frequency of 5 to 6 days per week to safeguard against loss and perhaps to produce supercompensating effects. The reasoning behind this recommendation is that although athletes can maintain training adaptations by training 3 days per week, 1 to 3 additional days of training each week may produce supercompensating effects that will improve performance. Training frequencies were maintained at 4 to 6 days per week in studies that found performance improvement after tapering (Anderson et al. 1992; Costill et al. 1985; Houmard 1991; Sheply et al. 1992).

Gradual Versus Drop Tapers

Gradual tapers are those in which training mileage progressively decreases from the start to the end of the taper. Training mileage is reduced dramatically at the beginning of a drop taper and remains at that low level for the remainder of the time. Most of the studies cited earlier used drop tapers, although that may not have been the best procedure to use. One study compared gradual tapers with drop tapers and found the gradual taper superior. A group of triathletes improved 11.8% on a 5K run after a 10-day gradual taper, whereas a second group improved only 3% by using a drop taper (Zarkadas, Carter, and Bannister 1994).

Despite those results, in some situations a drop taper may be superior to a gradual taper. A drop taper is probably the best procedure to use for short tapers, those of 7 days or less, because a reduction in mileage of even 80% or 90% is unlikely to cause a loss of endurance in a period of such short duration (Houmard et al. 1994; Sheply et al. 1992). A gradual procedure is probably the best choice for longer taper periods, however, because athletes are more likely to maintain endurance by keeping their training mileage at a moderate level during the first 1 or 2 weeks of the taper. In addition, the gradual reduction in training mileage may help athletes peak at the end of the taper when the greatest reduction in mileage takes place.

Tapering Suggestions

I will provide some suggestions for conducting tapers in this section. Table 18.1 summarizes these suggestions.

I believe that a major taper should be 2 to 3 weeks in length for distance, middle distance, and sprint swimmers. I suggest, however, that the major taper be preceded by a pretaper period of 1 to 2 weeks. The purpose of the pretaper is to help coaches assess the level of fatigue and possible training imbalances for each swimmer. Coaches can then establish the duration and structure of the major taper to provide a balance of rest and work that will allow each swimmer to achieve a peak performance at its end. Of course, a pretaper is feasible only when swimmers have completed a season of reasonable length, one longer than 17 weeks. When seasons are short, the last 2 weeks before the taper must be used for additional training. The training procedures for each week of the pretaper and the major taper will be described in the next few sections.

Pretaper

The pretaper is a period of reduced training that provides a safety valve for swimmers who may need longer than 2 to 3 weeks to achieve a full taper and a peak performance.

Table 18.1 Summary of Research on Tapering Parameters

TRAINING VARIABLE	**SUGGESTIONS FOR SHORTER AND LONGER EVENTS**	
	Short events 19 sec–2 min	**Long events 4–20 min**
Duration	14–21 days	7–14 days
Weekly mileage	30%–40% of pretaper maximum	40%–60% of pretaper maximum
Daily mileage	1/3–1/2 of pretaper maximum	1/2–2/3 of pretaper maximum
Intensity		
Mileage swum above the anaerobic threshold	25%–40% of usual pretaper amount	40%–50% of usual pretaper amount
Reduction of usual training speeds	Not more than 20% of pretaper speeds	Not more than 20% of pretaper speeds
Weekly frequency	4–6 days/wk	5–6 days/wk

In this period, training mileage and intensity are reduced somewhat, although not to taper levels. Training frequency should be maintained at its normal number of sessions per week. The purpose of the pretaper is to assess how quickly each swimmer is likely to recover from his or her previous months of hard training.

Training mileage should decrease by 15% to 20% if athletes are swimming 9,000 yd or m or more. Athletes who are training once a day for 5,000 or 6,000 yd or m should remain at their normal mileage, but they should reduce their usual basic endurance training intensity by approximately 2 to 3 sec per 100 yd or m. The speed of threshold and overload sets should remain at normal season levels, although the mileage at those levels should also decrease by 15% to 20%. The quantity, but not the quality, of sprint training should decrease as well. Land resistance and flexibility training should be cut back to maintenance levels.

The swimmers' recovery rates should be evaluated at the end of each of the 2 pretaper weeks. Swimmers who are responding well will become more energetic by the end of the 1st week. They may perform better in meets, and they will probably sprint faster in training. Their results on various performance tests, whether blood testing or standardized sets, should also improve dramatically. These swimmers can safely go back to regular training for the next 1 or 2 weeks.

Swimmers who do not seem to be recovering after the 1st week should begin their taper in the next week. That is, they should begin to taper during the 2nd week of the pretaper period. The program during that week should be like the one that I will describe for the 1st week of the taper in the next section.

Taper Period

The taper should last 2 or 3 weeks. Training mileage should decrease gradually during each week so that swimmers do not risk losing endurance while they are recovering. The amount of recovery training should increase considerably, while the amounts of basic (En-1), threshold (En-2), overload (En-3), and sprint training should decrease gradually. Athletes should maintain swimming speed in these sets near pretaper levels. They should not respond to the reduced volume by swimming faster average speeds, except on short sprint sets. Swimming too fast is a common mistake that will delay the recovery process. Swimmers should understand that they are trying to recover, so they should not increase training intensity during the taper.

Table 18.2 outlines a general plan for tapering senior sprint, middle distance, and distance swimmers who have been training twice per day for 5 to 6 days of each week. I am assuming a usual pretaper weekly mileage of 40 to 50 km for sprinters and 70 to 85 km for middle distance and distance swimmers.

Week 1

Training frequency should stay near the normal level, but swimmers can miss two or three morning training sessions to get some additional rest that may aid the recovery process.

The amount of recovery training should increase from its usual 10% to 15% of weekly mileage to between 30% and 40% of that total. Basic endurance (En-1) mileage should decrease to between 30% and 40% of the total. The average speed for basic endurance training can safely be reduced by 1 to 3 sec per 100 without losing endurance. Even so, endurance may be maintained better by swimming basic endurance repeats at pretaper speed, allowing the reduction in total training mileage to stimulate recovery.

The morning sessions should be shortened to approximately 2,000 yd or m for sprinters and to 3,000 or 4,000 yd or m for middle distance and distance swimmers. Most of the morning mileage should be in the form of recovery and basic endurance swimming, kicking, pulling, and stroke drills. If possible, morning training should take place at the time when the preliminary heats will be held to help orient swimmers'

Table 18.2 Training Frequency and Mileage During the Taper

TAPER PHASE	FREQUENCY	MILEAGE/DAY		MILEAGE/WK	
		Sprinters	**Middle distance and distance**	**Sprinters**	**Middle distance and distance**
Pre-taper		8,000–10,000	14,000–16,000	50k	85k
Taper period					
Week 1	10–11/wk	4,000–5,000	8,000–9,000	25k	40k
Week 2	8–10/wk	2,000–3,000	4,000–6,000	15k	25k
Week 3 (meet begins mid-week)	Two sessions daily until meet begins	Warm-up only			

biological clocks toward competing at that time. Scheduling the morning swim at that time will also provide some additional rest because most swimmers will be able to train later than usual in the morning. Similarly, the second session of the day should be held at the time of the finals if it is practical to do so.

Sprinters should swim 2,000 to 3,000 yd or m in the afternoon session. Middle distance and distance swimmers should swim 4,000 to 5,000 yd or m in the afternoon. Middle distance, distance, and long-sprint swimmers should set aside three afternoon sessions to maintain aerobic and anaerobic muscular endurance, completing one mixed set of threshold (En-2) and race-pace swimming during each session. That set can be 800 to 1,200 yd or m in length for sprinters and up to 2,000 yd or m in length for middle distance and distance swimmers. They can do the swimming as one descending set by descending to race pace near the end, or they can do two sets by swimming the first at threshold speed and the second at race pace. The remainder of the afternoon endurance mileage should be in the basic endurance and recovery categories. Short sprinters do not need to swim at threshold or overload endurance speed at this time. They can maintain their aerobic endurance with short daily sets of basic endurance training.

Sprinters should include two short race-pace sets during this week. They may swim as fast as possible on these repeats: One or two broken swims or a short set of repeats at desired race speed is suitable for this purpose. Sets such as 4 to 6 × 50 with 2 to 3 min of rest or 3 to 4 × 100 with 2 to 5 min of rest are suitable for this purpose.

All swimmers should do some sprint training during this week. For this purpose, middle-distance and distance swimmers can use sets of 4 to 6 × 25 on a 2 min send-off or 3 to 4 × 50 on a 3 min send-off. Long and short sprinters can use pace work for sprint training. They can swim short sets such as 4 to 6 × 25 at 100 speed or 3 to 4 × 50 at 200 speed. They should also do a short set of sprint or race-pace swims during two mornings of this week to stay in the habit of swimming fast early in the day.

Swimmers should warm up well before each training session and swim down for 800 to 1,500 yd or m after each training session. Stretching should continue to precede each practice period. Dry land resistance training should be discontinued. Some may not agree with this last piece of advice, but research suggests that strength and power on land will increase during the taper for a period of at least 15 days with no further training (Costill et al. 1985). Sprinting should provide the needed stimulus for maintaining strength and power in the water, so additional land training is not necessary.

The only exception to the plan I just outlined concerns swimmers, generally sprinters, who showed signs of being excessively fatigued at the end of the pretaper period. Their anaerobic power is still probably depressed, and they may require a major reduction in training mileage to recover their speed. Consequently, they should reduce their training mileage and intensity drastically during the 1st week of the taper. They should train only once per day for 3,000 to 4,000 yd or m, most of it in the form of warming up, recovery, and low-intensity basic endurance swimming. They should practice stroke drills and work on starts and turns. They should maintain training intensity by swimming only one or two mixed descending sets at threshold (En-2) and overload (En-3) endurance speeds during the week. These should not total more than 800 yd or m each. They should do some pace training during 2 or 3 days but do only one short race-pace set during the week.

Week 2

The plan suggested for this week is almost identical to that of the preceding week except that training mileage should decrease even further. Sprinters may be training no more than 3,000 to 4,000 yd or m per day, and middle distance and distance swimmers should reduce their daily mileage to between 4,000 and 6,000 yd or m. Training frequency should be the same as it was in the previous week. Those who seemed to be excessively fatigued during the previous week should perform the regular program this week if they show signs of recovering. Otherwise, they should continue with their reduced program of the previous week.

Middle distance swimmers, distance swimmers, and long sprinters should swim between 2,000 and 3,000 yd or m in the morning, with most of the mileage at recovery and basic endurance (En-1) speed. They should swim two mixed sets of threshold and race-pace training during this week. These sets should be similar in length and intensity to the ones of the previous week. The remainder of their mileage should consist of warm-up, recovery, and basic endurance (En-1) swimming in the form of stroke drills, pulling, kicking, and swimming sets that are no longer than 2,000 yd or m.

Short sprinters should swim 1,000 to 2,000 yd or m during the mornings when they train and 2,000 to 3,000 yd or m in the afternoon. Most of that mileage should continue to be in the form of warming up, recovery, and basic endurance (En-1) swimming in sets of 1,000 to 1,200 yd or m. They should swim race-pace sets of 400 to 800 yd or m twice during this week.

Middle distance and distance swimmers should perform sprinting in the same way and in the same amount as they did the previous week. Long and short sprinters should do some pace work two or three times during the week. Those efforts will serve as their sprint training. As in the previous week, swimmers should do some small amount of pace work two or three mornings of the week to stay attuned to swimming fast early in the day. Athletes should continue to stretch before each training session to maintain the greatest possible range of motion.

Week 3

The schedule I recommend for this week is based on the assumption that the competition will be held during the last 1 to 4 days of the week. Swimmers should continue to come to the pool twice each day, training as they did during the previous week until they are within 3 days of the start of competition. After that, their training should consist only of long warm-ups, stroke drills, and swim-downs with some small amount of pace work. Swimmers can reduce training for the final 3 days before the meet without fear of losing endurance. The additional rest may restore or supercompensate anaerobic capacity and muscular power more completely.

General Comments on Tapering

Considerable attention should be focused on perfecting starts, turns, and relay starts during the taper. Swimmers should practice starts and turns at least every other session. Pace training should also be a priority. Athletes should swim underdistance repeats until they can duplicate their ideal pace for races within 0.20 to 0.50 sec per 50 and 100 segments respectively. In some cases, swimming at ideal race speed may not be realistic when swimmers are not shaved down. In that case, swimmers may want to swim at their ideal race stroke rates instead of race speeds when they are doing pace work.

Coaches and swimmers should spend some time discussing meet and race strategy. Coaches should advise swimmers about warming up properly, particularly under the crowded conditions they will encounter at most major meets. They should be cautioned to spend 15 to 20 min swimming down after their races so that they will recover more quickly and completely. Coaches and swimmers should also discuss the strategy for swimming preliminaries and finals with regard to such matters as the difficulty in qualifying for the finals and the lane positions they prefer if they qualify. Swimmers should also be counseled about their race plans against certain competitors in the finals.

A good portion of the swimmers' warm-ups, swim-downs, basic endurance training, and recovery training should be in the form of stroke drills. Swimmers should also concentrate on using the best possible mechanics in all their pace, sprint, and intense endurance swimming. The fatigue of hard training sometimes causes swimmers' strokes to deteriorate somewhat, so the taper is an excellent time to polish technique.

Swimmers should not attempt to make major stroke changes at this time. Most swimmers are not able to change their strokes in competition without weeks of practice. Consequently, attempting major stroke changes at this time may have a detrimental effect because swimmers could go into competition with strokes that do not feel natural and may be less efficient.

Shorter Tapers

The general 3-week taper plan just presented may require adjustments for certain swimmers and certain situations. Some swimmers may respond better to tapers that are 1 or 2 weeks in length. The general plan can be adapted for a 2-week taper simply by using the format described for the final 2 weeks of the 3-week plan.

The 3-week format can also be adapted for a shorter taper with additional adjustments. A short taper should begin 7 to 10 days before the competition. At that time, training mileage should decrease by 80% to 90%. Recovery training should increase as it did in the general plan, and most of the remaining mileage should be in the form of basic endurance (En-1) training. Two endurance maintenance sets that include threshold (En-2) and race-pace training should be scheduled between the 3rd and 7th days of this short taper. Those sets should be similar to the ones described for the 2nd week of a 3-week taper. Swimmers on a short taper should, like the others, simply warm up and swim a small amount of pace work during the final 3 days before the competition begins.

Oversprinting

Many swimmers make the mistake of sprinting too much during the taper. They do so perhaps because they feel good as they recover or because they hope to gain confidence with some fast swims. Whatever their reasons, too much sprinting may interfere with the recovery of anaerobic power. If swimmers have done enough sprint training throughout the season, they should reduce, not increase, the amount of sprinting they do to produce recovery or superadaptation of muscle contraction speed and rate of anaerobic metabolism.

Weight Gain

Swimmers should reduce their caloric intake during the taper to prevent accumulation of excess fat tissue during this time of reduced training volume. A weight gain of 2 to 4 lb should be expected, however, because many swimmers will have been somewhat dehydrated during the season from chronically low muscle glycogen levels. They will gain water weight during the taper because replacement and supercompensation of muscle glycogen will cause them to superhydrate. Their bodies will store approximately 3 g of water for every 1 g of glycogen they deposit (Wilmore and Costill 1999). Consequently, the first 2 to 4 lb of weight gain during the taper will come primarily from additional water storage, not from an increase of adipose tissue. Swimmers should avoid weight gain beyond this level by reducing caloric intake to match the new, lower output.

Individualizing Tapers

Humans are so complex that a myriad of factors can affect the delicate balance between the various kinds of training that will produce an outstanding performance. Age, sex, the length of events, the volume of previous training, and individual capability to respond to and recover from training will all influence this balance. Therefore, most swimmers will need to use somewhat individualized tapers. The following list includes some of the more common individual adjustments required during tapers.

- Young adult swimmers seem to need more time to recover than age-group swimmers, probably because older swimmers have more muscle tissue and greater anaerobic power. Consequently, they may need more time to repair and enhance that tissue during the taper.
- Females seem to need less time for recovery than males do.
- Distance swimmers should generally maintain a greater volume of training during their tapers, and the length of their tapers should probably be shorter than they are for sprinters. Distance swimmers generally recover faster from training, and they cannot afford to risk losing their aerobic capacity by resting too long or by reducing training volume too much.
- Sprinters frequently need to reduce their training volume more and use longer tapers to be certain that they have optimized their anaerobic power.
- Swimmers who train 10 or 11 mo of the year seem to recover faster than those who train for only a few months of the year. Athletes who train regularly throughout the year are generally better adapted, so they tend to recover faster, whether they are sprinters or distance swimmers.

The previous list makes it clear that the time needed to produce a taper can differ from one person to the next. Coaches adept in the art of tapering know how to determine and correct the undesirable responses of certain individuals to the taper. Coaches should be prepared to change the general taper plan for any swimmer who is not responding well. In such cases, coaches will need to rely on personal experience and knowledge of the individual swimmer's response to a taper to determine what changes to make.

Shaving Down

Athletes should shave down before major competitions. A shaved body produces significantly less drag, evidenced by the fact that swimmers' stroke lengths increase when they shave down. In one study, the average distance that swimmers covered with each stroke cycle increased by 5% after they shaved down (Anderson et al. 1992). When those swimmers were tested for a submaximal 200 yd swim, their stroke rates were significantly lower after shaving down. This result indicated a greater stroke length because they completed the 200 swim at the same speed before and after shaving down. The reduction in stroke rate was most noticeable during the final 100 yd of the swim, indicating also that they were less tired at that time.

Psychological Factors

The success of tapers is related not only to the physiological changes that take place but also to the athlete's state of mind. Swimmers must believe that they are going to swim well for a taper to have its full effect. The axiom "Performance is 90% mental and 10% physical" probably understates the physiological contribution to performance in one respect, but it is dead on in others. Poorly conditioned athletes cannot will themselves to peak performance, no matter how strong they are mentally. But when athletes are well conditioned, the axiom becomes accurate. Among well-conditioned athletes, the individual athlete's state of mind largely determines success or failure.

During the taper, athletes may be full of anxiety about the upcoming competition. That anxiety may affect their recovery and thus their state of mind. The uncertainties of the taper, particularly the swimmers' feeling about whether they are getting too much or too little rest, may erode confidence. They need support and guidance from their coaches when that happens. They need to be convinced that their training programs have been sound and that all signs indicate they are going to swim well. Leading experts around the world are unanimous in their advice that coaches must remain calm and exude an attitude of confidence during the taper, even when they may be just as anxious as the athletes are. That does not mean coaches should lie to swimmers. The swimmers should be told the truth if the coach does not feel that the taper is going well. That assessment should be coupled with suggestions for remedying the situation, however, so that the swimmer can feel confident that he or she will be tapered well when it comes time to compete.

Good performance on paced or broken swims will give swimmers confidence during the taper. Good scores on evaluation measures such as blood tests, tests of power, sprints, and measures of stroke length and stroke rate will have the same effect. Unfortunately, however, some swimmers do not perform well on these tests during the taper. For reasons that remain largely unknown, some athletes swim poorly during a taper yet often swim well at the meet. I suspect that these athletes realize intuitively that they must reduce swimming volume and intensity to restore their anaerobic power. Therefore, they hold back on these efforts, often without realizing that they are doing so. Swimmers who react in this way should probably not take part in evaluation swims and tests during the taper. The results will only cause anxiety and send them into the meet lacking confidence.

Preparing Swimmers for the Competition Site

Swimmers should be prepared for the problems they might encounter at the meet site. Crowded pools, long lines to get into the meet or dining hall, different styles of food preparation, different time zones, inadequate gutter systems, gutters with flat walls, poor visibility on turns, poor starting block construction, and shallow pools are some of the common unnerving circumstances that swimmers can encounter at meet sites. Coaches should discuss these and other items with swimmers before they arrive at the meet site. In some cases, swimmers should go through simulation training to prepare for particular pool conditions they may encounter at the meet. Coaches should investigate the meet site when possible or discuss the meet site and meet conditions with others who have been there so that they can tell their swimmers what to expect. The swimmers will have confidence in their preparation if they know that coaches have considered all eventualities. When possible, the team should arrive at the site a few days early so that swimmers can adjust to the surroundings.

Different Tapers for Men and Women

Many coaches believe that women require shorter tapers than men. To my knowledge, no controlled scientific study has investigated this belief. Nonetheless, the assessment may be accurate. Millard and associates (1985) reported lower creatinephosphokinase (CPK) levels in women than in men following heavy training, even though the swimmers of both sexes swam the same workouts. This finding suggests that similar training caused greater muscle damage in men than in women. Women may be able to recover faster because they have less muscle damage to repair.

In one of the few taper studies in which the subjects were females, Kenitzer (1998) reported that a group of female swimmers performed best after tapering for 2 weeks. The group of 15 swimmers was evenly divided between sprinters (5), middle distance (5), and distance (5) swimmers. They tapered for 4 weeks by reducing their mileage by 25% weekly. Their performance and peak blood lactates were measured for a set of 4 × 100 at the end of each week. They achieved their best values at the end of the 2nd week and showed signs of declining performance during the final 2 weeks of the taper. This small amount of scientific support and a great deal of anecdotal evidence suggests that women do indeed require shorter tapers than men do.

Retaper

In the past decade the number and proximity of major competitions has increased. Swimmers must now go through a major taper for an important meet and then undergo one or more retapers for subsequent meets. The training procedures used during a retaper depend largely on the length of time before the next major competition. If the second meet will take place within 2 or 3 days, swimmers should simply continue to rest. When the time between meets is longer, athletes need to return to some solid training before starting to taper again. The next few paragraphs will describe procedures for retapering for competitions held 1 or more weeks after the preceding one.

One-Week Retaper

When major meets are separated by only 1 week, swimmers should do some recovery swimming for 2 days after the first meet, train for 2 days, and then rest again. The volume should be 50% to 60% of normal during the 2 training days, most of it at basic endurance (En-1) speed in the form of stroke drills, kicking, pulling, and swimming. Swimmers should do a few sprints or some pace 50s and 100s on these days. They should warm up as they would for the meet and do some paced underdistance swims on the last 2 days before the start of the meet.

Two-Week Retaper

When the time between important meets is 2 weeks, swimmers should train at recovery levels for 3 days, train for 5 to 6 days, and then retaper for 4 to 5 days. The training days should be similar to those during a typical week of the race preparation phase of the season except that weekly mileage should be 60% to 70% of normal for that phase. Two peak days should be planned during this training period. Swimmers should do some threshold and race-pace swimming on those days. The remaining training days should be made up of basic endurance swimming and underdistance paced swims. The plan for the final 4 to 5 days of the retaper should be similar to the plan for the final 4 to 5 days of a full taper.

Three- and Four-Week Retapers

For longer retapers of 3 to 4 weeks, swimmers should again spend 3 days doing recovery swimming immediately after the first competition. They should then train until they are within 1 week of the start of the next competition. The retaper should take place during the final 5 to 7 days before the second competition begins. The training should be similar to that suggested for the final week of a major taper.

During the training period, weekly mileage should be maintained at 60% to 70% of the normal season training volume. Plans for the training weeks should be similar to those used during the race preparation phase with somewhat more basic endurance training. Athletes should plan for 2 peak training days out of every 5 during this time. They should swim threshold and overload endurance sets on those days, but the length of those sets should be 20% to 30% less than their normal length during the specific and race preparation phases of the regular season. Athletes must remember that they do not want to risk becoming excessively fatigued by doing too much intense training during the retaper. Their goal is to maintain aerobic and anaerobic training effects, not to improve on them. They should also swim sprint and race-pace sets during the retaper. The sets can be their normal length because they are not very long to begin with.

Swimmers can return to dry land training when the time between major meets is 3 weeks or longer, but they should keep that training at a maintenance level. Training during the final week of the retaper should be similar to the training suggested for the final 7 days of a major taper.

Retapering After 6 Weeks or More

Athletes should be able to maintain their performances for 4 to 5 weeks on the retaper programs I have outlined. If the time between meets is 6 to 10 weeks or slightly longer, they should return to regular training until they are within 2 weeks of the next competition.

Swimmers should plan their training like a miniseason during this time. The first 1 1/2 to 2 weeks should be like the general preparation period, and the remaining training time should be split between a specific preparation period and a race preparation period. Training volume, frequency, and intensity should be the same as they would be during a regular season. The swimmers should allow 7 to 14 days for a taper at the end of this period and conduct it as outlined for the final 2 weeks of a major taper.

Minor Tapers

Minor tapers are usually 2 to 5 days long. They are used when good performance is desired in early season or midseason meets. Swimmers usually do not shave for these meets, so their performances will usually not be as fast as they will be later. The recovery weeks of mesocycles should be planned to coincide with periods when minor tapers are desired so that those weeks do not interfere with regular training.

The method for implementing a minor taper is to reduce training mileage dramatically for 2 to 5 days. A daily total of 3,000 to 6,000 yd or m is most commonly used for this purpose. Swimmers should do additional recovery training during those days and avoid doing major high-intensity endurance or sprint sets. A typical training session might include 1,000 to 2,000 yd or m of recovery swimming, 1,000 to 2,000 m of basic endurance training, and a few sprints or paced swims.

19

Overtraining

New in this edition:

- A discussion of the differences between hard but necessary training, overreaching, and overtraining
- An examination of the possible roles of the immune system and antioxidants in overtraining
- A section on tests for diagnosing overtraining

Overtraining is the term used to identify a condition that appears when athletes perform poorly because of training. The condition is also called *failing adaptation* because the adaptation process reverses itself and causes loss of previously gained training effects. In other words, athletes become worse rather than better because of their training. The reasons for the condition of failing adaptation have not been identified with any certainty. Some believe failing adaptation is caused by an athlete's exceeding his or her tolerance to a particular form of training or by the cumulative effects of normal training that are not balanced by adequate nutrition or sufficient time for rest and recovery. Anxiety and emotional upset are other factors that have been implicated. Severe anxiety caused by a crisis in an athlete's emotional life can also be a potent stressor, which, when added to the stress of normal training, can cause failing adaptation.

The ability to train athletes without overtraining them is one of the talents that great coaches possess. Even the most knowledgeable coach will find it difficult to design a training program that will not overtrain some members of a team during a season. Morgan and his associates (1987) reported that 10% of the collegiate male and female swimmers they studied became seriously overtrained at some time during a typical swimming season. Physical and biochemical tests can help in the diagnosis of overtraining, but none have been proven any more reliable than the intuition of a sensitive coach who understands his or her swimmers well. Scientific tests cannot prevent overtraining; they can only signal its occurrence. Unfortunately, they provide information after the fact. The effective coach is able to train athletes toward a peak performance without allowing them to become overtrained.

A discussion of the physiological basis for overtraining, how to treat it, and how to prevent it will be the primary topics of this chapter.

What Is Overtraining?

Overtraining seems to be associated with changes in neuromuscular, hormonal, and immune system functions that reduce the ability of athletes to tolerate training. The basis for overtraining was presented several decades ago by Hans Selye (1956) in his famous discourse on the stress syndrome. Selye defined stress simply as wear and tear on the body. Factors that cause stress were termed *stressors,* for obvious reasons. Physical exercise, illness, injury, and the emotional upset and anxiety were identified as primary stressors. Factors that seemed to reduce a person's tolerance to stressors were poor diet, lack of sleep, and inadequate rest and recovery.

Selye theorized that the resources for dealing with stress came from a store of general adaptation energy. This concept was an abstraction because no particular area in the body stores general adaptation energy. Nevertheless, Selye believed that humans reacted to stress as though they possessed a finite store of general adaptation energy for dealing with it. He felt that heredity determined the size of that store.

Besides having a store of general adaptation energy for dealing with all stressors, humans reacted to specific stressors as though they also had stores of specific adaptation energy for each. Selye believed that proper training could increase the stores of specific energy, which were also hereditary. In other words, athletes could increase their tolerance to the stress of physical exercise, and perhaps other stressors, with proper training. The most common specific stressors that act on swimmers are training, academic demands, social demands, emotional demands, illness, and injury. The sources for replacing the store of general adaptation energy are rest and good nutrition.

A schematic of the Selye stress theory is illustrated in figure 19.1. The reservoir of general adaptation energy is indicated by the large labeled container. Energy flows downward from it to replace energy lost daily from each of the specific stressors. The diagram also shows that diet and rest can replenish the reservoir of general adaptation energy. Selye believed it was possible for the general adaptation energy supply to become depleted, or nearly so, when

1. the requirement from any specific activity became inordinately high,
2. the demand from several areas increased unexpectedly, or
3. diet and rest did not adequately replace general adaptation energy.

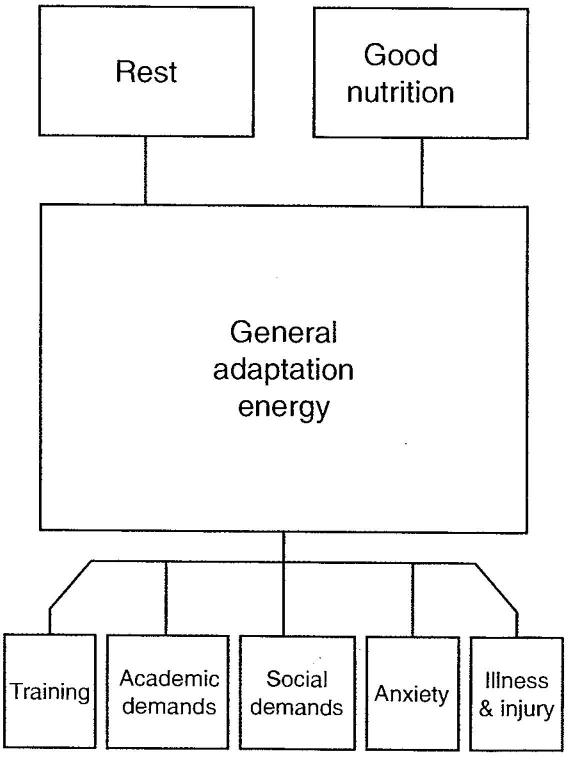


Figure 19.1 Selye's general adaptation theory applied to competitive swimmers.

The reactions that some swimmers show to training and competition lend support to Selye's stress theory. Athletes frequently display symptoms of overtraining when they suddenly and dramatically increase their training volume or intensity. Similarly, they often exhibit symptoms of overtraining after sudden and dramatic increases in demands from other stressors. For example, their ability to train usually declines when they have a personal crisis or when other demands on their time increase. In this respect, many coaches have noticed that the ability of athletes to tolerate training decreases when they have serious emotional conflicts. Likewise, their tolerance for training usually falls when they have final examinations or participate in many social activities. In the case of examinations, it is not certain whether anxiety about the outcome or lack of rest and sleep causes depletion of the store of general adaptations energy. Lack of rest and sleep are probably the culprits when social demands increase. Athletes who attend many social functions or participate in a many outside activities frequently do not get enough sleep or "quiet time" to replace the energy they have lost.

It is unfortunate that the term *overtraining* has become associated with this condition. The connotation is that athletes are training too much. In reality, Selye's theory implicates many other causative factors. Training is only one of these, and it is the one most necessary to an athlete's success in competition. The last thing I wish to do is to give the impression that swimmers should avoid hard work for fear of becoming overtrained. Quite the contrary. Difficult workloads are required to stimulate physiological systems toward optimal levels of adaptation. Only when they exceed an athlete's tolerance do they become counterproductive. When that happens, the consequences of training shift from their usual anabolic (building up) effects to outcomes that are catabolic. In other words, the training effects tear athletes down.

Sadly, cases of overtraining are more frequent among highly motivated athletes because they are always *overreaching* or trying to exceed their limits, often before their bodies are ready to do so. One of the saddest experiences in sport is to see a dedicated athlete fail after making countless sacrifices in the pursuit of success. Athletes must walk a fine line in their training. It must be sufficiently intense and voluminous to produce an overload, but not so intense or voluminous that it will cause failing adaptation. Swimmers must frequently overload each energy system with intense and challenging swimming sets while simultaneously providing enough time for rest and recovery so that the stress does not become intolerable. They must regularly replace the calories they use, and they must manage other potential sources of stress so that they do not interfere with training.

Hard Training Versus Overtraining

Normal hard training causes physical and emotional symptoms of stress that may persist for 2 to 48 hr. Athletes may feel fatigued, heavy, tight, and even sore, particularly if they have overreached during a particular training session and have experienced muscle glycogen depletion or tissue damage. They may also be irritable, emotionally upset, and lacking in motivation. These symptoms will be most acute during training and will subside during the recovery period. In extreme cases of overreaching, these symptoms may extend to the next training session or two before they subside. If training is properly cycled, the symptoms will be gone or greatly reduced within 24 to 48 hr.

Athletes will experience no detrimental effects from normal hard training. In fact, as indicated earlier, that training will probably cause improvement of certain physiological mechanisms. Even when athletes overreach, the effect is temporary and need not be detrimental if they take adequate time for recovery before attempting another such training session.

Overtraining, on the other hand, is a condition in which these symptoms persist for several days and seem to increase in severity with each passing day. Performance in training and competition worsens progressively with increasing time. Athletes often complain that they feel as if they are losing conditioning, and in fact they are. Many of the training adaptations they gained earlier are now diminishing through catabolism, and they are returning toward the physical state of untrained persons in spite of the fact that they are training regularly and conscientiously. The information in table 19.1 may help in determining the differences between normal reactions to training and those that indicate overtraining.

Overreaching and Overtraining

Overreaching is a condition in which athletes train beyond their ability to adapt to that training. In other words, they push themselves to the point where the rebuilding

Table 19.1 Differences in the Way Athletes React to Hard Training When They Are Not Overtrained and When Overtrained

TRAINING PARAMETERS	NORMAL REACTION HARD TRAINING	REACTION WHEN OVERTRAINED
Fatigue sensations	Tired but exhilarated by performance.	Exhausted and feeling disappointed with effort. Unable to swim at maximum effort for any length of time. Greater difficulty swimming at submaximum speeds.
Technique integrity	Some loss of technique as indicated by higher stroke rate and lower stroke length during maximum efforts.	Stroke rates are increased and stroke length decreased almost from the start of training. Occurs during both maximum and submaximum efforts.
Physiological measures	Heart rates and blood lactates are normal for the effort expended.	Difficulty reaching maximum heart rate. Heart rates are higher during submaximum efforts. Peak blood lactates are lower. Blood lactates are higher for submaximum efforts.
Feelings of well-being	Approaches each new training session feeling tired but reasonably recovered from previous training.	Feels exhausted at the start of each new training session.
	Muscles may feel weak and fatigued at the end of a training session but not unusually so.	Muscles feel heavy, weak, and sore almost from the beginning of training.
	Headaches, nausea, and even vomiting may occur during particularly difficult training sessions.	Headaches and nausea are more frequent, even when training is no more intense than usual. Vomiting may occur at training intensities that are usually well tolerated.
Attitude and motivation	May be tired but motivation to train is high. Rises to challenge. Pleasant and courteous to teammates. Seems happy and can be amused when something humorous occurs.	Expresses dislike for training. Complains when challenged. Negative and irritable toward teammates.

(anabolic) processes or metabolism and tissue repair cannot possibly keep pace with the breakdown or catabolic processes. Overreaching could be considered a short-term form of overtraining in which adaptation is compromised but no loss of previous adaptations occurs.

Athletes are prone to overreach in training just after they have made a significant improvement in their conditioning. They are able to train faster, and every training session becomes a party during which their performances become better and better. Consequently, they become highly motivated and train at a supramaximal level while ignoring the need for periodic recovery. These athletes will come down to earth with a thud after several days, or in some cases after only a few days of training in this manner. Their training repeats will suddenly become slower and more difficult to do. If at that point they swim at basic endurance speeds for a few days, the situation will correct itself. No significant loss of previous training adaptations will occur, and they will be able to resume regular training. If they push on in spite of the obvious decline in their training speed, they will become severely overtrained within a few weeks.

Coaches and athletes may wonder if occasional overreaching stimulates greater increases in physiological function than training within present capability. That question cannot be answered now. A case could certainly be made that occasional overreaching may provide the breakthrough stimulation that leads to greater improvements, particularly when athletes are near their genetic limits for certain physiological functions. On the other hand, overreaching that is too frequent or too long lasting will certainly lead to failing adaptation. I believe that athletes should not be discouraged from overreaching because of the possibility that it might stimulate a breakthrough in physical condition. Coaches should enforce some needed recovery time after one or two such sessions, however, and they should permit athletes to overreach only during one or two training sessions each week.

What Causes Overtraining?

Overtraining in swimmers can be caused by

1. several days or weeks of intense or voluminous training that is not balanced with periods of reduced intensity and recovery training or
2. a major and extended increase in one or more stressors that reduces an athlete's tolerance to normal training to the extent that he or she enters a period of failing adaptation.

Intense Training With Inadequate Recovery

Intense training or a large volume of training causes damage to structures in and around muscles and depletes their supply of glycogen. When training is cycled properly, periods of recovery between every one to three sessions of intense training and short periods of recovery at the end of each training macrocycle can correct those situations. The muscle structures will be repaired and enhanced during the recovery periods, and the glycogen will be replaced. When the same muscle tissues are exposed to acidosis day after day, however, repair will be minimal at best and the extent of the damage may increase until muscular tissue is lost and with it, strength and anaerobic power. Tissue damage may even reduce endurance. VanHeest (1997), in a study involving national and world-class swimmers, reported that reductions in aerobic capacity were associated with increased tissue damage. Chapter 17 provided suggestions for cycling training to prevent prolonged muscle glycogen depletion and extensive tissue damage

Training intensity appears to be a more potent stressor than training volume as far as muscle damage is concerned. Athletes can perform a large volume of low- to moderate-intensity training without producing acidosis and muscle damage, but intense training has the opposite effect. High-intensity training produces acidosis, which can disrupt muscle membranes and allow protein substance to leak from them into the intercellular spaces. But be aware that large and sudden increases in training volume can cause overtraining, particularly if athletes do not reduce their training intensity to compensate for the increased mileage.

Although controversial, research suggests that training with inadequate glycogen supplies may also cause overtraining. As we know, muscle glycogen is the preferred source of energy for training near and beyond anaerobic threshold speeds. As I described in chapter 17, repeated days of hard training cause a gradual reduction of muscle glycogen. Again, the intensity of training more than the volume of training causes this reduction. Fat metabolism can support a large volume of low- to moderate-intensity training. Therefore, muscle glycogen is not as likely to become depleted. On the other hand, as little as 30 min of intense swimming will deplete muscles of more than half of their glycogen, and a typical mixed training session that includes a significant amount of intense swimming can probably deplete muscle glycogen by nearly 75%. When this happens, the athlete needs 24 to 36 hr to replace that energy source in the muscles. Athletes who train intensely for several days in a row will not replace muscle glycogen as fast as they are depleting it. This process will reduce their muscle glycogen to the point where they will be forced to use other sources for energy during training.

One of these sources will be the protein that makes up the solid portions of muscle fibers. When muscle glycogen is low and the athlete needs energy for training, the muscles react by consuming their own protein material for energy. An increase in protein use can be particularly damaging. Research shows that an increase in the protein supply of muscles regulates both muscle hypertrophy (Goldspink, Garlick, and McNurian 1983; Laurent and Milward 1980) and mitochondrial size and number (Booth and Holloszy 1977). Consequently, an increase in muscle protein catabolism could cause athletes to lose strength when muscle size decreases and to lose endurance when the number and size of mitochondria declines. Athletes may literally cannibalize their muscle tissue for energy, losing the muscular strength and endurance they worked so hard to attain.

Costill and associates (1988) have presented evidence that connects low muscle glycogen levels to overtraining in swimmers. They subjected 12 well-conditioned male collegiate swimmers to 10 days of training at an average mileage of 9,000 m per day. Four of those swimmers showed signs of overtraining during the training period. They had difficulty finishing the sessions and were not able to maintain their usual training speed. Six swimmers appeared to tolerate the training without unusual disturbance in function. Although several physiological measurements were taken, the only one that differentiated the 4 swimmers who were having difficulty from the others was a low level of muscle glycogen. After 10 days, their muscle glycogen levels were approximately 40% lower than those of the other subjects. The 6 swimmers who were able to tolerate the increased training maintained high levels of muscle glycogen from the beginning to the end of the training period.

Diet analysis showed that the 4 swimmers who were having problems in training consumed approximately 1,000 fewer calories per day than they were expending. In contrast, the caloric intake of the 6 swimmers who tolerated training matched their daily caloric output. The 4 swimmers who had difficulty during training did not exhibit one of the most important symptoms of overtraining. Their performance did not deteriorate on 25 yd sprints and 200 yd time trials. But the training program was only 10 days long. Their performance would probably have deteriorated had they continued training for several more weeks with low levels of muscle glycogen.

Coaches and athletes might be wondering why the body does not consume fat for energy in preference to protein when muscle glycogen supply is low. That cannot happen because low muscle glycogen levels seriously limit the transfer of energy from fat even when large amounts of fat are available in the body (McArdle, Katch, and Katch 1996). When free fatty acids are converted to acetyl-CoA, they must combine with oxaloacetic acid to enter Krebs cycle and be oxidized. Glucose metabolism is primarily responsible for producing oxaloacetic acid. Thus, a sufficient amount of glucose must be available to produce oxaloacetic acid before fat can be metabolized in Krebs cycle. The significance of this observation is that swimmers will not be able to metabolize fat for energy when their muscle glycogen and blood glucose supplies are low. Consequently, they will have to rely on the protein in their muscles. Over time they will lose endurance and power.

The information in this section supports the assumption that failing adaptation may result from muscle damage and muscle glycogen depletion that develop slowly over several weeks. Some time must pass before athletes lose enough muscle tissue to cause a noticeable loss of performance. Observations of swimmers in training support this notion. Most athletes seem to respond quite well to training for the first 4 to 8 weeks of a season. After that, however, those who have been swimming intensely without sufficient recovery time and those who have not been regularly replacing their lost glycogen and protein will begin to show signs of overtraining.

Swimmers who schedule adequate recovery time into their training weeks and maintain their muscle glycogen with an adequate supply of calories and carbohydrates may be able to tolerate high training mileage without becoming overtrained. On the other hand, athletes may become overtrained when their diets are inadequate and when they train too intensely too often without sufficient recovery time. Once they become overtrained, athletes will need to reduce their training volume and intensity and improve their diets.

Accumulation of Several Stressors

The accumulation of several stressors can also cause overtraining. One stressor may be insufficient to cause failing adaptation. When several occur together, however, they become sufficient to cause fatigue and poor performance. Disruptions in the central nervous and hormonal systems rather than muscle damage or low muscle glycogen supply seem to cause this type of overtraining. Unfortunately, the exact nature of these disruptions has not been identified. Overtraining of this type seems to come on more rapidly than overtraining caused by muscle damage and glycogen depletion, perhaps because of the greater involvement of the nervous and endocrine systems.

Excessive hormonal secretions brought on by anxiety and emotional upset have been implicated as a contributing factor to this form of overtraining. Anxiety is associated with the fight-or-flight reaction. When people become acutely anxious, the adrenal gland secretes epinephrine (adrenalin) and norepinephrine in greater quantity. Exercise, particularly intense exercise, has the same effect. These hormones stimulate the heart, the respiratory system, and the metabolic rate to prepare people for a real or perceived crisis. The psychological response is one of being ready, or up, for a major effort.

The adrenal gland also secretes cortisol, another hormone that may be involved in overtraining. Secretions of this hormone also increase during periods of intense training. Cortisol increases protein breakdown, which in time, could cause a loss of training adaptations if not balanced by replacement of proteins in the muscles.

Results like these suggest that anxiety coupled with intense exercise or an overabundance of either over an extended period could reduce the circulating concentration of these hormones in the blood, resulting in low motivation, tissue damage, and an inability to mount maximum effort. Excessive stress from outside the training environment could do likewise. A disruption in family relationships, such as an impending divorce or a death in the family, can result in a level of emotional upset that causes the effects of normal training to be excessive. Serious rifts between friends of either sex can cause a similar reaction.

An overabundance of outside responsibilities and activities can also cause overtraining of this type. Even when responsibilities require only time and thinking, they have an emotional content that stimulates the nervous and endocrine systems. Consequently, participation in too many activities, particularly those that involve responsibility, can interfere with recovery from training. Lack of sleep can do likewise. Athletes need rest and recuperation time as well as an adequate amount of sleep to recover from the daily effects of hard training. Staying out late too often can seriously impair recovery and precipitate failing adaptation. This problem can be exacerbated when these activities include excessive drinking or drug use. Besides their toxic effect on body tissues, both stimulate protein catabolism through their stimulatory effect on body processes. They will slow the recovery process, which in time can lead to failing adaptation.

Some athletes are less susceptible to the emotional stresses of training and outside activities than others are. Therefore, they can tolerate greater amounts of both without becoming overtrained. These athletes are usually outgoing, positive, and confident.

They possess an ability to compartmentalize their activities and responsibilities so that the anxiety from one does not intrude on others. They do not dwell on mistakes or poor performances, and they do not become moody or depressed about them. They learn what they can from their mistakes and poor performances, resolve to correct them, and then look to the future.

Some athletes react in a much different way. They do not compartmentalize well, and they allow mistakes and poor performance to get them down for extended periods. These athletes, because of their lowered tolerance for emotional upset, are more susceptible to overtraining. They should reduce their outside activities. Certain forms of relaxation training could be useful to them. They may find that they will improve more by reducing the amount of intense training and the number of competitions they engage in during each season.

Immune Reactions and Overtraining

Many coaches have commented that athletes seem more susceptible to infectious illness than nonathletes. This observation is probably not true when athletes have sufficient tolerance to deal with training and other stressors. Because of its effect on the immune system, excessive stress, the kind that results in overtraining, tends to reduce the resistance of swimmers to illness, particularly colds, flu, and other kinds of respiratory infections (Pyne and Gleeson 1998; Wigermaes et al. 1998). The graph in figure 19.2 illustrates the reaction of the immune system to exercise. Moderate exercise seems to increase resistance to upper-respiratory infections, whereas excessive exercise decreases it.

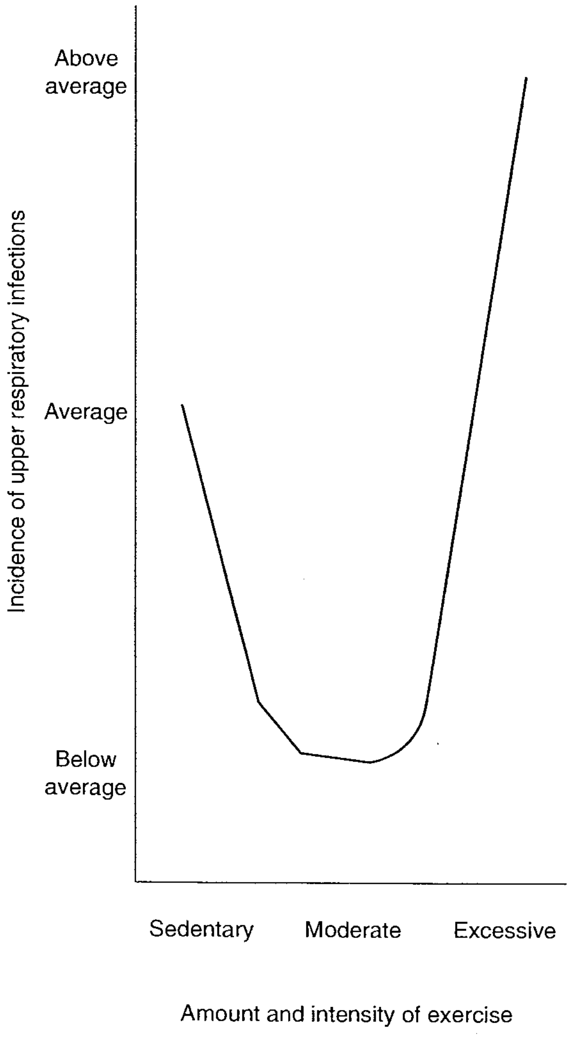


Figure 19.2 The J-shaped relationship between exercise and the incidence of upper-respiratory infection.

Athletes in training should take flu shots to increase their resistance to the various viral strains that could infect them. At the first sign of a cold, they should use some of the new medications that reduce the severity and length of colds. Athletes should also reduce their training to recovery levels or refrain from training altogether during periods when they have upper-respiratory infections. Daily doses of recovery training may also reduce the incidence of viral infections. The results of one study suggest that recovery swimming after intense training can reduce the suppressing effect of that training on the immune system and in so doing protect against invading bacteria, viruses, and germs. Wigermaes and coworkers (1998) found that the concentration of white blood cells was suppressed in runners during the recovery period after intense training. The degree of suppression was much less, however, when they engaged in active rather than passive recovery activities. These authors concluded that active recovery minimizes the drop in white blood cells following intense training and may decrease the vulnerability of athletes to infections. Supplementing the diet with protein, particularly glutamine, may also protect swimmers against immune suppression. In a study in which a group of competitive swimmers trained for 25 weeks, it was reported that lymphocyte suppression could be avoided by administering branch-chain amino acid and glutamine supplements (Kreider, Miriel, and Bertun 1993).

Antioxidants and Overtraining

As we know, oxygen is essential to good performance in endurance activities. It would seem then that athletes could not get too much oxygen. Under certain circumstances, however, oxygen can precipitate tissue damage through the formation of *free radicals*. Most of the oxygen consumed combines with hydrogen to form water in the electron transport chain. But some of that oxygen, about 2% to 5%, leaks out of the electron transport chain in the form of free radicals. These are the same free radicals carried in cigarette smoke and environmental pollutants. In a sense, free radicals are waste products of oxidation. They are substances that contain oxygen, such as superoxide, hydrogen peroxide, and hydroxyl radicals. Normally, most of the free radicals produced in the body are quickly converted back to oxygen and water. In addition, the body contains a natural defense system against the damaging effects of free radicals, which includes enzymes that remove them. Additionally, the antioxidant vitamins A, C, E, and beta-carotene, a precursor of vitamin A, also participate in the removal of free radicals. Not all the free radicals produced are removed, however, and they can accumulate in the body over time. When free radicals accumulate in the body, they increase the potential for cell damage because of the damage they can cause to DNA, proteins, and fats within those cells.

Some scientists have suggested that athletes in training could be at greater risk for tissue damage than sedentary persons are. Their training causes them to consume great amounts of oxygen every day, resulting in the production and accumulation of a greater number of free radicals (Ji 1995; Kanter, Nolte, and Holloszy 1993; Starnes et al. 1989). The prevailing opinion, however, is that normal training also increases the antioxidant enzymes so that that additional free radicals can be removed before they do any damage (Alessio 1993; Higuchi et al. 1985; Quintanilha 1984). Indications are, however, that very intense training not balanced by adequate periods of recovery may eventually result in the accumulation of large amounts of free radicals. That accumulation may cause tissue damage and failing adaptation (McArdle, Katch, and Katch 1996). For example, free radical production is increased by lactic acid production (Demopoulos et al. 1986) and by increases in the secretion of adrenalin and noradrenalin (Cohen and Heikkila 1974).

Because of the potential for free radical accumulation during training, some experts have suggested that athletes should supplement their diets with antioxidant vitamins, particularly vitamins C, E, and beta-carotene. This suggestion may have some merit. The body cannot synthesize these vitamins. Therefore, we must replace them through the food we eat.

Studies with humans also suggest that supplementing the diet with antioxidants may reduce tissue damage from free radicals. In one study, a dietary supplementation with 200 mg of vitamin E daily reduced the concentration of free radicals after exercise (Pincemail , 1987). People who supplemented their diets with beta-carotene, vitamin C, and alpha tocopherol, an active ingredient of vitamin E, also reduced the concentration of free radicals following exercise (Kanter et al. 1993).

Selenium and coenzyme Q10 have also been mentioned as having antioxidant properties. Although studies are few in number, the available information suggests that supplementing the diet with coenzyme Q10 is not necessary because its effectiveness as an antioxidant is open to question. Supplementation with small amounts of selenium may be beneficial, however, because it acts as an antioxidant in combination with vitamin E. Deficiencies are rare, but athletes may require more of this micromineral.

Because of the research cited and other similar studies, some experts have suggested that athletes should supplement their diets with additional amounts of antioxidant vitamins so that they can remove more free radicals. In doing so they may reduce the amount of tissue damage from training and build a defense against failing adaptation. Athletes may wish to supplement their daily diets with 400 to 800 mg of vitamin C, 400 mg of vitamin E, 30 mg of beta-carotene, and 60 to 100 micrograms of selenium. Each of these can become toxic if consumed in excessive quantity. In the quantity I have recommended, however, there is no danger of that happening. For example, vitamin E supplements that were 200 times the recommended daily allowance have been used with no complications (Bendich and Machlin 1988). Let me caution that I am not recommending megadoses of the antioxidant vitamins. The supplements I have recommended will be adequate to remove the additional free radicals produced during training. Megadoses will not provide any more protection, and they could cause complications because of their toxicity.

If an athlete prefers not to supplement, antioxidant vitamins and the micromineral selenium are available in the following foods:

- *Beta-carotene:* sweet potatoes, spinach, broccoli, carrots, apricots, mangoes, and papaya
- *Vitamin C:* broccoli, grapefruit, mangoes, oranges, papaya, and strawberries
- *Vitamin E:* almonds, sunflower seeds, wheat germ, margarine, and mayonnaise
- *Selenium:* meats, seafood, and whole-grain products

Symptoms of Overtraining

The most common symptoms of overtraining are listed in table 19.2. Remember that these are all common reactions to training and competition. Only when they seem exaggerated and persist for several days should overtraining be suspected. The symptoms can be placed in three categories: those involving performance, those that that are primarily physical, and those that are emotional in nature.

Performance Symptoms

The first sign of overtraining that coaches and athletes should notice is poor performance in meets and in training. When athletes have been swimming consistently slower in training over several days, they may be overtrained. The same thing may be happening when their performance in meets become progressively worse over a period of a few weeks.

Diagnosing overtraining with performance is complicated by the expectation of slower competition and training times during midseason when athletes are swimming

Table 19.2 Symptoms of Overtraining

PERFORMANCE	PHYSICAL	EMOTIONAL
Slower times during maximum effort	Loss of weight	Depression
Higher heart rates at submaximal speeds	Joint and muscle soreness	Irritability
Increased stroke rates for submaximal and maximum efforts	Allergic reactions	Insomnia
	Loss of appetite	Anxiety
	Head colds and sinusitis	Withdrawal
	Nausea	Difficulty concentrating
	Lack of energy	Loss of confidence
		Lowered motivation

in a tired state. Another complicating factor is that training performance may be normal or even good during long endurance sets even when swimmers are overtrained. Some swimmers, particularly distance swimmers, become so well trained aerobically that they can swim very well in training even when extremely fatigued. Only after they rest and fail to improve their performance does it become evident that something went wrong in the training process.

There are several ways to differentiate normal midseason performances from those that signal overtraining. As mentioned earlier, overtrained athletes may be able to perform well in long endurance sets of low to moderate intensity. The telltale clue appears when these swimmers try to perform quality swims in training, when they swim time trials, or when they compete in races. They will not be able to swim much faster than they did during their endurance sets in training. In my experience, the inability to swim at normal speed during repeats at threshold speed and faster is the best indicator that athletes may be entering a state of failing adaptation.

Even this response may not be evident in the early stages of overtraining. By simply trying harder, many athletes are able to maintain their performance in spite of failing adaptation. Therefore, another way to spot overtraining is to evaluate whether athletes seem to require greater than normal effort to achieve normal times in training. If swimmers require higher heart rates and faster stroke rates to achieve a particular time, complain of fatigue during moderate-speed swims, or are unable to swim sets at or beyond threshold pace without becoming excessively fatigued, they may be overtrained.

Physical Symptoms

The most common physical symptoms of overtraining are a loss of weight that cannot be explained from dietary habits or training volume, loss of appetite, muscle or joint soreness, feelings of weakness that persist even during recovery periods, and allergic reactions. Let me discuss each of these symptoms in detail.

Swimmers will normally lose some weight during the first weeks of the season, but their weight should stabilize after that. Sudden weight loss during the middle of the season warns that overtraining may be imminent. Diagnosing overtraining from weight loss, however, is not always easy. Daily fluctuations in body weight are common and normally occur when training is cycled properly. Swimmers will routinely lose 1 to 3 lb from the beginning to the end of a training day. Most of this weight loss will result from dehydration caused by sweating and loss of muscle glycogen, and swimmers will normally replace it by the next training day or two. Weight loss that continues over several days with little or no sign of recovery signals the possibility of overtraining.

Athletes often lose their appetites when they become overtrained. As a result, they will fail to replace their muscle glycogen from day to day, and they will complain that they have no energy. With the close association between lack of energy and nutrition, one might assume that overtrained athletes would eat more than usual, but that is not the case. They generally lose interest in food and do not feel hungry even though they may be losing weight.

Ascertaining whether muscle and joint weakness and soreness are the result of overuse or a symptom of overtraining is difficult. The same is true of allergic reactions. They may indicate a real medical problem, or they can be a signal that the athlete is entering a period of failing adaptation. Heavy muscles and a feeling of weakness may accompany a particularly intense training session, but the symptoms should disappear quickly. Several consecutive days of feeling heavy and weak, however, may be a sign of overtraining. Muscle and joint soreness, like weight loss, is normal during the early weeks of training and following intense training sessions. Swimmers may also feel soreness when a new form of training is added to the program. But when athletes complain of sore muscles or joints over several days in the middle of the season, particularly after normal or relatively easy training sessions, overtraining should be suspected.

Athletes who complain of sore shoulders or knees may not necessarily be overtrained. Some may be suffering symptoms of overuse that have more to do with their anatomy and their mechanics than with overtraining. A physician or trainer should treat those swimmers. Overtraining should not be suspected unless the athlete has no history of tendinitis and unless other symptoms of failing adaptation are present.

Swimmers demonstrate symptoms similar to allergic reactions when they become overtrained. Hives, rashes, head colds, and stuffy noses are the most common signs. Of course, these symptoms may also indicate true allergic reactions. Therefore, swimmers should see a physician when these symptoms appear. Overtraining should be suspected when the symptoms persist and there is no medical explanation for them.

Emotional Symptoms

The physical and emotional reactions of athletes to overtraining are so intertwined that it is impossible to separate the two. Some negative disturbances in an athlete's disposition are apparently a normal response to intense training (Morgan et al. 1987). Only when those disturbances become unusually severe and persistent should overtraining be suspected. Raglin and Morgan (1989) and Morgan and associates (1987), citing research spanning more than 10 years, have stated that overtraining is nearly always accompanied by depression and anxiety. This reaction is interesting in light of the fact that mild exercise has been shown to have the opposite effect (Morgan 1985). Athletes who are overtrained may become unusually irritable. They may appear uptight and show signs of having difficulty in concentrating at practice and at other times during the day. Their manner may suggest a loss of confidence, and they may withdraw from social gatherings. In practice, they may prefer to swim by themselves in an empty lane. Another way they may avoid interacting with teammates is to arrive just before practice begins and leave immediately after it ends. They may also experience insomnia and restless or interrupted sleep. Specifically, they will have difficulty getting to sleep, and when they do sleep, they will toss and turn or wake up several times during the night. As with other symptoms, an occasional down period, an occasional emotional reaction, or an occasional restless night may mean nothing. When these conditions persist for several days, however, overtraining may be present. Unfortunately, a swimmer will already have entered a state of failing adaptation when these symptoms become persistently noticeable. Nevertheless, if overtraining is discovered early, it can be corrected with 3 to 7 days of recovery training. If allowed to go untreated until the condition becomes severe, several weeks will be required to recover and then regain lost training effects.

Diagnosing Overtraining With Physical and Psychological Tests

A considerable amount of research has focused on finding physiological "markers" that can identify athletes who are overtrained before the condition becomes severe. Attempts have included measures of oxygen consumption, blood lactate, heart rate, stroke rate, muscular power, anaerobic capacity, blood pressure, red and white blood cells, ECGs, urinary and blood proteins, muscle enzymes, and psychological mood states. None of these methods have proved entirely accurate. Individual normal levels vary widely for these measures. Baseline measures can vary widely among these categories. Consequently, it is difficult to know whether changes in the levels are abnormal reactions that indicate overtraining or simply normal reactions to hard training. Nevertheless, some of these measurements have shown a degree of predictability that could make them useful for spotting overtraining in the early stages. Those will be discussed in the following sections.

Oxygen Consumption

The most reliable indicator of overtraining may be a deterioration of swimming economy. In other words, swimmers may require more oxygen to swim a particular speed when they become overtrained. Costill (1986) reported on a cross country runner who required 14% more oxygen to run at a particular submaximal speed when he became overtrained. The runner's oxygen cost was 49 ml/kg/min for a submaximal run at the time of his best competitive performance, but it increased to 56 ml/kg/min later in the season when his performance deteriorated. Miller and colleagues (1989) have also reported decreases in economy for a group of swimmers who were overtrained.

A reduction in swimming economy, however, is not a foolproof indication of overtraining. The difficulty inherent in diagnosing overtraining with this measure is that economy also declines when athletes are training hard. Before economy can be used as a marker for overtraining, criteria must be established that differentiate the amount of decline that signals overtraining from the normal decline that occurs during hard training. Another suggestion is to permit a few days of recovery time before administering a swimming economy test. Then only the overtrained swimmers will show decrements in performance.

The major drawbacks to using oxygen consumption to evaluate overtraining are the expense and expertise required to do so. The oxygen consumption of swimmers should be measured while they are swimming. Doing this requires expensive analyzers and trained test administrators, besides taking time away from training. This procedure may be workable for use with national-level swimmers at training camps where facilities, equipment, and trained personnel are available. For most coaches, however, the expense and lack of expertise does not permit use of this procedure.

Blood Lactates

Blood lactates have also been used to evaluate overtraining. Tests have been designed that use both submaximal and maximum efforts. Blood tests following submaximal efforts act similarly to measures of oxygen consumption for measuring changes in swimming economy. A swimmer may be overtrained when his or her blood lactate concentration is higher at standardized submaximal speed or, conversely, when the swimmer achieves a particular blood lactate concentration at slower speed. A large reduction in peak blood lactate concentration following a maximum effort swim may also indicate an overtrained state.

These measures, like oxygen consumption, are not foolproof. Glycogen depletion is one factor that could cause a misdiagnosis. Lower blood lactate concentrations may occur at submaximal and maximum speeds when athletes are glycogen depleted. Thus, they may appear to be improving their aerobic capacity when they are actually becoming overtrained (Frohlich et al. 1988). Similarly, athletes who have larger concentrations of glycogen in their muscles on a subsequent test will also have higher blood lactate concentrations at similar speeds. Consequently, they may appear to be overtrained when they are not.

A study by Tegtbur and associates (1988) may help in making judgments about overtraining from blood tests. The study showed that speeds at the anaerobic threshold needed to be corrected for reductions in peak blood lactate values before they could be used to diagnose the effects of training. In other words, if a particular swimmer exhibited a reduction of 15% in maximum blood lactate, his or her velocity at the anaerobic or some fixed threshold would have to be increased by 15% before it would accurately reflect the athlete's threshold pace. If that increase resulted in a slower threshold pace than the swimmer achieved on previous tests, the swimmer may be overtrained. The swimmer was probably responding well to training if it did not.

When blood lactates are used to diagnose overtraining, swimmers should have a few days of rest to reduce the transitory effects of hard training and muscle glycogen depletion before they are tested. A maximum effort swim should also be included in the test to determine whether any change has occurred in the athlete's peak blood lactate.

The principal disadvantage of blood tests is that they require expensive equipment and an experienced administrator, although these requirements are less burdensome than those needed to measure oxygen consumption. Blood testing is considerably less expensive and requires less training. Coaches can learn the procedure in a short time and conduct it at their training sites as long as trained medical personnel are available to ensure the safety of the swimmers.

It may be possible to spot impending overtraining by measuring for peak blood lactates after maximum effort swims conducted over the same distance from test to test. Overtrained athletes will have similar or lower maximum blood lactate concentrations for maximum efforts over a particular distance, but their times will be slower than on previous tests.

Maximum blood lactate values require interpretation to improve their accuracy for diagnosing overtraining. They will normally be reduced somewhat during periods of emphasis on endurance training. Therefore, coaches need to assess the degree of reduction in peak blood lactates that distinguishes overtraining from a normal training-induced reduction.

Increases in resting blood lactate concentrations have also been used to indicate overtraining. Normal resting blood lactates are in the neighborhood of 1.0 mmol/L. Therefore, resting values of 2.5 to 4 mmol/L have been suggested to indicate overtraining. This method also has pitfalls. Resting blood lactate concentrations may be normal for some swimmers even when they are overtrained. Resting blood lactate measurements used to screen for overtraining should be taken before training and after the swimmers have been resting for 5 or 10 min. The measurements should be taken on the day following a day of low-intensity or recovery training and at the same time of day for each test. Following these suggestions will reduce the possibility of contamination from previous hard training and other activities the swimmer may have engaged in before arriving at the training site.

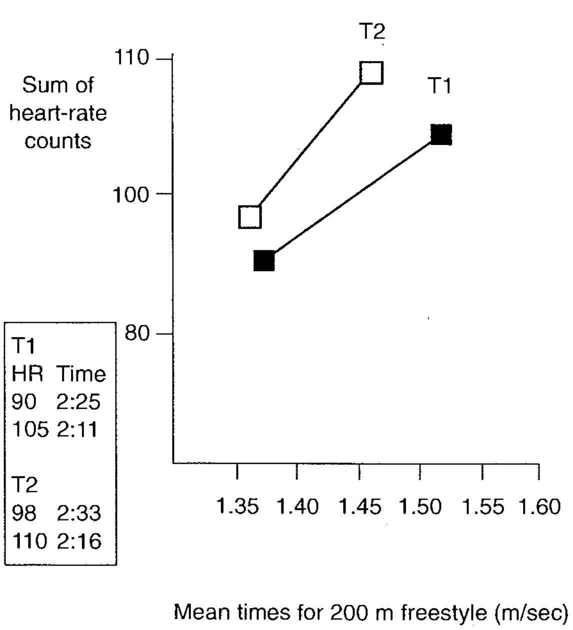


Figure 19.3 A heart-rate profile that suggests overtraining.

Heart Rates

The heart-rate profile (Sharp et al. 1984) described in chapter 16 can also be used to diagnose overtraining. A swimmer may be overtrained when his or her heart rate is higher at a particular submaximal speed. The heart rate of the cross country runner in the study by Costill (1986) increased by 24 bpm (18% increase) for the same submaximal running speed when he was tested in an overtrained state. A heart-rate profile that may indicate overtraining is shown in figure 19.3.

The athlete in this example swam times of 2:25 and 2:11 for each of two 200 m swims on his first test. The sum of his working and recovery heart rates were 90 and 105 respectively. Notice that he swam slower times with higher heart-rate counts on his second test. His times were 2:33 and 2:16 with heart-rate counts of 98 and 110. These combinations of times and heart-rate counts indicate greater effort for slower times on the second test. These results do not necessarily indicate overtraining. Many reasons could explain the results. For example, the athlete may have been training too little or too easy during the time between the two tests, or he may have been ill before the second test. But if diagnoses such as these can be discounted, then overtraining should be suspected.

Resting heart rates have also been used to diagnose overtraining. Reports of increases of 6 to 10 bpm have been associated with overtraining in the literature (Dressendorfer, Wade, and Schaff 1985; Stray-Gunderson, Videman, and Snell 1986). To improve the accuracy of this measure, athletes should rest quietly for 5 or 10 min before counting their resting heart rates.

As with resting blood lactates, an athlete who exhibits a large increase in his or her resting heart rate may be overtrained. Again, however, the absence of an increase in the resting heart rate is not proof positive that an athlete is *not* overtrained. Not all overtrained athletes show an increase in resting heart rate.

To complicate matters further, resting heart rates may actually decline when overtraining has come on slowly over a long time because athletes may have reduced their training involuntarily when they became overtrained. Reduced resting heart rates accompanied by an inability or lack of desire to reproduce previous maximum efforts may indicate overtraining, but a decreased resting heart rate accompanied by adequate maximum efforts indicates an improvement in physical condition.

Another method suggested for diagnosing impending overtraining is to measure the difference between lying and standing heart rates. A large difference may indicate poor recovery from training that can over time result in overtraining. Heart rates increase when people rise from a reclining position because the heart must work harder to push blood from the legs back to the heart against gravity. The amount of increase is usually less for well-trained persons because their vessels react quickly by dilating and reducing the pressure against which the heart must pump. Vessel dilation may be slower when athletes become excessively fatigued; therefore, the difference between the lying and standing heart rates will increase. The graph in figure 19.4 shows the response of an athlete who has become overtrained. The chart begins in January when the athlete was untrained. Notice that both his lying and standing heart rates decline over several months of training and that the difference between the two narrows as well. This athlete apparently became overtrained sometime in July, as indicated by increases in both lying and standing heart rates and an increase in the difference between the two. Finally, notice that the athlete's heart rates begin to decline toward earlier levels when some time was provided for recovery.

Recovery heart rates may also be good markers of overtraining. Overtraining should be suspected when athletes require more time to recover from a standardized submaximal swim or set of repeats. The validity of this method will improve when the speed of the swim or swims is sufficient to elevate an athlete's heart rate close to maximum (greater than 160 bpm). For greater accuracy, the swimming and recovery times should be standardized from test to test. A recovery time of 45 sec to 2 min is sufficient to evaluate the recovery of well-trained athletes. Although their heart rates may not return to normal in this time, the amount of slowing will provide a good indication of the swimmers' state of fatigue. Slower recovery of the heart rate by 8 to 10 bpm may be an indicator of overtraining.

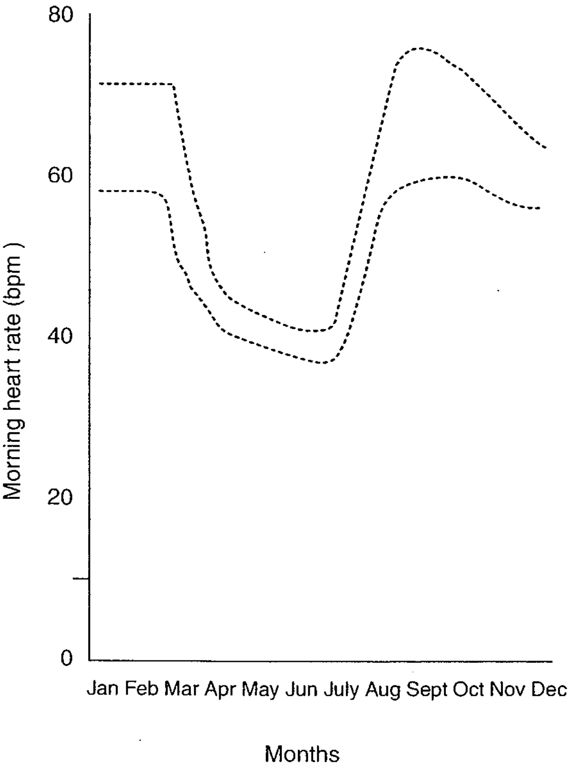


Figure 19.4 A method for diagnosing responses to training. Changes in both the lying and standing morning heart rates are plotted during several days of each month.

Adapted from Czajowski 1982.

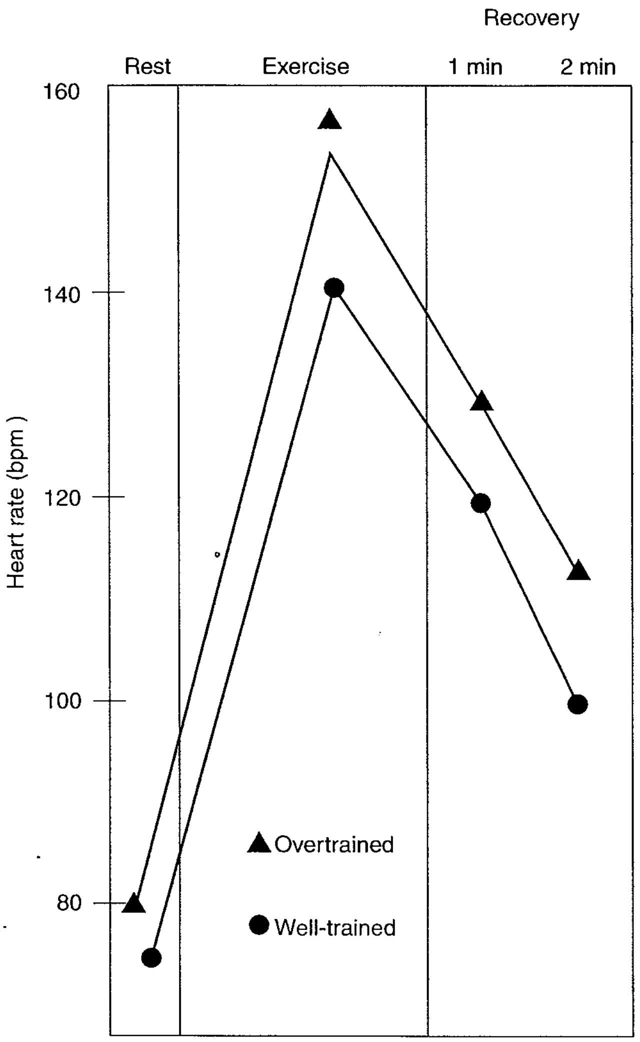


Figure 19.5 Changes in resting, exercise, and recovery heart rates that may take place when an athlete becomes overtrained.

The graph in figure 19.5 illustrates the changes in resting, exercise, and recovery heart rates that may take place when an athlete becomes overtrained. Notice that under normal training conditions (well-trained) the values are 70 and 140 bpm for resting and exercise rates. Values were 120 after 1 min of recovery and 100 after 2 min of recovery. When overtrained, the same athlete showed a 10 bpm increase in resting heart rate (80 bpm) and a 20 bpm increase in exercise heart rate (160 bpm). Recovery heart rates were also approximately 10 bpm higher at 1 and 2 min after exercise.

Heart rates are somewhat more erratic than measures of swimming economy and blood lactate. Consequently, they may not be as reliable for diagnosing overtraining. On the positive side, they require no expensive equipment and are easy to administer and evaluate. The most valid and reliable results will be achieved with the use of a good heart-rate monitor. Unless they use the proper technique, athletes and coaches are prone to miscounting heart rates. Nevertheless, even manually counted heart rates provide a measure that coaches can use to diagnose overtraining as long as they are aware of how they may misinterpret the various heart-rate measures.

Stroke Rates and Stroke Lengths

An excellent method for identifying overtraining that has not received much attention is measuring for differences of stroke rates and stroke lengths. Recent research suggests that increases in both or either may be an accurate method for spotting overtraining. Athletes who become less efficient (lower swimming economy) have to swim a particular speed with a higher stroke rate to compensate for a shorter stroke length. The number of strokes taken per pool length can also be counted in lieu of measuring stroke rates. Obviously, a swimmer's stroke length will be shorter when he or she requires more strokes to swim a standard distance.

Stroke rates can be used to diagnose overtraining by selecting a standard-speed swim of 200 to 500 yd or m. The speed of the swim should be in the neighborhood of 85% to 95% of the athlete's best time so that it is fast enough to cause some fatigue without requiring a maximum effort. A fatigued swimmer can swim easy with no change in stroke rate or stroke length when the effort is not taxing. The effort must be sufficient to cause overtrained swimmers to compensate for reduced economy by increasing their stroke rates. Weiss and coworkers (1988) showed that speeds above the anaerobic threshold are sufficient for this purpose.

Several devices are now available that allow the measurement of stroke rates during repeats and competitions. Of course, no special equipment is required to count the number of strokes that swimmers take per length. The relationship between stroke rate and stroke length will be discussed in detail in part III of this book.

Devices are also available to measure swimmers' stroke lengths, although stroke lengths can be calculated simply by stroke counting. The distance covered during each stroke cycle can be determined from the number of cycles required to travel a particular distance. Those computations should be made between the flags in the middle of the pool length so that the length and velocity of a swimmer's push-off do not introduce errors into the computations.

Although not as precise, an easier method is simply to count the number of strokes a swimmer uses to swim a particular distance. When that number increases, stroke length has decreased even though the amount of that decrease is not known. Distances of 25 yd or m are usually too short to see a noticeable decrease in stroke length with stroke counting. When they are overtrained, mature, skilled swimmers usually will not increase their stroke count by even one cycle. An increase of one stroke cycle would compute to a huge loss in stroke length, a greater loss than even the most overtrained swimmer is likely to have. A change in the stroke count becomes a more reliable measure over longer distances because small decreases in stroke length will manifest themselves when a larger number of strokes have been counted.

Determining Stroke Length by Stroke Counting

This section explains a procedure for calculating stroke length from stroke counting. The athlete is swimming in a 50 m pool, and the distance between the flags is 40 m for each length. The swimmer requires 20 stroke cycles to complete this distance; therefore, the stroke length is 2.0 m/cycle.

Distance between flags = 40 m
Number of stroke cycles = 20
Stroke length = 40 m ÷ 20 stroke cycles = 2.0 m/stroke cycle

The difficulty in making a completely reliable determination from these measures is that some loss in stroke length and a concomitant increase in stroke rate will probably occur during periods of hard training and between the beginning and end of weeks when a steady depletion of muscle glycogen has occurred. Therefore, the results will be more accurate if the test is administered after athletes have had a few days of rest. Coaches will have to rely on their judgment and experience to distinguish normal training-induced stroke rate increases and stroke length decreases from those that are excessive and indicative of overtraining.

Measurements of stroke rates and stroke length are, next to heart rates, probably the easiest measure to use for identifying overtraining. These methods may be more reliable than heart rates. When athletes must stroke faster to swim a standard time, there is a good possibility that they need some rest and recovery or may soon become overtrained. The reliability and validity of these measures for diagnosing overtraining have not been investigated, but they show great promise for this purpose.

Standardized Repeat Sets

Heart rates, stroke rates, and stroke counts are probably the best methods available to the average coach for evaluating overtraining. They do not require expensive equipment or trained personnel, and they can be measured without interrupting normal training. Therefore, coaches are advised to develop standardized sets of repeats, like those described in chapter 16, to measure improvements in physical condition and to evaluate athletes for overtraining. Sets of repeats developed for this purpose should measure performance in the overload endurance area so that both aerobic and anaerobic metabolism are heavily involved. Consequently, the sets should probably be 1,000 to 3,000 yd or m in length. Swimmers should perform repeats of 100 to 500 yd or m on short rest. Swims of 50 m, even on short rest, do not provide enough time to collect the information needed for evaluation. For the reason stated earlier, the speed of the swims should be faster than anaerobic threshold speed. If that speed is not known, heart rates of 160 to 170 bpm or perceived efforts of 17 to 18 on a Borg scale indicate an adequate swimming speed.

Some combination of the following should be measured during these standardized sets of training repeats: exercise and recovery heart rates, stroke rate, stroke count, and average repeat speed. As with heart-rate profiles, when exercise and recovery heart rates are higher for similar or slower swims, the athlete may be entering a period of

Table 19.3 Results for Two Standardized Sets of Repeats

TEST DATE	REPEAT SET	AVERAGE TIME	EXERCISE HEART RATE BPM	RECOVERY HEART RATE AFTER 45 SEC BPM	STROKE RATE CYCLE/M	STROKES PER REPEAT
1/20/99	20 x 100/1:20	1:06.00	160	97	38	56
2/12/99	20 x 100/1:20	1:07.50	170	110	40	60

The results of the second test may indicate overtraining if lack of training and illness can be ruled out. Notice that the swimmer's average time is slower, yet his exercise heart rate, recovery heart rate, stroke rate, and stroke count are all higher. These measures all indicate that more effort was required to swim slower on the second test than the first. Therefore, the athlete may be in failing adaptation.

failing adaptation. Likewise, failing adaptation may be indicated when a higher stroke rate or a greater number of strokes are required to swim similar or slower repeat times. The data listed in table 19.3 show an athlete who may be overtrained. Exercise and recovery heart rates were higher for slower times, and the athlete was swimming with a faster stroke rate and taking more strokes per repeat. These measures indicate greater effort for slower times on the second test as compared with the first. If other factors can be ruled out, overtraining may be the cause.

Including all these measures in a test is cumbersome, however, and the results are seldom as neat and clear cut as I have represented them in table 19.3. Consequently, the accuracy of such tests for diagnosing overtraining will improve with the inclusion of several measurements. I have indicated previously how each of these measures by itself could provide a misleading analysis. But when several of these measures point in the same direction, the probability of a correct diagnosis of overtraining increases. For example, a swimmer may swim slightly faster times with a higher exercise heart rate and a slower recovery rate on a subsequent test. In that case, it will be difficult to determine whether the increases of exercise and recovery heart rates were due to overtraining or simply faster swimming. A good indication that the swimmer is not overtrained would be a stroke rate or stroke count that has not changed. If either or both of these measures is unusually high, the athlete may be entering failing adaptation. A more complete description of the meaning of various combinations of these measures on standardized tests was provided in chapter 16.

Flexibility Tests

Overtraining may cause a reduction in the range of motion around certain joints. Measurements of shoulder and ankle flexibility over several decades have convinced me that this is a reliable indicator of overtraining. Other sources have also alluded to this response. Kibler, Chandler, and Stracener (1992) reported that a decrease of flexibility often preceded the symptoms of muscle damage (soreness, pain, and swelling) that signal overtraining. Testing flexibility on a periodic basis, each week or every other week, may help coaches spot impending overtraining before it becomes serious and causes significant reductions in performance.

I suggest measuring and comparing the range of motion for horizontal extension at the shoulder joint, ankle extension (plantarflexion) or flexion (dorsiflexion) ability, and lower back hyperextension. Baseline measurements of the range of motion in these joints should be established early in the season. Flexibility may increase during the season, particularly if stretching exercises are included in the training program. Later in the season, overtraining should be suspected if, in combination with other indicators, a significant reduction occurs in the range of motion in two or three joints. Flexibility measurements should be conducted after a few days of easy or recovery swimming. Occasional tightness will normally occur on the day after an intense training session. Only when tightness continues after a day or two of recovery should overtraining be suspected.

Tests of Power and Buffering Capacity

Some persons speculate that power and buffering capacity will decline when athletes become overtrained. Therefore, tests such as one repetition of a weightlifting exercise with maximum resistance, one pull on a swim bench, or a vertical jump have been proposed to diagnose overtraining. The validity of such tests are doubtful, however, because they are too short to reflect major changes in swimming performance and, except for the swim bench test, are not specific to swimming. Even that test is not truly specific to swimming, as Costill and his associates have shown (1985). A better method is to perform sets of 50 or 100 swims. They are long enough to reflect both anaerobic and aerobic changes, and it is not likely that athletes can maintain their performance on these sets through motivation alone. Motivated athletes can muster enough resolve to perform well for short efforts even when they are overtrained.

Blood Pressure

Kirwan and associates (1988) reported a pronounced rise in resting diastolic blood pressure when athletes were having difficulty tolerating training. This was reported in the study, described earlier, in which the training volume of swimmers was deliberately doubled for 10 days. Although not conclusive, their results suggest that increases in resting diastolic pressures of 10 mm Hg may signal overtraining.

Hormones

Several hormones have been implicated in overtraining. The first is cortisol, which is secreted by the cortex of the adrenal gland. Its function is to aid in the maintenance of normal blood glucose and free fatty acid levels. Also implicated are adrenaline (epinephrine) and noradrenalin (norepinephrine). Epinephrine stimulates blood flow, oxygen consumption, and the breakdown of glycogen. Norepinephrine increases heart rate and blood pressure. The normal response to training is a reduction of secretions of cortisol, adrenalin, and noradrenalin at a standardized workload (Winder et al. 1979). Because of this, some experts have speculated that higher than normal blood levels of these hormones may signal overtraining.

Cortisol has received the most attention as a marker for overtraining. O'Connor and his coworkers (1989) reported that a high resting level of cortisol was significantly related to overtraining. The results of the study by Kirwan and associates (1988), however, suggest otherwise. They reported that an increase of cortisol was a normal response to hard training and could not be used to identify overtrained athletes.

Psychological Mood States

Paper and pencil tests that indicate the moods of athletes have been gaining acceptance in recent years for diagnosing overtraining. They are easier to administer and evaluate than tests that measure oxygen consumption, blood lactate, hormones, and enzymes. Morgan and his coworkers used one of the best of these tests to diagnose overtraining in several studies. Called the *profile of mood states* (POMS), the test was developed by McNair, Lorr, and Droppleman, (1971). The test consists of 65 items that measure levels of tension, depression, anger, vigor, fatigue, and confusion. Vigor is considered a positive mood state, so it is scored positively. The other five are deemed negative mood states, so high scores are assigned a negative value. A composite score is computed by subtracting the score on vigor from the sum of the scores on the five negative measures. That score is multiplied by 100 to eliminate negative values, and the resulting positive number reveals whether the athlete is lacking in interest and vigor or has an optimistic outlook on life. High scores reflect a tendency toward depression, lack of interest, low energy, and poor motivation, whereas low scores manifest an optimistic outlook.

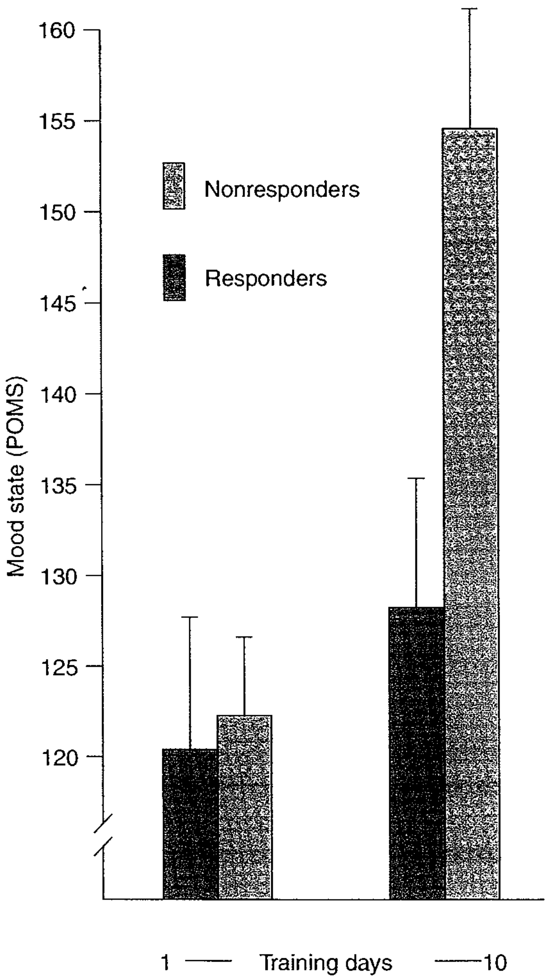


Figure 19.6 The effect of 10 days of intensified swim training on scores for the profile of mood states.

Adapted from Morgan et al. 1988.

Morgan and his various coworkers have administered this test to more than 186 male and female swimmers over a period of several years. They found unusually high scores on the POMS test characteristic of swimmers considered by their coaches to be overtrained. Over time, the POMS test has been able to identify 74% of the male and 89% of the female swimmers who were considered overtrained (Raglin and Morgan 1989).

In a study concerning the effect of a sudden increase in training mileage on swimmers, Morgan and his associates (1988) used the POMS test as one of the markers for overtraining. Figure 19.6 presents the results of that study. Of the 10 swimmers tested, 6 tolerated the training increase well, and 4 did not. Subjects in the first set were called responders, and those in the second set were identified as nonresponders. Although scores on the POMS test increased for both groups, the 4 swimmers who had difficulty with the training program increased their scores significantly more than the others did.

Judging from these results, the POMS test may be a valuable tool for diagnosing impending overtraining. The POMS test may be a good instrument for identifying overtraining if norms can be established for normal and extranormal increases with hard training. Coaches must be able to distinguish the normal reduction in a swimmer's pleasant outlook that accompanies an increase in training mileage from a movement toward depression that signals overtraining. A survey of the available literature suggests that absolute POMS scores above 150 or relative score increases greater than 25% signify that overtraining may be imminent.

Although the POMS test identifies persons who are more depressed than average, high scores should not be considered symptomatic of clinical depression. High scores mean only that an athlete may be overtrained and may require some rest and recovery from training. They do not mean that the athlete is suffering from a neurotic psychological condition. For that reason, this test should not be used to predict serious psychological disturbances. Disruptive changes in behavior, not the result of a psychological inventory, should be the cause of a coach's recommendation that a swimmer seek professional help.

Symptom Checklists

Bompa (1999) has developed another paper and pencil test that may be useful in spotting potential overtraining. The test is a self-report checklist that can be used to evaluate a chronic condition of inadequate recovery that often precedes overtraining. With this test, athletes report their reactions to several symptoms during each training day. The reactions are charted to reveal a pattern of adjustment to training. Several symptoms should be charted daily:

- Resting heart rate in bpm
- Body weight in lb or kg
- Hours of sleep

- Quality of sleep, reported as deep, normal, restless, bad with breaks, or not at all
- Tiredness, reported as very rested, normal tiredness, very tired, or painfully tired
- Training willingness, reported as very willing, good, poor, unwilling, or did not train
- Appetite, reported as very good, good, poor, eat because I should, or did not eat
- Competitive willingness, reported as high, average, low, or not at all
- Muscle soreness, reported as no pain, little pain, moderate pain, or severe pain

Figure 19.7 shows a sample of charts for length of sleep, quality of sleep, training willingness, and appetite. Taken from Bompa (1999), these charts are those of an athlete training for the Olympic Games. The athlete was obviously not responding well to training from the 11th through the 16th day of the month.

Bompa's checklist has value because coaches can adapt it to their training philosophies and environments. A coach could construct a custom checklist by taking all or some portion of these symptoms and charting them. To establish normative data, the coach should start early in the season when athletes are not overtrained. Athletes should receive instructions about what the different ratings mean so that they will rate themselves using the same scale. Once the normative data have been collected and evaluated, any temporary reduction from those ratings should be considered a poor adjustment to training. Significant reductions that persist over several days may indicate impending overtraining.

Summary of Tests for Diagnosing Overtraining

The best methods for diagnosing overtraining in its early stages are those that are readily available to coaches, such as counting heart rates, counting stroke rates, stroke counting, and flexibility measurements. Sensitivity to the warning symptoms listed in table 19.1 can also help coaches recognize this condition before it becomes severe. Paper and pencil tests and checklists that evaluate psychological mood states also appear to be highly reliable for evaluating overtraining. Measurements of enzymes, hormone, urea, and 3-methlyhistidine are no more reliable or valid than the simpler measures for spotting overtraining. Possibilities for misdiagnosis are just as great when one attempts to determine whether changes in the measures are reactions to normal hard training or indicators of overtraining. And, of course, measurement of enzymes, hormone, urea, and 3-methlyhistidine are expensive, time consuming, and require extensive training.

Relieving Overtraining

Three to 7 days of recovery training are usually sufficient to reduce the symptoms of overreaching if the condition is caught before a severe loss of training adaptations has occurred (Urhausen, Kullmer, and Kindermann 1987). The situation is different if the athlete has been overreaching for an extended period and has lost a significant portion of the training effects acquired earlier. The athlete will be in an overtrained state, and a period of 2 or 3 weeks to 3 mo may be required for recovery. Morgan and coworkers (1987) have reported on a number of swimmers who required several weeks to return to normal mood states after becoming overtrained. They also reported on others who never fully recovered during 4 to 6 weeks of rest.

When athletes show signs of overreaching after several days of intense training, their training intensity and volume should be reduced for 2 to 3 days. They should swim at recovery and basic endurance levels during that time, doing a few sets of sprint training to maintain their speed. This procedure should relieve the problem if it is the result of short-term overreaching.

A longer period of recovery will be required if athletes fail to recover. Poor recovery indicates overtraining and a loss of training adaptations. In that case, athletes should

Name ______________________ Month ____________

Length of sleep (hrs)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
12+																															
11																															
10						●																									
9				●			●	●	●	●																					
8	●	●	●		●						●																				
7																															
6												●		●																	
5													●		●	●															
4																															
No sleep																															

Quality of sleep

Deep		●					●																								
Normal	●		●	●	●	●		●	●	●																					
Restless											●																				
Bad with breaks												●	●	●		●															
No sleep															●																

Training willingness

Very willing	●	●	●		●	●	●	●																							
Good				●					●	●																					
Poor											●																				
Unwilling												●	●	●		●															
Did not train															●																

Appetite

Very good		●	●	●	●	●	●																								
Good	●							●	●	●																					
Poor											●																				
Eat because should												●		●	●	●															
Did not eat													●																		

Figure 19.7 A checklist for evaluating responses to training.

Adapted from Bompa 1999.

be dismissed from training for 3 to 5 days. When they return, they should train with reduced intensity and volume until recovery occurs. As indicated earlier, that may take 2 weeks to several months, depending on the severity of the condition.

Training frequency should be reduced to once per day to provide more time for rest, recovery of muscle glycogen, and regeneration of muscle tissue. The majority of the training should be completed at recovery and basic endurance speeds. In addition, athletes should complete some short sets of sprints several days during the week to maintain their speed. They should not do any extended sets at threshold or overload endurance speeds, nor should they do any long sets of race-pace or lactate tolerance training.

They can, however, test their progress toward recovery by swimming short sets of repeats (600 to 800 yd or m) at threshold or overload endurance speeds or by descending to these speeds near the end of basic endurance sets. They will be on the road to recovery when they can do those swims with stroke rates, stroke lengths, and heart rates similar to those they required for the same speeds before they became overtrained. They must be able to perform without suffering a relapse during the next training session.

The physical or emotional condition of athletes should be monitored with whatever evaluation devices the coach has chosen to use—self-reports, standardized repeat sets, heart rates, or other measures. Coaches should be careful about having athletes resume hard training too soon when they begin to show signs of recovery. Test results, attitude, body weight, heart rates, and so on should indicate recovery for 3 to 5 days before an athlete begins intense training after a serious bout with overtraining. If an athlete returns to hard training before recovering completely, the condition could recur.

Athletes who became overtrained because of external stressors of an emotional nature should be given some time away from training even though excessive work was not the precipitating factor. They should use their free time to resolve whatever personal conflicts they might have. Heart-to-heart talks with instructors, friends, and parents may be in order. They should also use the time to catch up on neglected school work, home chores, and club duties that may have caused the stress to become excessive. They may need to talk with the coach and other swimmers whom they respect if anxiety about their performance has been causing their emotional unrest.

Swimmers trying to recover from overtraining should give close attention to rest and diet. They should make every effort to sleep a minimum of 8 hr per night. Scheduling periodic 30 min or 1 hr rest periods once or twice during the day is also a good idea. Their diets should contain (1) an adequate number of calories, (2) extra amounts of complex and simple carbohydrates, and (3) adequate amounts of vitamins and minerals. They will need to correct deficiencies in all these areas before they can recover.

Preventing Overtraining

The fact that swimmers become overtrained does not necessarily mean that they will perform poorly at the end of the season. Personal experience has shown that many swimmers who followed the procedures outlined earlier after becoming overtrained went on to post personal best times. Nevertheless, avoiding overtraining is always preferable to curing it after it develops.

The chances of becoming overtrained can be reduced by customizing training programs to each individual swimmer's lifestyle and to his or her capacity for tolerating training and other stressors. Individualized programs require that coaches possess knowledge of athletes and their reactions to training that comes only after a few years of working together. Complicating matters, there is a limit to the amount of customizing that a coach can do in a group framework. A certain amount of conformity is usually necessary because of crowded pool conditions and limited training hours. But coaches can modify the training of some athletes when personal experience indicates that a change is the proper approach to take to prevent overtraining. They can also modify the training of any athlete who exhibits early signs of overtraining.

Relieving Overtraining

- Reduce daily training mileage and intensity.
- Train once per day.
- Swim 80% of mileage at basic endurance level.
- Rest away from pool.
- Resolve conflicts that may be adding stress.
- Increase carbohydrate intake.
- Check for vitamin, mineral, and caloric deficiencies.
- Take a 1-week break from training if condition is severe.

Cycling the intensity of training from day to day will also reduce the incidence of overtraining. Recovery periods need to be incorporated into the training program, throughout each week and each season phase. Weekly cycles, such as those described in chapter 17, should be constructed with an eye toward providing 24 hr or more of recovery after every one or two sessions of intense endurance training for replacing muscle glycogen. Mesocycles should be constructed to provide 3 to 7 days of reduced training after each 2 to 4 weeks of intense effort. As I have stated several times, these recovery periods are *safety valves* that provide time for the body to catch up with energy replacement and needed repair of body tissues so that full blown overtraining is less likely to develop. A 1- or 2-week break should occur after each season of the training year so that athletes can recover from the season-long responses of the endocrine and central nervous systems to the emotional effect of training and competition.

Perhaps the most important thing that athletes can do to reduce the possibility of becoming overtrained is to eat an adequate diet. They must consume enough calories to support the work they are doing. The diet should contain 500 to 600 g of complex carbohydrates daily or, to be more specific, 10 g of carbohydrate per kg of body weight (Sherman and Maglischo 1991). To put this in terms that are easier to understand, 2,000 to 3,500 of the calories an athlete consumes each day should be in the form of carbohydrates. A diet with this daily carbohydrate intake will replace muscle glycogen in half the time of a typical diet.

Another method that may help prevent the glycogen depletion that precedes most cases of overtraining is to drink carbohydrate solutions during training sessions. Several products on the market can be used for this purpose. Some are premixed. Others are in powder form and should be mixed with water to form a 10% solution. These drinks should be kept beside swimmers' lanes where they can drink them whenever they feel thirsty during practice. The glucose in these drinks will maintain blood glucose at a higher level so that more glucose will be transported into muscles where it can be used for energy during training. This practice will reduce the rapid combustion of muscle protein that may be responsible for overtraining.

Finally, preventing overtraining also requires anticipating the effects of other stressors in swimmers' lives so that they can be reduced before their accumulated effect reaches disruptive levels. Training should be motivating, but the atmosphere should not be so pressurized that the swimmers are continually anxious about their performance. They must learn that the training process will include peaks and valleys and that they should strive for the peaks without becoming excessively concerned about the valleys. They should attempt to keep their effort high and their anxiety low during intense training sessions. They should also cycle the emotional intensity of these sessions with periods of more relaxed training.

Swimmers frequently take on more outside responsibilities than they can handle when they are training. This situation can result in their becoming overstressed. Coaches should counsel them to reduce their participation in other activities when they are training hard, particularly activities that reduce the time available for rest, sleep, and recovery. They should also decrease their participation in activities that require the expenditure of emotional energy. At the same time, coaches should be sensitive to other commitments that swimmers have and be willing to give them a few days off on occasion to catch up on their schoolwork and put their other affairs in order.

Preventing Overtraining

- Provide 24 to 36 hr of basic endurance and sprint training after every day or two of threshold and overload endurance training.
- Provide 3 to 7 days of recovery training after every 2 to 4 weeks of hard training.
- Advise swimmers to eat a high-carbohydrate diet.
- Encourage athletes to drink a carbohydrate solution during training sessions.
- Counsel athletes to reduce other sources of stress or reduce training when they expect additional stress.
- Do not allow athletes to become overextended by taking on too many responsibilities.

part III

Racing

The topics of stroke rates and stroke lengths, pacing, race strategy, warming up, massage, hyperventilation, and swimming down all bear on the success of swimmers in competition. The next three chapters will discuss these important but often overlooked topics.

Coaches are increasingly using measures of stroke rates and stroke lengths in the training of swimmers. Their goal is to find the optimum combination of the two that will result in the best performance at each particular race distance. Chapter 20 presents the latest research on these measures of performance along with suggestions for improvement in each of these parameters.

Pacing and strategy are very important to competitive success, yet swimmers are often left uneducated about them. Chapter 21 provides some split times for exceptional swims at each race distance and for each stroke. Analyses of data on stroke rates, stroke lengths, swimming velocities, start times, and turn times are valuable aids in learning to swim races more effectively. This chapter includes information on the interpretation and utilization of such data.

The final chapter in this section deals with procedures for warming up before races and swimming down afterward. Results of some of the most pertinent studies on procedures such as warm-up, hyperventilating, and massage have been detailed in chapter 22. Also included are suggestions for speeding recovery after races and swimming down.

20

Stroke Rates and Stroke Lengths

New in this edition:

- More detailed coverage of the relationship between stroke rates, stroke lengths, and swimming velocities
- Refuting the opinion that the best swimmers have the longest strokes with data from recent World and Olympic Championships
- A section on teaching stroke rates
- Several new drills for improving the relationship between stroke rates, stroke lengths, and swimming velocity
- A section on the way in which the relationship between stroke rates, stroke lengths, and swimming velocity changes during races
- A section on using stroke rates to pace races

Measurements of stroke rates and stroke lengths are rapidly becoming common place in competitive swimming. Reports from most major meets now routinely include computations of stroke rates and stroke lengths along with swimming velocity and split times for races. The stroke rate refers to a swimmer's cycling or turnover rate in races. Stroke rates can be expressed according to the number of stroke cycles swimmers take each minute (cycles/min) or the time they require to complete one stroke cycle (time/cycle). A stroke cycle includes two armstrokes, one with the right, one with the left, in the front crawl and backstroke. A stroke cycle is one complete stroke in the breaststroke and butterfly where body parts move simultaneously.

Stroke length, also called distance per stroke, refers to the distance a swimmer travels during each stroke cycle. Stroke length is calculated as the number of meters the swimmer's body moves forward during one stroke cycle. Swimming velocity refers to the forward speed of the swimmer.

Calculating Stroke Rates, Stroke Lengths, and Swimming Velocity

Each of these measurements can provide important information about the race to swimmers. Let me describe how to calculate each, starting with stroke length.

Calculating Stroke Length

A swimmer's stroke length (SL) can be calculated in several ways. The most accurate method is to use videotape to measure the distance the swimmer's body moves forward during one stroke cycle. The most common method, however, is to count the number of stroke cycles the swimmer requires to complete a known distance and then to divide that number into the distance. For example, if a swimmer requires 20 stroke cycles to cover 40 m, his or her average stroke length over that distance would be 2.0 m/cycle (40 ÷ 20 = 2.0).

When calculating stroke length in this way, the most accurate method is to select a distance in the middle of one pool length so that the distance the swimmer covers without stroking during the turn and push-off will not affect the calculations. The most commonly used method is to count the number of stroke cycles swimmers take between the flags in the middle of the pool.

Calculating Stroke Rate

An easy method to calculate the stroke rate (SR) with a regular stopwatch is to time one stroke cycle. The resulting value would be expressed as time per cycle (time/cycle). A typical value of this kind might be 1.10 sec/stroke cycle. The accuracy of determining the stroke rate in this way can be improved by timing two or more cycles and then finding the average by dividing the number of cycles into the time. For example, if the time for three cycles is 3.30 sec, divide the time by 3 to calculate a result of 1.10 sec/stroke cycle.

Stroke rates can also be expressed as stroke cycles per minute. The values are calculated by dividing the average time per stroke cycle into 60 sec. The formula to the left demonstrates how the time for three stroke cycles can be converted into stroke cycles per minute. Three stroke cycles were counted, and the time was 3.2 sec. Thus, the swimmer was stroking at a rate of 1.067 sec per stroke cycle, which was equal to 57 stroke cycles per min.

Method for Calculating Stroke Cycles per Minute From the Average Time per Stroke Cycle

The swimmer completed three stroke cycles in 3.2 sec.

3.2 sec ÷ 3 stroke cycles = 1.067 sec/stroke cycle

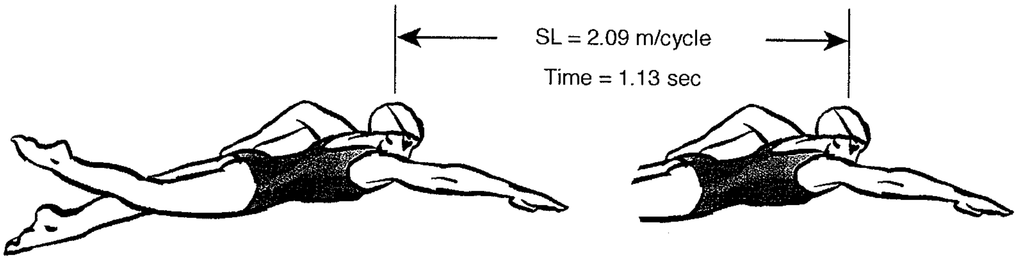
60 sec ÷ 1.067 stroke cycles/sec = 57 cycles/min

Each method for expressing stroke rates has its advocates. I prefer expressing rates as stroke cycles per minute (cycle/min) for several reasons. For one, it communicates to swimmers easily. Fractions are not required to express rates in this way. The differences in stroke rates from one part of a race to another or from one race to another can also be communicated in whole numbers instead of fractions. For example, telling a swimmer that his or her stroke rate declined 4 cycles/min, from 54 to 50, during a race points up the magnitude of the effect of that decline on race performance better than saying that the cycling rate changed from 1.11 sec/cycle to 1.20 sec/cycle during the race.

Calculating Swimming Velocity

A swimmer's velocity during any portion of the race can be calculated as the dividend of his or her stroke length divided by the stroke rate. The time per stroke cycle rather than stroke cycles per minute should be used for this calculation. The drawing in figure 20.1 illustrates the relationship between stroke rate, stroke length, and swimming velocity. The swimmer in this illustration has an average stroke length of 2.09 m/cycle during the portion of the race for which calculations were being made. Her time per stroke cycle was 1.13 sec/cycle (53 cycles/min). Dividing her stroke length by her stroke rate yielded a swimming velocity of 1.85 m/sec.

I mentioned earlier that stroke rates and stroke lengths are now being measured at most major meets. The procedure for doing so, however, is time consuming, expensive, and labor intensive. As many as five video cameras are placed along the pool length to record races. Following the race, a team of workers must labor feverishly to calculate the swimmers' stroke rates, stroke lengths, and swimming velocities for several portions of the race to make the rates available to the swimmers as soon as possible.



SL = 2.09 m/cycle
Time per cycle = 1.13
SR = 60 ÷ 1.13 = 53 cycles/min
Velocity = 2.09 ÷ 1.13 =1.85 m/sec

Figure 20.1 Swimming velocity can be calculated from a swimmer's stroke length and stroke rate.

Devices for Measuring Stroke Rates, Stroke Lengths, and Swimming Velocities

Recently, a number of timing devices have come on the market that allow coaches to measure stroke rates and, in some cases, stroke lengths quickly and easily. One of the best of these, a video performance monitor developed by the YSDI company, is pictured in figure 20.2. This device allows a coach not only to take splits for various portions of a race but also to time stroke cycles. The distance of each portion of the race for which splits, SLs, and SRs are desired and the number of stroke cycles that will be timed per segment are programmed into the video performance monitor beforehand so that after the split and cycle times have been taken, the monitor can perform and display the calculations immediately. The values displayed include split time, stroke rate, stroke length, and swimming velocity. The video performance monitor can also be interfaced with a video camera so that values can be displayed on the exposed tape as they are calculated, along with a visual record of the race.

Several stopwatches on the market will calculate stroke rates in cycles/min along with split times for desired segments of a race. Stroke length and swimming velocity for various segments of the race can be calculated after this information has been secured. By knowing the stroke rate for a particular race segment, the number of stroke cycles required to cover a particular race segment can be determined by calculating the time per stroke cycle and dividing that time into the time for the segment. Stroke lengths can then be calculated by dividing the number of stroke cycles into the distance of the race segment. Swimming velocity can be calculated by dividing the stroke length by the time per stroke cycle. Most swimming magazines contain advertisements for these stopwatches, one of which is shown in figure 20.3.

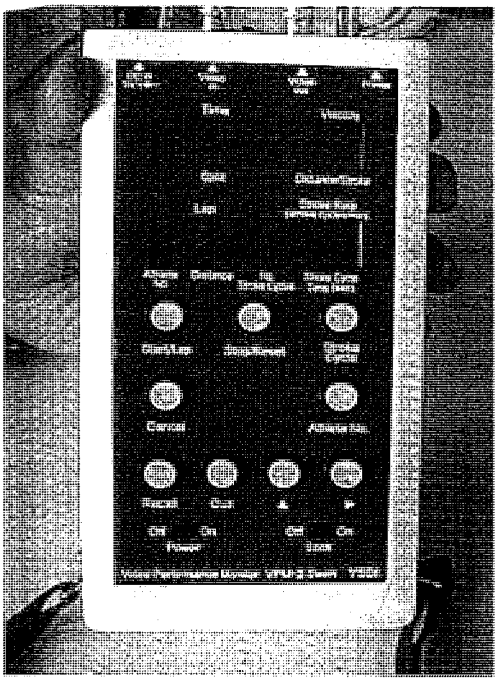


Figure 20.2 A video performance monitor.

This device is manufactured and marketed by the YSDI Company of Tokyo, Japan. The machine can be purchased from YSDI Ltd., Nishiya-Cho 701-32, Hodogaya-Ku, Yokohama, Japan 240 or from U.S. Speed Matrix Corp., 8911 East Palm Tree Drive, Scottsdale, AZ 85255. Besides functioning as a stopwatch for recording race splits, the device also produces values for stroke rate, stroke length, and swimming velocity for any segment of a race.

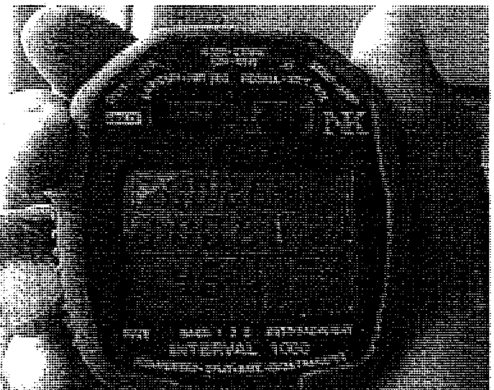


Figure 20.3 A stopwatch that will also calculate stroke rates.

This stopwatch is manufactured and marketed by the Neilsen-Kellerman Co., 104 West 15th. Street, Chester, PA 19013.

Relationship of Stroke Rate and Stroke Length to Swimming Speed

The relationship between stroke rate, stroke length, and swimming velocity is complex. One aspect of this complexity is that the relationship is negative. A swimmer's stroke length will decrease as his or her stroke rate increases and vice versa. Athletes will swim fastest when they use some optimum combination of the two, whereas maximum or minimum values in either will produce slow times (Craig and Pendergast 1979; Pai et al. 1984).

Long stroke lengths are possible only at very slow rates. Conversely, stroke length necessarily decreases as stroke rate increases. The relationship between stroke rate, stroke length, and swimming velocity forms the classic *inverted U*, illustrated in figure 20.4. The graph demonstrates that although stroke length will be very high at slow stroke rates, swimming velocity will be slow. At the same time, at a very high stroke rate, a swimmer's stroke length will fall off so much that swimming velocity will also be slow. Some combination of a submaximal stroke rate and a submaximal stroke length will produce a fast swimming velocity, although that combination may be different for each athlete and each stroke.

In the example in figure 20.4, an athlete was asked to swim a series of 50 m swims at progressively faster stroke rates. At the slowest rate, 20 cycles/min (3.0 sec/cycle), the swimmer was able to cover 3.5 m with each stroke cycle, but the velocity was very slow, 1.16 m/sec (3.5 ÷ 3.0 = 1.16). Stroking at the fastest rate (80 cycles/min), the swimmer could cover only 1.00 m per cycle (0.75 sec/cycle). The swimming velocity was calculated to be 1.33 m/sec (1.00 ÷ 0.75 = 1.33). This swimmer's fastest swimming velocity of 2.06 m/sec was achieved with a stroke rate of 62 cycles/min (0.97 sec/cycle) and a stroke length of 2.0 m/cycle (2.0 ÷ 0.97 = 2.06).

When swimmers want to go faster they increase their stroke rate, even though their stroke length decreases. At first, their stroke length will decrease by only a small amount with each increase in stroke rate. Therefore, swimming velocity will continue to increase until the stroke rate is very high, in excess of 60 cycles/min in most cases. After that, however, the drop-off in the stroke length will be so great with every additional increase in the stroke rate that swimming velocity will decrease.

Extremely fast stroke rates require large and rapid outputs of energy, most of which must come from anaerobic metabolism. When swimmers use anaerobic metabolism, lactic acid accumulates rapidly, leading to acidosis and inability to maintain those rates. Consequently, swimmers can maintain stroke rates in excess of 60 cycles/min only for 50 races. The stroke rates that swimmers can maintain become progressively slower as race distances increase in length.

For each race distance and for each swimmer, there is probably an optimum combination of stroke rate and stroke length that will produce the best performance. In every case, both will be lower than the maximum the swimmer could achieve by stroking as fast as possible or by swimming with the longest possible stroke. In 50 races, the purpose is to find the combination of stroke rate and stroke length that will result in the fastest possible swimming velocity. The element of pacing comes into play in all other events. Athletes will purposely swim somewhat below maximum speed early in those races so that they can delay acidosis and maintain the fastest possible average speed for the entire race distance. Consequently, they should use the most efficient and energy-saving combination of stroke rate and stroke length that will allow them to swim at their desired speed.

Stroke lengths will generally increase as stroke rates decrease for longer races. Stroke lengths will increase for most swimmers as they move from 50 to 100 events because their stroke rates may decrease by as much at 10 cycles/min. Likewise, when swimmers move from 100 to 200 events, stroke lengths will increase and stroke rates will decrease, at least early in the race. Stroke lengths will generally remain the same or increase only slightly from 200 to 400 or 500 events even though a swimmer's stroke rate will generally decline by 4 to 5 cycles/min. This probably occurs because swimmers are preserving energy by not exerting as much force per stroke in the longer event. The same pattern is evident when swimmers move from 400 to 800 and 1,500 m races. Their stroke lengths remain about the same even though their stroke rates decrease by 2 to 5 cycles/min. Again, swimmers are probably saving energy in the longer events by exerting less force per stroke.

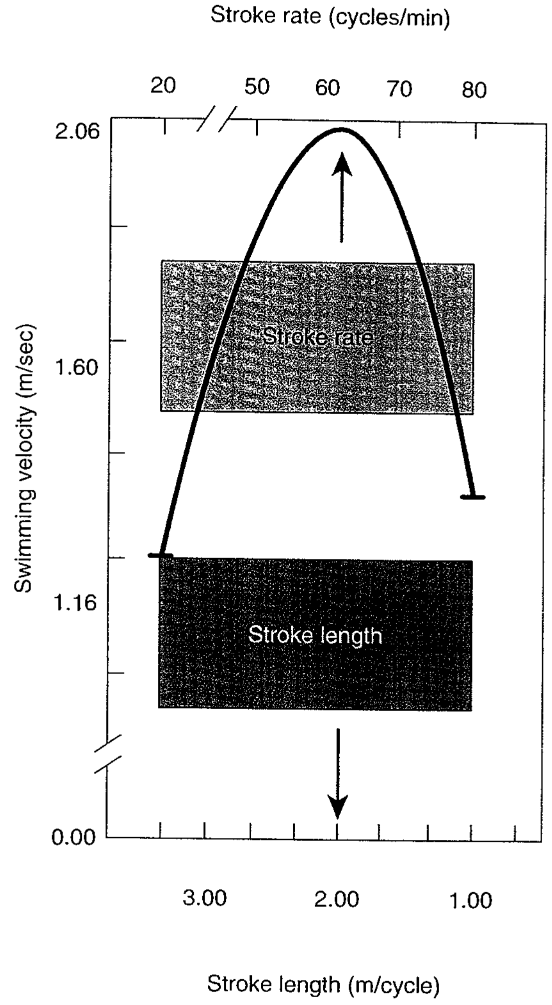


Figure 20.4 The relationship between stroke rate, stroke length, and swimming speed. The fastest speed for any particular race distance is achieved by using some optimum combination of stroke rate and stroke length. In this example, the swimmer's fastest velocity of 2.06 m/sec is achieved by stroking at a rate of 62 cycles/min with a stroke length of 2.00 m/cycle. Velocity drops off at higher stroke rates because of a loss in stroke length. Velocity also drops off at slower stroke rates because they are so slow that even a major increase in stroke length cannot produce a fast velocity.

The fastest swimmers are often reported to have the longest stroke lengths for a particular race distance (Craig et al. 1985; Letzlter and Freitag 1983). The assumption is that the fastest swimmers can cover more distance with each stroke cycle, no matter what their stroke rate. This idea has led to an overconcern with taking long strokes in all races. Recent research suggests that the proper combination of stroke rate and stroke length is more important to swimming success than simply taking long strokes (Mason and Cosser, 2000). With measures of stroke rates and stroke lengths becoming increasingly available at major international competitions, it has become apparent that the top performers do not always have longer stroke lengths than swimmers who place lower or fail to final. For example, Brooke Bennett won the 800 m freestyle at the 1996 Olympic Games. Her stroke length varied between 1.65 and 1.83 m/cycle throughout the race. Stroke lengths for the other seven finalists ranged between 1.76 and 2.19 m/cycle, with most in the range of 1.90 to 2.09 m/cycle. Bennett was able to swim faster for the 800 m distance because she maintained stroke rates between 51 and 54 cycles/min throughout. In contrast, the stroke rates of the other seven finalists were generally between 43 and 48 cycles/min.

Each of the medal winners in the men's 1,500 m freestyle at the 1996 Olympic Games used higher stroke rates than the remaining five competitors. The stroke rates of Kieren Perkins, Daniel Kowalski, and Graeme Smith varied between 43 and 48 cycles/min throughout the race, whereas the rates of the other five swimmers were between 35 and 45 cycles/min, with most swimming at rates between 38 and 43 cycles/min. The stroke lengths of the 1,500 medalists also tended to be shorter, generally between 2.14 and 2.24 m/cycle. In contrast, the stroke lengths of three of the remaining five swimmers were between 2.35 and 2.70 m/cycle.

The lack of a relationship between stroke length and success is also apparent in sprint events. The average stroke length for Jingyi Le, winner of the women's 100 m freestyle, was 1.99 m/cycle, whereas four other competitors in that race had greater average stroke lengths. Likewise, the average stroke length for Alexander Popov, winner of the men's 100 m freestyle at the 1996 Olympic Games, was 2.38 m/cycle, whereas three of the other finalists had average stroke lengths between 2.39 and 2.60 m/cycle.

A more accurate statement about the influence of stroke length on swimming speed would be to say that a swimmer can increase speed by increasing stroke length provided it does not result in an inordinate decline in stroke rate. Even after increasing stroke length, a swimmer could have a shorter stroke than his or her competitors do. The swimmer's time will improve because of that length increase, provided his or her stroke rate does not decline significantly.

The influence of stroke length on swimming speed cannot be separated from the influence of stroke rate. They are intrinsically related. Some swimmers may find it easier to improve their performance by increasing their stroke lengths, others by increasing their stroke rates. Regardless, any method for improving one of these stroke parameters must involve its effect on the other. I will have more to say about this in a later section on using stroke rates and stroke lengths to improve swimming velocity. For now, let me return to the relationship between stroke rate, stroke length, and swimming velocity.

One job of the coach is to help athletes find the optimum combination of stroke rate and stroke length that will allow them to swim at some desired speed with the least energy expenditure. The optimum combination of rate and length will undoubtedly be different for each swimmer and for each event. Nevertheless, the range of differences is small enough to allow us to make generalizations concerning the best rates for each event. For example, most world-class swimmers use stroke rates that are between 40 and 45 cycles/min during 1,500 m races. In contrast, most use stroke rates between 60 and 65 cycles/min in 50 m races. The opposite effect occurs with regard to stroke length. Stroke lengths are greatest during longer races and gradually decline as race distances become shorter. Most world-class male distance swimmers have stroke lengths between 2.25 and 2.50 m/cycle during their 1,500 m competitions. The stroke lengths for male world-class sprinters range between 1.90 and 2.15 m/sec in 50 m races.

Female and male swimmers use similar stroke rates in their races, although the stroke lengths of females are generally somewhat shorter. World-class female swimmers use stroke lengths of 1.90 to 2.20 in 1,500 m races and stroke lengths of 1.71 to 1.96 in 50 m races. Table 20.1 provides examples of the stroke rates and stroke lengths used by world-class male and female swimmers, compiled from the results of the championship and consolation finals at the 1996 Olympic Games and at the 1998 World Swimming

Championships. The stroke rates and stroke lengths were those the swimmers used in the first half of their races, so the effects of fatigue will not influence the comparisons. Swimmers can use this information to find the correct range of stroke rates for each event.

Data on stroke rates and stroke lengths for finalists at the 1984 U.S. Olympic Trials were listed in the previous edition of this book. Comparing those data with the data in table 20.1 indicates that the stroke rates used in the various events have changed very little in the last 12 to 14 yr. The exception was the 200 m breaststroke, in which the men were stroking 2 to 6 cycles/min slower in 1984. Stroke lengths have not changed much either with the exceptions of the 200 breaststrokes for both men and women and the 100 and 200 m backstrokes for men. The stroke lengths for 200 m breaststrokers improved 0.20 to 0.60 m/cycle for women and 0.10 to 0.26 m/cycle for men during the intervening 12 to 14 yr. The stroke lengths of male backstrokers increased approximately 0.23 m/cycle in the 100 event and 0.37 m/cycle in 200 races during the same span.

Another point of interest concerns the ways that swimmers adjust the relationship between their stroke rates and stroke lengths as they move from one event to the next. Table 20.2 provides some data on those adjustments. The stroke rate and stroke length for the same person competing at two different race distances were compiled for male and female competitors at the 1996 Olympic Games and the 1998 World Championships. The effect of these changes on the swimmers' velocities was also compared. All comparisons were made in the first quarter of their races so that fatigue did not play a role. Stroke rates and stroke lengths were compared for swimmers who competed in both the 50 and 100 m freestyles. Similar comparisons were made for swimmers who competed in the 100 and 200 m freestyles and in the 100 and 200 m stroke events. Stroke rates and stroke lengths were also compared for swimmers who competed in both the 200 and 400 m freestyles and for those who competed in both the 400 and 800 m freestyles for women, or the 400 and 1,500 m freestyles for men.

Table 20.1 The Range of Stroke Rates and Stroke Lengths for Male and Female World-Class Swimmers in Each Competitive Event

EVENTS	STROKE RATES IN CYCLES/MIN	STROKE LENGTHS IN M/CYCLE
Women		
50 freestyle	60–65	1.79–1.96
100 freestyle	53–56	1.80–2.05
200 freestyle	48–54	2.10–2.20
400/500 freestyle	42–55	1.75–2.20
800/1,000 freestyle	44–54	1.75–2.10
1,500/1,650 freestyle	NA	NA
100 backstroke	50–56	1.75–2.03
200 backstroke	42–44	1.90–2.08
100 breaststroke	47–53	1.60–1.90
200 breaststroke	34–45	1.97–2.48
100 butterfly	52–56	1.77–1.85
200 butterfly	45–54	1.74–1.90
Men		
50 freestyle	56–67	1.88–2.16
100 freestyle	50–56	2.17–2.50
200 freestyle	43–51	2.25–2.41
400/500 freestyle	38–46	2.20–2.60
800/1,000 freestyle	NA	NA
1,500/1,650 freestyle	39–43	2.26–2.53
100 backstroke	48–53	2.05–2.20
200 backstroke	42–44	2.27–2.46
100 breaststroke	52–55	1.50–1.88
200 breaststroke	38–42	2.14–2.28
100 butterfly	52–56	1.90–2.15
200 butterfly	48–54	1.91–12.18

Sources: Competition Analyses of Swimming Events: Olympic Games, Atlanta, GA, 1996. Published by IOC Subcommission on Biomechanics and Physiology of Sport. Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia. Prepared by The Biomechanics Department, Australian Institute of Sport.

As freestyle swimmers progressed up the ladder from 50 to 100 m, stroke rates tended to decrease by 5 to 10 cycles/min and stroke lengths increased by 0.10 to 0.30 m/cycle. This resulted in velocity decreases of 0.03 to 0.09 m/sec. As swimmers moved from the 100 m to 200 m freestyle event, stroke rates tended to decrease by 6 to 11 cycles/min and stroke lengths increased between 0.26 and 0.44 m/cycle. Their swimming velocities

Table 20.2 Changes in Stroke Rates and Stroke Lengths for the Same Swimmers in Different Events

EVENT RANGE	SEX	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE	SWIMMING VELOCITY IN M/SEC
50 to 100 m freestyle	F	–3 to 10	+0.10 to 0.28	–0.04 to 0.09
	M	–5 to 10	+0.15 to 0.30	–0.03 to 0.09
100 to 200 m freestyle	F	–6 to 10	+0.26 to 0.36	–0.10 to 0.22
	M	–7 to 11	+0.21 to 0.44	–0.03 to 0.07
200 to 400 m freestyle	F	–5 to 7	–0.03 to 0.15	–0.14 to 0.18
	M	–4 to 7	+0.20 to 0.35	–0.03 to 0.10
400 to 800/1500 m freestyle	F	–3 to 5	+0.11 to 0.13	–0.06 to 0.10
	M	–2 to 3	+0.06 to 0.14	–0.03 to 0.09
100 to 200 m butterfly	F	–4 to 8	+0.05 to 0.16	–0.13 to 0.20
	M	–4 to 8	+0.08 to 0.27	–0.05 to 0.17
100 to 200 m backstroke	F	–2 to 4	+0.05 to 0.08	–0.04 to 0.14
	M	–5 to 9	+0.09 to 0.21	–0.04 to 0.15
100 to 200 m breaststroke	F	–7 to 11	+0.21 to 0.44	–0.03 to 0.07
	M	–9 to 10	+0.26 to 0.29	–0.06 to 0.08

Sources: Competition Analyses of Swimming Events, Olympic Games, Atlanta, GA, 1996. Published by the IOC Subcommission on Biomechanics of Sport. 1998 World Swimming Championships, Perth, Australia, published by Biomechanics Department, Australian Institute of Sport.

decreased between 0.03 and 0.22 m/sec. Swimmers' stroke rates decreased less as they moved from 200 to 400 m freestyle events. Decreases were between 4 and 7 cycles/min. Their stroke lengths changed from a small decrease of 0.03 to an increase of 0.35 m/cycle as they moved from the shorter to longer of the two events. Swimming velocities decreased more for women than for men as swimmers moved from the 200 m event to the 400 m event. The decrease for women was in the range of 0.14 to 0.18 m/sec, whereas for men the decrease was between 0.03 and 0.10 m/sec. Decreases of stroke rates were even less for both males and females as they moved from 400 m to 800 m or 1,500 m. Rates declined by only 2 to 5 cycles/min. Stroke lengths increased very little, between 0.06 and 0.14 m/cycle. Velocity decreases were also small, between 0.03 and 0.10 m/sec.

Stroke rates decreased by 4 to 8 cycles/min for butterfly swimmers as they progressed from 100 to 200 race distances. Their stroke lengths increased between 0.05 and 0.27 m/cycle during the longer of the two events. Their swimming velocities decreased between 0.05 and 0.20 m/sec for the 200 distance.

In backstroke events, stroke rates for men declined 5 to 9 cycles/min between the 100 and 200 race distances but they decreased by only 2 to 4 cycles/min for women. Stroke length increases were considerably greater for men as they moved from the 100 to the 200 race, ranging between 0.09 and 0.21 m/cycle, whereas women only increased their stroke lengths between 0.05 and 0.08 at the 200 distance. Despite these differences, the drop in swimming velocities was similar for both sexes as they moved from 100 to 200 events. The velocities decreased between 0.04 and 0.15 m/sec for males and between 0.04 and 0.14 m/sec for females during their 200 races.

Stroke rates decreased between 7 and 11 cycles/min as breaststroke swimmers moved from the 100 to 200 distance. Their stroke lengths increased between 0.21 and 0.44 m/cycle in the longer race. These changes resulted in greater velocity decreases for men than for women. The velocity for men decreased by 0.06 to 0.08 m/sec at the 200 distance, whereas the velocity of the women slowed only 0.03 to 0.07 m/sec.

Some researchers have suggested that swimmers use slightly faster stroke rates for the same race distances in short-course pools than they use in long-course pools (Wirtz, Wilke, and Zimmerman 1992). Others dispute that recommendation (Keskinen, Keskinen, and Mero 1996). All agree that swimmers are able to maintain slightly greater stroke lengths in short-course pools, probably because turning more frequently provides additional rest that permits them to hold a slightly higher level of effort throughout short-course races.

Factors That Influence the Optimum Combination of Stroke Rate and Stroke Length

Table 20.1 shows that the range of stroke rates and stroke lengths used by the finalists at the 1996 Olympic Games and the 1998 World Swimming Championships were quite large in every event. Within each event, the stroke rates used by these swimmers often differed by 4 to 10 cycles/min, and stroke lengths varied by 0.10 to 0.50 m/cycle. Differences in the size and stroking efficiency of the swimmers probably accounted for the variations. Taller swimmers will typically use slower stroke rates and cover more distance with each stroke than shorter swimmers do. The simple fact that they are taller contributes to their slower stroke rates and greater stroke lengths. In addition, they generally have longer limbs than smaller swimmers do, allowing them to cover more distance with each stroke. Their longer limbs also require more time to move through the water, explaining their slower stroke rates.

Most, but not all, small swimmers will stroke faster and have shorter stroke lengths than their taller competitors do. Some, however, have been able to achieve the same stroke rates and stroke lengths of larger swimmers by stroking more efficiently. Swimming more efficiently involves using motions that generate more propulsive force with each stroke and reduce drag by assuming more effective body positions and using more rhythmic movements. Swimmers with excellent kicks and swimmers with very large hands will probably also use slower stroke rates and have greater stroke lengths.

Should Stroke Rates Be Taught?

Opinions differ about whether swimmers need to be taught to use some optimum combination of stroke rate and stroke length for each race distance or whether they intuitively select what is for them the best combination of each (McArdle and Reilly 1992). There is some truth on both sides of this question. Swimmers do tend to select stroke rates for each race distance on the basis of feel and intuition, but those rates are not always the most efficient. Chollet and coworkers (1996) investigated whether attempts to alter self-selected stroke rates would increase energy cost. Their hypothesis was that even though a particular combination of stroke rate and stroke length might be more efficient, the conscious effort required to achieve and maintain a rate that did not feel normal would increase the energy cost of swimming. They measured actual exercise heart rates and postswim blood lactates to evaluate the energy cost of swimming. They were surprised to find that exercise heart rates and postswim blood lactates tended to be slightly lower when subjects concentrated on maintaining a prescribed stroke rate rather than one that felt intuitively correct. A review of the self-selected rates that world-class swimmers have used in their races also suggests that even some of these high-level athletes are making errors by stroking too fast or too slow during their races. For example, one swimmer was able to achieve a velocity of only 2.09 m/sec using a stroke rate of 61 cycles/min during the first 25 m of a 50 m freestyle race at the 1996 Olympics.

His stroke length was 2.06 m/cycle. The same athlete was able to swim at a faster velocity of 2.14 m/sec in the first 25 m of the 100 m freestyle by slowing his stroke rate to 56 cycles/min, which allowed him to swim with a stroke length of 2.31 m/cycle. This swimmer probably would have been able to swim faster in the 50 event if he had used a stroke rate that was somewhere between 56 and 60 cycles/min.

Comparing results in this way has demonstrated that many competitors at the 1996 Olympic Games made similar errors in the combinations of stroke rate and stroke length they used during their races. The usual mistake they made was to swim with a stroke rate that was too high in shorter events. Many 100 specialists moved their arms too rapidly when they swam the 50, and some 200 specialists moved their arms too fast when they swam 100 races. On the other side of the coin, some sprinters tended to stroke too rapidly early in the race when they competed in 200 events. Distance swimmers were not immune to these errors. Some 1,500 specialists moved their arms too rapidly when they competed in the 400 event and particularly when they swam the 200 m freestyle.

Two approaches are possible for improving swimming speed through manipulating the relationship between stroke rate and stroke length. The first approach is to increase stroke length for a particular race distance without decreasing stroke rate by an inordinate amount. The second approach is to increase the stroke rate without decreasing stroke length by an inordinate amount. The calculations below show how swimming velocity can be increased for 50 m with both approaches. The influence of the start has been disregarded to make the calculations easier to understand.

The swimmer in this example has before-training values of 60 stroke cycles per min and a stroke length of 1.75 m/stroke at that rate. Therefore, her time for 50 m calculates to 28.57 (50 ÷ 1.75 m/sec = 28.57). The calculations show that she could improve her time to 27.77 if she increased her stroke rate to 63 strokes/min with only a small decrease in stroke length. Alternatively, an improvement in stroke length to 1.84 m/stroke cycle would also produce a time of 27.77 as long as her stroke rate did not decrease more than 1 cycle/min.

Two Approaches for Improving Swimming Speed by Manipulating Stroke Rate and Stroke Length

Before training
Stroke rate = 60 strokes/min
Stroke length = 1.75 m/stroke cycle
60 strokes/min = 1.00 sec/stroke cycle
1.75 m/stroke cycle ÷ 1.00 sec/stroke cycle = 1.75 m/sec
50 m ÷ 1.75 m/sec = 28.57 sec

Approach #1: Increasing Stroke Rate

After training
Stroke rate increased to 63 strokes/min.
Stroke length declined to only 1.71 m/cycle.
63 strokes/min = 0.95 sec/stroke cycle
1.71 m/cycle ÷ 0.95 sec/stroke cycle = 1.80 m/sec
50 m ÷ 1.80 m/sec = 27.77 sec

Approach #2: Increasing Stroke Length

After training
Stroke length increased to 1.84 m/cycle.
Stroke rate declined to only 59 cycles/min.
59 strokes/min = 1.02 sec/stroke cycle
1.84 m/cycle ÷ 1.02 sec/stroke cycle = 1.80 m/sec
50 m ÷ 1.80 m/sec = 27.77 sec

Traditional wisdom is that athletes should concentrate on improving their stroke lengths to swim faster. This is generally true. An increase in stroke length gained by increasing muscular power, by using a more effective stroking pattern, or by reducing form drag should improve a swimmer's time without increasing the energy cost of the swim. But this generalization oversimplifies the complex relationship between SR, SL, and swimming speed. Not all swimmers can increase their stroke length without losing speed. In some cases, their stroke rates simply decline too much. Others may expend an inordinate amount of energy pulling slower with greater force. There is no easy solution. Each swimmer should search for the optimum relationship between stroke rate and stroking effort that will provide the desired average velocity for a particular race distance with the least expenditure of energy. Some swimmers may find it easier to increase that average velocity by increasing their stroke rates rather than their stroke lengths. Others may find that just the opposite approach works best for them. Coaches should experiment with both approaches for improving swimming velocity. Initially, their efforts should be geared toward improving swimming velocity by increasing stroke length, but they should be willing to experiment with increasing stroke rates if that approach does not seem to be working.

Finding the Optimum Relationship Between Stroke Rate and Stroke Length

An athlete's chance of reproducing fast swims can be improved by determining his or her optimum combination of stroke rate and stroke length for each of his or her events. One procedure he or she can use for this purpose is to swim a series of 25 to 100 repeats at race speed using a variety of different stroke rates. The stroke rates can be calculated with an ordinary stopwatch by timing three stroke cycles, or they can be calculated in stroke cycles per minute using one of the stopwatches designed for that purpose. The information in table 20.1 can be used to identify the probable range of stroke rates in each race where the swimmer's optimum will be found.

Initially, the swimmer should attempt to swim at the low end of the probable range of stroke rates. The swimmer should then gradually increase the stroke rate until he or she finds one that seems to produce the same time with less effort or one that produces a faster time with no increase in effort. Immediate postswim heart rates, recovery heart rates, or perceived efforts should be used to evaluate the energy cost of the swims.

Another method for determining optimum stroke rates for a particular race distance is to calculate those rates during several competitions. The narrow range of stroke rates that consistently produces the best times in a certain event is probably the optimum range for that swimmer.

Surprisingly, swimmers' optimum stroking rates for a particular race distance generally do not change when they shave and taper. Their stroke lengths may increase when they rest, and stroke lengths will certainly increase after they shave down, but their stroke rates will not change much. A few swimmers increase their stroke rates somewhat when they rest and shave, but to my knowledge none decrease their stroke rates when they rest and shave.

Drills for Improving the Relationship Between Stroke Rate, Stroke Length, and Swimming Velocity

As I indicated earlier, athletes can take two approaches to improve the relationship between stroke rates and stroke lengths so that they will be able to swim faster or with less effort. The first is to increase stroke lengths while maintaining stroke rates at or near previous levels. The second is to increase stroke rates without reducing stroke lengths appreciably.

Stroke counting is one of the least complicated ways to improve this relationship. Drills for increasing stroke lengths should emphasize covering repeat distances in less time with fewer strokes and little or no reduction in stroke rates. Remember that stroke length increases achieved at the expense of decreases in stroke rate may produce slower times even though fewer strokes are taken. Swimming velocity can also be improved by increasing stroke rates provided the rate increase is not accompanied by an inordinate decrease of stroke lengths. Table 20.3 summarizes the relationship of changes in stroke rates and stroke lengths to the times for repeats and to the number of strokes taken during those repeats.

The effect will be a positive one when the number of strokes taken during the repeat does not change but the time is faster. That indicates that the swimmer's stroke rate has

Table 20.3 Influence of Changes in Stroke Rate and Stroke Length on Repeat Times and the Number of Strokes Taken During Repeats

NUMBER OF STROKES	SWIMMING SPEED	EFFECT ON STROKE RATE	EFFECT ON STROKE LENGTH
Desirable effects			
No change	Faster	Increase	No change
Fewer	Faster	No change	Increase
Fewer	Same time	Decrease	Increase
Undesirable effects			
No change	Slower	Decrease	No change
More	Slower	No change	Decrease
More	Same time	Increase	Decrease

increased with no significant loss of stroke length. If the number of strokes per repeat decreases and the swimming time remains the same or becomes faster, then the stroke length has increased, also a positive effect. A slower time with no change in the number of strokes indicates a negative effect. The stroke rate has probably decreased too much with little or no increase of stroke length. The effect will be even more negative if the number of strokes increases and the time for the repeat distance is the same or slower. That circumstance indicates a significant loss of distance per stroke (stroke length) coupled with an increase or no change of the stroke rate. I will present some drills for increasing stroke lengths and stroke rates in the following sections.

Stroke Counting Drills

One of the most common drills for increasing stroke lengths is to count strokes for one pool length and repeat the drill while attempting to cover the distance with fewer strokes. All of this is done at a slow speed. This is a good drill for young and inexperienced age-group swimmers. The efficiency of their strokes and their performances will improve when they attempt to cover each pool length with fewer strokes, regardless of the speed of their swims.

Although a drill like the one just described is excellent for inexperienced swimmers, it has limited value once athletes can swim with good coordination and reasonable efficiency. At that point, swimming speeds and stroke rates must be included in drills designed to increase stroke length. Because the relationship between the combination of stroke rate and stroke length that will produce the most efficient swimming velocity will be different for each race distance and for each swimmer, all three elements should be included in drills to improve stroke lengths. Following are some drills that include all three elements.

SWOLF

This drill is so named because it involves swimming and is scored like golf. The value of the drill is that it allows each swimmer to discover the best way to improve the relationship between stroke length and stroke rate to achieve a particular swimming velocity, whether through increasing stroke length, increasing stroke rate, or using some combination of the two. The drill is performed in the following manner. The athletes swim a particular repeat distance, 25 or 50 yd or m, while counting their strokes. Their times are noted, and the two measures, number of strokes and their time for the swim, are combined for a score. For example, a time of 30.00 for 50 m with a stroke count of 40 would produce a score of 70.

Once they have established a base score, swimmers can use any one of several variations of the game to improve the relationship between their stroke rates and stroke lengths. The goal is to reduce the score by (1) swimming faster with fewer strokes, (2) swimming faster with little or no increase in the number of strokes taken, or (3) swimming the same time or nearly so with fewer strokes. If the swimmer in the previous example were to swim 29.00 with the same stroke count, the score would be an improved 69. This swimmer's stroke rate has undoubtedly increased with little or no loss of stroke length, which accounts for the improved time. Similarly, the same time of 30.00 coupled with a reduced stroke count of 38 would produce an improved score of 68. In that case, the swimmer's stroke length will have improved and the stroke rate will have decreased with no detrimental effect on swimming speed.

The results will be more difficult to evaluate when lower scores result from faster times that are coupled with a greater number of strokes. This is generally a desirable effect because the lower score results from time reductions that are proportionally greater than the amount by which stroke lengths have declined. This effect can certainly be considered beneficial for improving sprint speed. Increases of stroke rates and the reduction of stroke lengths may not be advantageous for longer sprints, middle distance races, and distance events if the perceived effort that produced lower scores is beyond that which swimmers feel they could sustain over their race distance.

KICK-INS

The kick-in drill works best for increasing stroke length. To perform it, athletes swim a series of 50 or 100 repeats while counting the number of stroke cycles required to complete each repeat. Before starting, each swimmer should be assigned the maximum number of cycles they are permitted to use for the repeat distance in the allotted time. That number should be one or two cycles fewer than they generally need to complete that distance. The goal, then, is to complete the repeats with fewer strokes. If they do not finish the repeat when they have completed their assigned number of stroke cycles, they must kick the remaining distance to the finish. The send-off time for the repeats should be set so it is challenging but manageable if the swimmers can complete the repeats without kicking in. The time goal will motivate swimmers to try to reduce their strokes without sacrificing swimming speed. This drill puts a premium on increasing stroke length and doing so without increasing the energy cost of the swim.

STROKE COUNTING AT SPRINT SPEED

This drill can help sprinters increase their stroke lengths while swimming at race speed. The drill can be done in a number of ways. With one method, swimmers sprint 25 yd or m at maximum speed while trying to reduce their stroke count. This method puts a premium on swimming fast with a longer stroke length. Another method is to try to swim each repeat faster without increasing the stroke count. This encourages them to increase their stroke rates without shortening their stroke lengths. The distance that swimmers cover with a push-off can become a confounding variable with both drills. Therefore, swimmers should try to keep that distance similar from swim to swim. The influence of the push-off for different distances can be eliminated from this drill by counting only the number of strokes required to get from one set of flags to the next.

Still another method for increasing stroke length at sprint speed is for the athletes to swim only a specified number of stroke cycles while trying to cover more distance with each swim. For example, the coach can measure the distance a swimmer can cover with two or three stroke cycles, and then the swimmer can try to increase that distance. This distance should be measured in the middle of the pool to remove the influence of the push-off.

STROKE COUNTING AT RACE SPEED

The purpose of this drill is also to increase stroke length. The drill involves swimming a series of 25 or 50 repeats. The total distance of the set should be short, perhaps only 150 to 300 yd or m. The send-off time for each repeat should be long enough to allow the athletes to swim at race speed without becoming fatigued. They should swim the repeats at race speed while attempting to reduce their stroke counts from the beginning of the set to the end. A base score should be established on the first few repeats. Swimmers should then try to swim the same time with fewer strokes or swim a faster time without increasing the number of strokes they take.

LOWER, FASTER SWIMS

This is another drill in which athletes swim a set of repeats while counting strokes. This drill can help swimmers increase stroke length, increase stroke rate, or improve the relationship between the two measures and swimming speed. The repeat distances should be 50 or 100 yd or m. The swimmers begin the set by swimming the first two to four repeats at a moderate speed while counting their strokes. Then they should try to increase their stroke lengths by swimming the same speed with fewer strokes for the next two to four repeats. Finally, they should try to increase their stroke rates by swimming the final two to four repeats at a faster speed without increasing their stroke counts. The send-off times on these sets should provide a moderate amount of rest so that fatigue does not influence the results.

An example of a set of this type would be to swim 12 repeats of 50 m on a send-off time of 1 min. The first four repeats should be swum at a speed that is moderate for the swimmers involved. They should count their strokes for each of these repeats to establish base stroke counts. Then they should try to reduce their stroke counts by one or two cycles per repeat without losing speed on the next series of four swims. Finally, they should try to swim the final series of four repeats 1 to 2 sec faster without increasing their stroke counts from the number they used on the first four swims.

Drills Using Calculated Stroke Rates and Stroke Lengths

The previous drills involved stroke counting. The drills in this section use calculations of stroke rates and stroke lengths that can be performed with a stopwatch or with one of the timing devices mentioned earlier in this chapter. The simplest drills are those in which swimmers try to complete a certain repeat distance faster without increasing their stroke rates. The distances should be 12.5 to 50 yd or m, and the rest between each swim should be long enough that fatigue does not affect their efforts. Repeat distances should be between 50 and 100 yd or m when the purpose is to improve stroke lengths at or near race speeds. The swimmers should try to swim the same times with slower stroke rates or faster times without increasing their stroke rates. Either of these changes will mean that the swimmers have increased their stroke lengths.

To conduct a drill of this type for sprinters, the coach should first measure the distance that each swimmer can cover in 10 sec in the middle of the pool. Swimmers attempt to

- cover more distance with no increase in the stroke rate (in which case stroke length has increased) or
- cover more distance with a faster stroke rate (indicating that stroke length has not decreased significantly).

If their stroke rates increase but the distance they cover does not, their stroke lengths have probably decreased, and the effect will be negative. Correspondingly, there will be no increase of the swimmers' stroke lengths when the distances they cover and their stroke rates remain unchanged.

Stroke rate measures can also be used in combination with several of the stroke-counting drills described earlier. In this case, it is not necessary to time the swimmers during their drills. They can simply try to cover a specific distance with fewer strokes while swimming at specified stroke rates. Their compliance with those stroke rates should be monitored by coaches or other swimmers using a stopwatch or device for counting stroke rates. For example, an athlete can try to reduce his or her stroke count while sprinting a series of 25 m swims at a stroke rate that approximates the one he or she uses in 100 m races.

Swimmers can do a variation on this drill by attempting to swim the repeats with a faster stroke rate without increasing the number of strokes they take to cover the distance. Coaches should evaluate the energy cost of these repeats by recording times and heart rates or perceived efforts to ensure that the faster stroke rates are not increasing the swimmers' efforts inordinately. Any increase in immediate postswim or recovery heart rates or increases in the swimmers' subjective sensation of effort may not be beneficial.

Effects of Fatigue on Stroke Rate, Stroke Length, and Swimming Velocity During Races

A swimmer's stroke length will decrease as he or she becomes fatigued. For this reason, drills designed to improve the relationship between stroke rate and stroke length should be done when swimmers are both rested and fatigued. Rested efforts will help improve stroking efficiency, and fatigued drills will help swimmers maintain a better relationship between their stroke lengths and stroke rates late in races. Wakayoshi and colleagues (1993) reported that one of the adaptations to endurance training was an improved ability to maintain a longer stroke length later in races.

As I indicated earlier, there is no guarantee that swimmers self-select the best combination of stroke rate and stroke length when they are rested. In fact, indications are that many do not. Similarly, most are not likely to retain a good relationship between the two when they are fatigued. Some swimmers may increase their stroke rates at the expense of their stroke lengths, and others may make the opposite mistake by slowing their stroke rates too much to keep their strokes long. For this reason, all swimmers should experiment with different combinations of stroke rate and stroke length when they are fatigued as well as when they are rested.

A survey of the finalists at the 1998 World Championships revealed wide variations in the relationships swimmers maintained between their stroke lengths and stroke rates from the start to the finish of races. The information in table 20.4 indicates how the stroke rate, stroke length, and swimming velocity changed for some of these swimmers from the beginning to the end of various races.

I expected to see certain trends in this data, but they were not apparent. For example, I assumed that medalists would show smaller decreases in their stroke rates, stroke lengths, and swimming velocities from the beginning to the end of their races. But some medalists had large decreases in all three, and only their early speed made the difference. On the other hand, some swimmers increased their stroke rates and decreased their stroke lengths later in their races, whereas others slowed their stroke rates and increased their stroke lengths. I suspect that the swimmers did not plan all the changes and that they did not always make the most effective choices, despite the fact that they won medals. Stroke rate, stroke length, and velocity variations were similar for both male and female competitors, so the information in table 20.4 has not been presented separately for males and females.

Table 20.4 Effects of Fatigue on Stroke Rates, Stroke Lengths, and Swimming Velocities Among Contestants at the 1998 World Swimming Championships

	Ranges of change		
EVENT	**STROKE RATE CYCLES/MIN**	**STROKE LENGTH M/CYCLE**	**VELOCITY M/SEC**
50 m freestyle	0 to –7	+.28 to –.06	–.01 to –.15
100 m freestyle	0 to –10	+.21 to –.30	–.11 to –.39
200 m freestyle	–1 to –9	+.26 to –.32	–.03 to –.30
400 m freestyle	+3 to –12	+.36 to –.32	0 to –.12
800/1,500 m freestyle	+3 to –5	+.07 to –.23	–.02 to –.14
100 m backstroke	–3 to –8	+.15 to –.26	–.03 to –.06
200 m backstroke	+2 to –9	+.13 to –.27	–.08 to –.27
100 m breaststroke	+10 to –4	–.03 to –.31	–.03 to –.22
200 m breaststroke	+14 to –4	–.01 to –.88	–.03 to –.24
100 butterfly	+2 to –8	+.08 to –.30	–.11 to –.42
200 butterfly	0 to –6	+.06 to –.38	–.09 to –.32

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia. Biomechanics Department, Australian Institute of Sport.

As shown in the table, stroke rates decreased from the beginning to the end of races for swimmers in most events, although there were some exceptions. Most of the distance swimmers maintained similar stroke rates from the start to the finish of their races. One of the interesting findings was that the majority of female breaststroke finalists increased their stroke rates from the beginning to the end of both their 100 and 200 races. Another was that most men increased their stroke rates late in the 200 breaststroke races. The energy demands of breaststroke may require more careful pacing, even in 100 events. Therefore, the swimmers hold back until later in their races. I have no explanation for the fact that male breaststrokers increased their stroke rates only in 200 events.

Many swimmers decreased their stroke lengths as well as their stroke rates during their races. Fatigue is the probable explanation for this reaction. But some swimmers increased their stroke lengths from the beginning to the end of their races, perhaps to compensate for their declining stroke rates. This happened with most female sprinters in both the 50 and 100 events. Stroke lengths also decreased dramatically for breaststroke swimmers who increased their stroke rates from the beginning to the end of their races. The pattern of stroke length increases or decreases was randomly spread in most of the other events with the exception of the 800 and 1,500 m freestyles, in which stroke length changed little for most swimmers throughout their races.

Swimming velocity declined from the beginning to the end for all swimmers in all but one race. The exception was the 1,500 m freestyle, during which many swimmers increased their velocity during the final 50 m. For this reason, the segment of the race between 1,400 and 1,450 m was compared with the first 50 m of this race in table 20.4 so that the effects of fatigue would be more evident. Even so, the decline in swimming velocity from the beginning to the end was less in the distance events than it was in any others.

Five swimmers won gold medals despite the fact that their swimming velocity declined more than that of the other finalists from the beginning to the end of their races.

This happened in the men's 50 m freestyle, in both the men's and women's 200 m freestyles, in the women's 100 m breaststroke, and in the women's 200 m butterfly.

Pacing With Stroke Rates

Stroke rates are one of the best ways for swimmers to control their distribution of effort during races. The recommended patterns for pacing races are even pacing and negative splitting. Even pacing refers to starting races at the fastest speed that can be maintained throughout, without dropping off at the end. Negative splitting involves swimming the early portions of races at a slightly slower speed and then increasing speed later in the race. In practice, however, most athletes use fast-slow pacing, swimming the first portions of their races faster than the later portions. Many swim the early portions of their races too fast, and they develop acidosis too early, causing them to slow down too much in the later portions. Stroke rates provide an excellent method for teaching swimmers to control the first portions of their races. With only a small amount of practice, they can learn to control their speed early in races simply by using a slower stroke rate than they will use later.

Although some world-class swimmers appear to use this method for pacing their races, others do not, particularly in shorter events. Several reasons may account for this. One possibility is that the effect of a slower start is too difficult to overcome later. Another is that swimmers with greater aerobic capacity can afford to swim faster early in races without producing severe acidosis. A third explanation is that some swimmers win races despite the fact that they do not distribute their effort in the most economical manner over the race distance.

The bar graphs in figure 20.5 illustrate the typical patterns of stroke rate and stroke length changes during most races. A 200 m race has been used in this example. Swimmers use similar patterns of change for these two variables at other race distances.

The bar graphs in figure 20.5 show the changes in stroke rates and stroke lengths for Susan O'Neill during each 50 m segment of the 200 m butterfly when she won the gold medal at the 1996 Olympic Games. Values are shown for both the first and second 25 m portions of the first 50 m of that race because her SR, SL, and velocity changed so much between those two segments.

Her stroke rate was highest, 56 cycles/min, during the first 25 m of the race. It then declined to between 50 and 51 cycle/min and stayed there until the final 50 m of the race, when it increased to 52 cycles/min. Her stroke length was at it lowest point, 1.77 m/cycle, during the first 25 m of the race. It increased to 1.88 m/cycle during the second 25 m, perhaps because of the reduction in her stroke rate. Her stroke length dropped off during the middle of the race despite the fact that her stroke rate did not change appreciably. It declined to 1.84 and then to 1.79 m/cycle during the middle two 50 m segments, probably because of progressive fatigue. Her stroke length was at its lowest point, 1.70 m/cycle, during the final 50 m despite, or perhaps because of, an increase in her stroke rate.

Her time was considerably faster during the first 50 m of the race because of the start and because her swimming velocity was at its highest level during that time. Her velocity fell off slightly during each of the next two 50 m segments, and it dropped most during the final 50 m.

Susan started her race with a combination of stroke rate, stroke length, and swimming velocity that she could not maintain to the end. She might have been able to maintain a faster average velocity throughout if she had slowed her stroke rate somewhat during the first 25 m of the race. Of course, this is speculation on my part, but it is based on experience that shows that most swimmers perform better when they distribute their effort evenly over the race distance. Some research studies suggest the same conclusion.

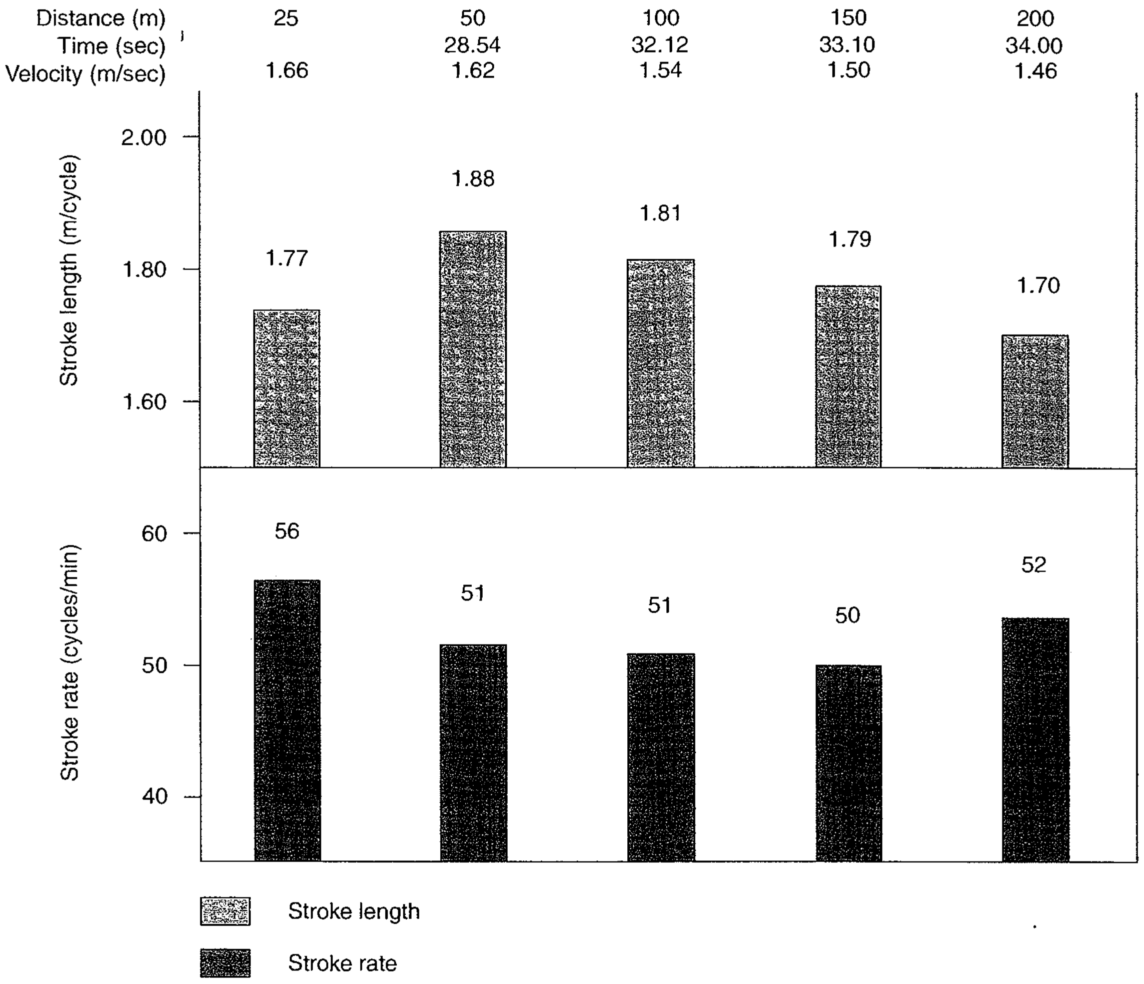


Figure 20.5 The stroke rate and stroke length changes for Susan O'Neill when she won th 200 m butterfly at the 1996 Olympics with a time of 2:07.76.

The bar graphs in figure 20.6 show the results for a swimmer who used a more even distribution of effort over the course of the race. These results are for Ian Thorpe when he won the 400 m freestyle at the 1998 World Swimming Championships. He used a stroke rate of 37 to 38 cycles/min for the first 350 m of the race and then increased it to 41 cycles/min during the final 50 m. His stroke length was 2.84 m/cycle on the first 50 of the race and then settled to a distance of approximately 2.6 m/cycle until the final 50, when it dropped to 2.52 m/cycle. The drop in his stroke length during the final 50 m of the race probably occurred because he increased his stroke rate.

After the first 50 m of the race, his swimming velocity stayed between 1.60 and 1.70 m/sec until the final 50 m, when his stroke rate increase improved his velocity to 1.72 m/sec. His split times were between 28.38 and 29.32 sec per 50 m throughout most of the race after the first 50 m. The increase of his stroke rate and velocity during the final 50 m improved his time to 27.09 for that segment.

The pattern displayed by Thorpe in figure 20.6 was an economical way to swim. His use of nearly constant stroke rates and stroke lengths throughout the race probably conserved energy. At the same time, his slower start probably delayed acidosis. As a result, he was able to swim faster in the late portions of the race.

Swimmers can use two strategies involving stroke rates to improve their pacing in races. With the first strategy, swimmers should determine the optimum combination of

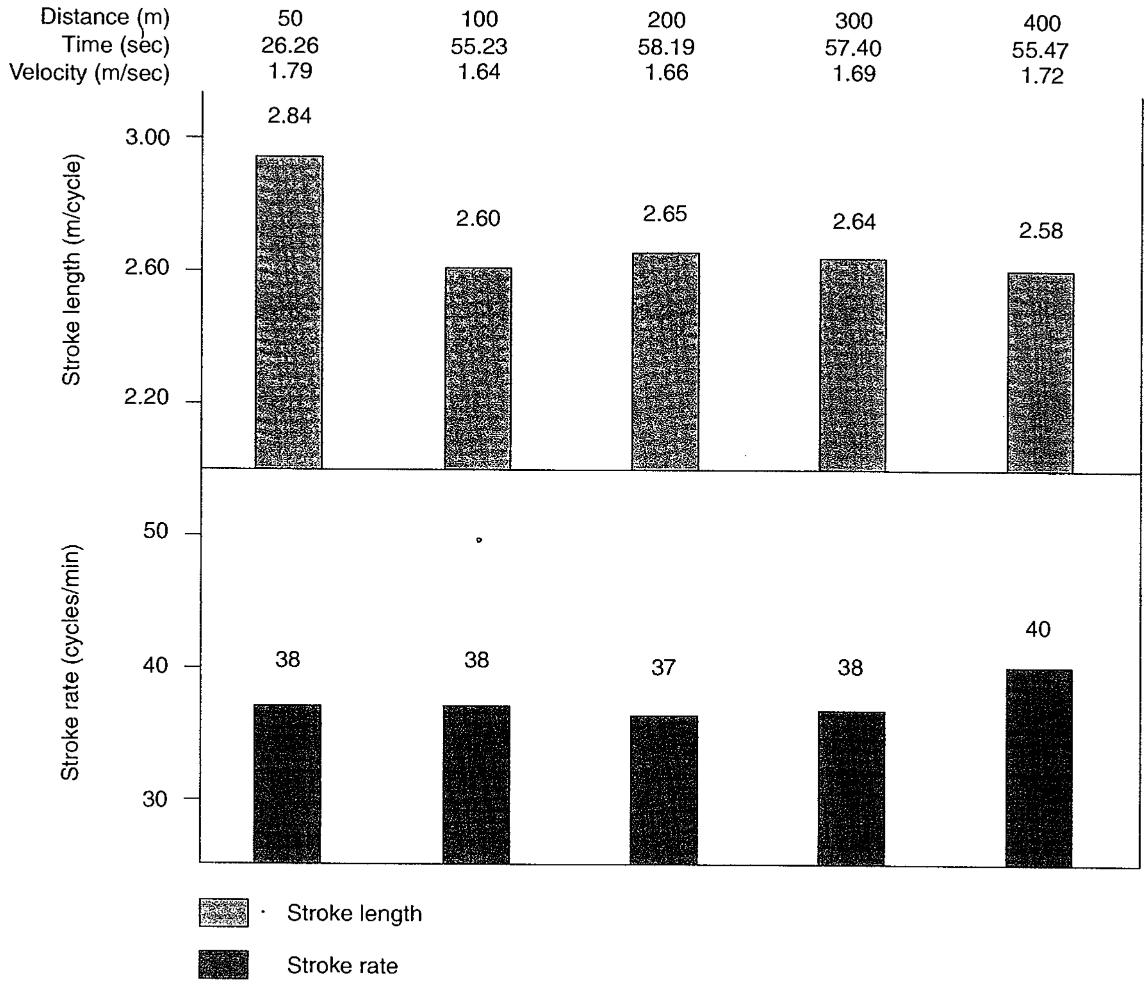
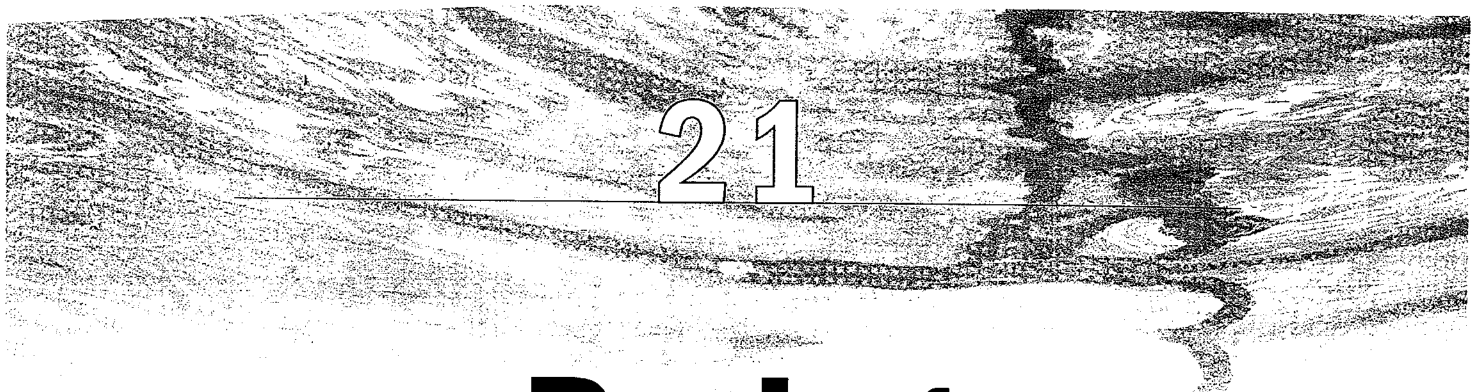


Figure 20.6 The stroke rate and stroke length changes for Ian Thorpe when he won the 400 m freestyle at the 1998 World Swimming Championships with a time of 3:47.48.

stroke rate and stroke length that will allow them to swim at their desired race velocity with the least effort. Then they should train themselves to use those stroke rates throughout the race until the final 25 or 50 segment, when they can increase their stroke rates. Swimmers can also use the strategy of starting races with a slightly slower stroke rate so that they can maintain their velocity by increasing their stroke rates as fatigue causes their stroke lengths to decline. Swimmers should experiment with both methods to determine which works best for them. I think it is safe to say that swimmers should not start races with stroke rates that they cannot maintain from start to finish.



21

Pacing and Strategy

New in this edition:

- A justification for pacing
- Updated race analyses to include results from the 1996 Olympic Games, the 1998 World Swimming Championships, and, in some cases, the 2000 Olympic Games
- Expanded race analyses to include data on stroke rates, stroke lengths, and swimming velocities

Pacing and racing strategy are misunderstood and frequently neglected in many training programs. This is unfortunate because both play a significant role in the performance of athletes. Pacing will be the first topic of this chapter, and a description of racing strategies and counterstrategies will follow.

Pacing

A properly paced race will generally be 0.50 sec faster per 100 yd or m than a poorly paced one. Pacing involves swimming the first half to three-quarters of races slower so that the remainder can be swum faster. Swimmers find that the total time for races is faster when they do this. Pacing is particularly noticeable in races of 400 m and longer. The 100 and 200 events should also be paced, although the second half of these races will usually be slightly slower than the first half.

Why Pacing Works

Athletes can race at maximum effort for only 40 to 45 sec before severe acidosis sets in. This does not mean that athletes can maintain maximum speed for 40 sec. The effects of progressive acidosis actually begin reducing the rate of anaerobic glycolysis after approximately 15 sec of all-out effort (Jacobs et al. 1983; Song et al. 1988). That rate, and consequently the swimmer's speed, will continue to slow over the next 25 to 30 sec until the swimmer can barely move his or her arms.

In races of 100 m and longer, athletes delay acidosis by swimming slower in the early stages. Swimming slower in the early stages of a race reduces the rate of anaerobic metabolism so that lactic acid accumulates more slowly and acidosis does not occur as quickly. Swimmers can usually more than compensate for the speed they give up early in the race by their increased speed later, thus achieving a faster overall time for the race. On the other hand, swimmers who make the mistake of swimming too fast early in their races usually find that they slow down so much in the latter portions that they lose any advantage they gained earlier.

Pace Plans

One of the most important decisions that swimmers make is choosing a pace, or swimming speed, for each race. Swimmers have used three general race plans over the years—even pacing, fast-slow pacing, and slow-fast pacing, also known by the term *negative splitting*. In even pacing, a swimmer holds an even pace through the entire race. Fast-slow pacing refers to swimming the early portions of the race faster than later portions. The strategy is to take the race out ahead of the competition and hang on to win at the finish. In slow-fast pacing, or negative splitting, athletes swim the early portions of a race slower than the later portions. The strategy with this pace plan is to delay acidosis early in the race by swimming slower and then make up the time by swimming faster at the end. Research has shown that fast-slow pacing is the least effective of the three methods but has been inconclusive about which of the other two methods is best (Mathews et al. 1963; Robinson et al. 1958).

Thirty years of studying the paces of world and national championship races has demonstrated to me that the most successful swimmers have used a fast-slow pattern in 100 events. Some have also used fast-slow pacing in 200 events, with only a slight drop-off from the first to later portions of their races. Most have used even pacing in 200 events. Even pacing is used by most of the successful swimmers in 400, 800, and 1,500 m freestyle events, although some outstanding swims have been achieved in the 400 event by athletes who used a negative-split pacing plan. Fifty-meter races are sprinted from start to finish. The only element of pacing that comes into play in this race is selecting the combination of stroke rate and stroke length that will produce the fastest swimming velocity.

I will review some aspects of swimming races before I discuss how swimmers use these different pace plans. Split times often give the wrong impression because of the positive influence of starts and turns. The start will cause the first split to be 1 to 2 sec faster than later splits even when athletes are swimming at a constant velocity throughout. This occurs, of course, because swimmers' flights through the air will be faster than any swimming speed they can attain. In addition, they will be able to maintain some of that speed for a short time after they enter the water, during the glide, before they actually begin swimming. Freestyle, butterfly, and breaststroke swimmers gain a greater advantage from their block starts than backstrokers do because backstrokers start in the water. Consequently, backstrokers' flights through the air will be shorter, and their glides after entry will be at a slower velocity.

The time for turning is added to the split time in freestyle and backstroke races; therefore, the only advantage swimmers gain on turns comes from the added velocity they achieve for a short time after pushing off the wall. The additional turn time added to the split and the increase in speed from the push-off tend to cancel one another, so that the only difference in time between the first and later splits in these races will be due to the influence of the start.

In butterfly and breaststroke races, however, the time it takes to turn will add to the difference between the first and later splits. After the start, all splits from breaststroke and butterfly races begin with a turn that will add nearly 1 sec to the split times, and this is more than the swimmer gains with the push-off. Consequently, the start will increase the swimmer's speed for the first split even when he or she is swimming at a constant velocity throughout the race, and the time required to turn will slow the speed of the second and later splits even when the athlete is swimming at a constant velocity. The combined influence of the start and turns causes the first split of butterfly and breaststroke races to be 2 to 3 sec faster than later splits when an athlete is swimming at a constant velocity. In contrast, the first splits of freestyle and backstroke races will be only 1 to 2 sec faster than later splits when the athlete is swimming at the same velocity because only the start influences the split times.

For those reasons, swimming velocities provide a better method than split times for evaluating pacing plans for races. Therefore, in the upcoming analyses I will provide swimming velocities along with split times for each race segment to permit more accurate evaluation of the differences in speed between the first and later portions of races. Stroke rates and stroke lengths will also be included in these analyses to indicate how swimmers have adjusted these parameters throughout their races.

Another piece of information needed to evaluate pacing plans concerns how fast swimmers swim the first portion of a race relative to their maximum speed for that distance. The phrase "taking races out" refers to the speed of the first quarter to first half of races. The ideal pace for taking races out is usually the slowest speed that an athlete can swim and still be in position to win the race or achieve a goal time. One way to estimate the proper speed for taking races out is to compare the first split to a particular swimmer's best time for that distance. This assessment indicates how much he or she has been holding back. Comparisons between split times and best times for the first portion of a race have shown a consistent relationship over the years. Let me offer an example of how to determine from a swimmer's best time the proper speed for taking out a particular race.

Suppose a female athlete swims 200 m in 1:58.00 with splits of 58.50 and 59.50. If that swimmer had a best time of 56.00 sec for 100 m, she would be swimming the first half of the race 2.50 sec slower than her best time. As I will show later, a swimmer is pacing a 200 race well when he or she swims the first split 2 to 3 sec slower than his or her best time for 100 m.

Although the times for early world- and national-record swims were considerably slower than those of today, the differences between the times for those early swimmers' first splits and their best times for the same distance are similar to those of the swimmers of today. For example, Frank Heckl won the 200 yd freestyle at the 1971 U.S. Short Course Nationals in a time of 1:40.55. His split at 100 yd was 48.80, which was 3.24 sec slower that his winning time in the 100 yd freestyle (45.56) at the same meet. His drop-off from the first to the second 100 segment of the race was 2.95 sec. Compare this with Matt Biondi's 1987 American-record time of 1:33.03 in the same event. He swam that race with splits of 45.34 and 47.69. Biondi's time for the 100 yd freestyle was an American record 41.80 at the same meet. Producing results almost identical to those of Heckl, Biondi swam the first 100 of the 200 event 3.46 sec slower than his best time for 100 yd, and his drop-off from the first 100 segment to the second was 2.35 sec.

The best pace plans for specific races can be learned by studying the splits from winning times at world and national championship meets. The paces used in these races are not always ideal as evidenced by the fact that some swimmers have posted faster times for the same race distance with different pace plans. Nevertheless, the plans that swimmers used in championship meets are frequently close to the ideal pace plans. In the following sections, I have selected races that exemplify pace plans that have been successful through the years. These examples represent patterns that swimmers used for most of the record swims, so I feel justified in stating that they represent the best methods for swimming those races. When swimmers of different sexes, from different parts of the world, and from different eras pace their most outstanding races in nearly the same manner, the conclusion seems inescapable that the methods they used are worth emulating.

In the selected race analyses, I will provide the following information, starting with the swimmers' split times for certain segments. In addition, where available, I will list their swimming velocities, their stroke rates, and their stroke lengths for those segments. Their start times for the first 10 or 15 m of their races will be included, and when available, their turn times. Turn times encompass a distance of 15 m, beginning 7.5 m before the turn and including the time to cover that distance, the time for the turn itself, and the time required to cover 7.5 m after the turn. The first analysis is for the 50 freestyle event.

50 Freestyle

I have selected the gold medal swim of Amy Van Dyken from the 1996 Olympic Games as an example for this event. Her time was 24.87. Table 21.1 presents the information. Amy's time for the first 25 m of that race was 11.73 sec, her velocity was 1.97 m/sec, her stroke rate was 61 cycles/min, and her stroke length was 1.92 m/cycle. She swam the second 25 m of the race in 13.14 sec. Her velocity dropped off slightly to 1.90 m/sec on the second 25 m. Her stroke rate increased slightly to 62 cycles/min, but her stroke length fell off to 1.83 m/cycle. Her time to cover the first 10 m of the race from a dive was 4.13 sec, one of the slower start times in the race. The fastest time was 3.83 sec, and the start times for most swimmers were in the neighborhood of 4.10 sec.

Besides her speed, the strong point of Amy's race was her ability to maintain her velocity near maximum for the entire distance. This, in turn, was probably a result of her ability to maintain her stroke rate in the face of increasing fatigue. The velocities of most swimmers decline by 0.10 m/sec or more from the first to the second 25 m of 50 races. Their stroke rates generally fall off by 2 or 3 cycles/min, and their stroke lengths usually decline by 0.12 m/cycle or more.

The best plan for a 50 freestyle race seems to be to sprint at maximum speed from start to finish. Swimmers should select a combination of stroke rate and stroke length that will provide their maximum velocity, and they should try to maintain that rate for the entire race while minimizing the drop-off of their stroke lengths. Although their velocity will drop off slightly from the first to the second 25 m of the race, the drop-off should not be more than 0.30 to 0.50 m/sec. That amounts to a difference of approximately 1.00 sec between the first and second 25 m for long-course 50 m races. The drop-off will be slightly less, between 0.70 and 0.90 in short-course races, probably because of the additional speed that swimmers gain from the push-off following their turns.

Table 21.1 A Pace Plan for 50 M Freestyle, LC

Amy Van Dyken—50 m freestyle—24.87
First place—1996 Olympic Games

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
25	11.73		1.97	61	1.92
50	24.87	13.14	1.90	62	1.83
Start time	4.13 (10 m)				

Source: Competition Analyses of Swimming Events, Olympic Games, Atlanta, GA, July 20–26, 1996. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

The splits for Matt Biondi's former American and NCAA record 50 yd freestyle swim are listed in table 21.2 as a guide to determining the ideal difference in time between the first and second halves of short-course 50 races. He swam the first 25 yd, including the turn and planting his feet on the wall, in 9.15 sec, and he swam the second 25 yd in 10.00. So his drop-off from the first to the second segment of the race was 0.85 sec.

Race analyses like the one in table 21.2 were not available for 50 races in butterfly, backstroke, and breaststroke at the time of this writing. Swimmers in these races probably sprint 50s in the same manner as freestylers, although the drop-off from the first to second 25 should be somewhat greater in short-course butterfly and breaststroke races because the second split includes the time for turning.

Table 21.2 Data for Matt Biondi's Winning 50 yd Freestyle Swim at the 1987 NCAA Championships

Matt Biondi—50 yd freestyle—19.15
Former American record—1987
NCAA Swimming Championships

DISTANCE	TIME IN SEC	SPLIT IN SEC
25	9.15	
50	19.15	10.00 (drop-off = 0.85 sec)

100 Freestyle

Data from Pieter van den Hoogenband's gold medal swim of 48.30 in the 2000 Olympic Games are shown in table 21.3. He swam a world-record time of 47.84 in the semifinals of that event, but the data were not available for that swim. The information in table 21.3 represents a typical pacing pattern. Pieter swam the first 50 m of this race in 23.32, which was 1.29 sec slower than his time for 50 m in the same meet. The difference in time was probably closer to 0.50 or 0.80 sec because a 50 freestyle race ends with a hand touch and the 50 split for a 100 race includes a turn.

Pieter swam the second 50 m of this race in 24.98. Therefore, the difference in time between his first and second 50 m of the race was 1.66 sec. In contrast, many of the other swimmers in this race swam their first 50 m only 1.00 sec slower than their best 50 time, and their second 50 of the race was more than 2.00 sec slower than the first. Pieter's

Table 21.3 A Pace Plan for 100 M Freestyle, LC

Pieter van den Hoogenband—100 m freestyle—48.30
First place—2000 Olympic Games
Time for 50 m—22.03

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
25	10.74		2.15	56	2.28
50	23.32	12.58	2.04	51	2.38
75	35.42	12.10	1.99	52	2.28
100	48.30	12.88	1.90	50	2.30
Start time	NA				
Turn time	7.28				
Finish time	2.74				

Source: Competition Analyses of Swimming Events, Olympic Games, Sydney, Australia, Sept. 16–23, 2000. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

25 m splits were 10.74, 12.58, 12.10, and 12.88 sec for the first to fourth 25 m segments, respectively.

Pieter's stroke rate was 56 cycles/min for the first 25 m of the race. He maintained a nearly constant stroke rate of 51 to 52 cycles/min for the middle 50 m of the race, and his stroke rate was 50 cycles/min during the final 25 m.

Pieter's stroke length was 2.28 m/cycle over the first 25 m of this race and 2.38 m/cycle on the second 25. Then it dropped to 2.28 m/cycle again on the third 25 before increasing slightly to 2.30 m/cycle on the final 25 m. The stroke lengths of most swimmers will decrease by 0.10 to 0.20 m/sec, as Pieter's did, when they become fatigued late in this race. That decline can increase their time by 2 to 4 sec over 50 m.

Pieter's swimming velocity was 2.15 m/sec on the first 25 m of this race. His velocity dropped to 2.04 m/sec on the second 25 m, to 1.99 m/sec on the third 25 m, and finally to 1.90 m/sec on the final 25 m of the race.

His start time was not available, but his turn time was 7.28 sec. That was one of the slower turn times of the final competitors. Most of the finalists had turn times between 7.00 and 7.13 sec. His finish time was 2.35 sec, which was one of the best for the finalists. Most finished their race in times of 2.38 to 2.55 sec.

One could argue that Pieter should have used a slightly slower stroke rate during the first 25 m of this race, when his stroke rate was 56 cycles/min. He might have been more effective if he had used a stroke rate of 50 to 52 during that 25. His time might have suffered slightly because his swimming velocity would have been slightly slower, but he may have had more energy for the final 50 m, enabling him, perhaps, to maintain a stroke length in excess of 2.30 m/cycle and a velocity closer to 2.0 m/sec over the final 25 m. Of course, this is only speculation. Most swimmers, even world-class athletes, begin their 100 races with stroke rates that are slightly higher than average, as Pieter did. The excitement of the race may cause them to do this, or they may be attempting to maintain the velocity from their start for a longer time. Consequently, it is difficult to be certain whether swimming at a stroke rate slightly faster than average on the first 25 m of the race is a mistake.

Pieter's velocity fell off quite a bit at the finish of his race. This drop-off is typical of most 100 swimmers. Apparently, they cannot afford to hold back too much early in such a short race. They must tolerate some drop-off in their speed late in a race to remain competitive early. The stroke rates of most swimmers decrease, as Pieter's did. Rates usually decline by 3 to 5 cycles/min from start to finish, but Pieter maintained his stroke length better than most do.

A suggested plan for swimming a 100 m freestyle race in a long-course pool is to swim the first 25 m of the race within 0.50 sec of maximum speed. The time at 50 m should be slightly more than 1 sec over the swimmer's best time for 50 m. In other words, in this race swimmers should go out fast but not as fast as possible. They appear to reduce their velocity by approximately 0.10 m/sec, or by 0.50 sec, during the first 25 m. The drop-off in time from the first to second 50 m of the race should be less than 2.00 sec.

Swimmers should select the fastest stroke rate they can maintain for the entire race distance, provided, of course, that their combination of stroke rate and stroke length are optimum for this distance. Swimmers may stroke slightly faster in the first 10 to 15 m of the race, but they should settle in to their optimum rates before they have completed the first 25 m of the race. They may increase their stroke rates slightly on the final 25 m if they can do so without losing a great deal of stroke length and swimming velocity.

Swimmers should expect to slow down somewhat during the last 25 m of 100 races, probably because a good 100 swim requires a fast early velocity. In these races, it is probably better for swimmers to get out fast and drop off slightly more at the end than to swim too slow in the beginning and try to catch up later.

Swimmers appear to follow the same patterns in long-course and short-course 100 freestyle races. Matt Biondi's splits for his American-record 100 yd freestyle swim of 41.80 sec are shown in table 21.4. He swam his first 50 1.10 sec slower than his 50 time at the same meet, and the difference in time from the first to second 50 of his race was 1.30. Unfortunately, no information is available on stroke lengths, stroke rates, and velocity for this swim.

The rest gained with additional turns should make it possible for swimmers to take short-course 100 races out slightly faster and bring them back with slightly less drop-off, as evidenced by Biondi's splits for his short-course 100 yd race. Evidence that swimmers can maintain greater stroke length in short-course versus long-course races supports this statement (Keskinen, Keskinen, and Mero 1996), although the differences will not be great.

Table 21.4 A Pace Plan for 100 Yd Freestyle

Matt Biondi—100 yd freestyle—41.80
American record—1987 NCAA Men's Swimming Championships
Time for 50 yd—19.15

DISTANCE	TIME IN SEC	SPLIT IN SEC
50	20.25 (–1.10)	
100	41.80	21.55 (+1.30)

Source: USA Swimming Official Website. www.usswim.org

100 Butterfly

Pacing in the 100 butterfly is similar to that of the 100 freestyle. Athletes should swim the first 50 of the race approximately 0.50 to 0.80 sec slower than their maximum speed for a 50 race. The drop-off from the first to second 50 m will be greater than in freestyle, generally between 3.00 and 3.50 sec. The real difference is probably closer to 2.00 sec, however, because the split for the second 50 of the butterfly begins with a turn that takes about 1.00 sec to complete, whereas the first split in the freestyle event includes a turn.

The splits for Inge de Bruijn's gold medal and world-record swim of 56.61 in the 100 m butterfly at the 2000 Olympic Games, shown in table 21.5, exemplifies this pacing pattern. Her splits were 26.67 for the first 50 m and 29.94 for the second 50 m. Inge's best time for 50 m butterfly is 25.64, so she swam the first 50 m 0.97 sec slower than her best time for 50 m. Her drop-off was 3.27 sec from the first to second 50 of the race. Her 25 splits for the race were 12.39, 14.28, 14.54, and 15.40 for the first to fourth 25 m segments, respectively.

Table 21.5 A Pace Plan for 100 M Butterfly, LC

Inge de Bruijn—100 m butterfly—56.61
World record—2000 Olympic Games
Time for 50 m—25.64

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
25	12.39		1.74	54	1.93
50	26.67	14.28	1.79	57	1.79
75	41.21	14.54	1.76	56	1.76
100	56.61	15.40	1.67	56	1.67
Start time	6.73 (15 m)				
Turn time	8.64				
Finish time	2.92				

Source: Biomechanical Analysis, 2000 Olympic Swimming Championships, Sydney, Australia, Sept. 16–23, 2000. Prepared by the Biomechanics Department, Australian Institute of Sport.

Her stroke rate on the first 25, 59 cycles/min, was faster than her rate for any other segment of the race. She reduced it to 55 cycles/min on the second 25 m, increased it to 58 cycles/min on the third 25 m, and dropped it to 56 cycles/min on the final 25 m.

Her stroke lengths were almost identical over the first 50 m. They were 1.92 m/cycle for the first 25 m and 1.90 m/cycle during the second 25 m. Her stroke length dropped to 1.76 m/cycle on the third 25 m segment of the race and then to 1.73 m/cycle over the final 25 m.

Inge's swimming velocity was fastest over the first 25 m of the race at 1.81 m/sec. Her velocity remained fairly constant throughout the middle 50 m of the race, at 1.73 m/sec for the second 25 m and 1.72 m/sec on the third 25 m. Her velocity then dropped to its lowest level, 1.60 m/sec, during the final 25 m.

Her start time for the first 15 m of the race was 6.73 sec, which was one of the faster times of the finalists. Most had start times between 6.80 and 7.30 sec. Her turn time was 8.64 sec, which was the fastest in the finalists' range of 8.64 to 9.33 sec. Her finish time was 2.92 sec. Most of the finalists finished in times between 2.80 and 3.50 sec.

Again, one could argue that Inge's swim might have been better paced had she slowed her stroke rate and swimming velocity slightly during the first 25 m of the race. She maintained her stroke rate well from the start to the finish, but her swimming velocity fell off dramatically during the final 25 m. She might have been able to maintain a slightly longer stroke and a faster velocity over the final 25 m if she had started the race with somewhat less effort.

Short-course 100 butterfly races are swum with a similar pace plan. Athletes swim the first 50 m approximately 0.50 to 1.00 sec slower than their best time for a 50 race. Their drop-off times will usually be slightly less from the first to second 50 of short-course 100 butterfly races, probably because of the added velocity and rest they gain from two additional turns. The usual drop-off in these races is between 2.40 and 3.00 sec.

100 Breaststroke

Athletes swim this race in a manner similar to the way they swim other 100 races. They swim the first 50 m approximately 0.50 to 0.80 sec slower than their maximum speed for 50 m. The drop-off from the first to second 50 of the race is generally between 3.50 and 4.00 sec, slightly greater than it is in freestyle events. Some swimmers stroke at an even rate throughout, whereas others increase their stroke rates by 2 to 5 cycles/min during the second half of the race. Swimmers' stroke lengths and swimming velocities generally fall off during the second half of the race. A survey of results from the 1996 Olympic Games and the 1998 World Swimming Championships shows that breaststroke swimmers who increase their stroke rates during the second half of the race do not lose quite as much velocity as those who start out with higher stroke rates. Swimmers who increase their stroke rates lose about the same amount of velocity as swimmers who maintain a relatively constant stroke rate throughout.

The analysis of Penny Heyns' gold medal performance in the 100 m breaststroke at the 1996 Olympic Games is shown in table 21.6. She swam the first 50 m of the race in 31.65 sec. Her best time for 50 m breaststroke, which she swam 3 yr later, was listed as 30.83. The difference between it and her time for the first 50 was 0.82 sec. Her time for the second 50 of the race was 36.08, a drop-off of 4.42 sec from the first 50 m of the race. Her splits by 25s were 14.50, 17.15, 17.42, and 18.66 from the start to the finish of the race.

Penny's stroke rates were excellent during this race. She exhibited a constant rate of effort that I believe represents the most efficient way to swim this race. She maintained a constant stroke rate of 51 cycles/min through the first three 25s and increased it slightly to 52 cycles/min during the final 25 m. Her stroke length remained constant for the first 50 m at 1.76 m/cycle and then fell off to 1.61 in the third 25 and to 1.52 m/cycle in the final 25 m, presumably because of fatigue. Her swimming velocity also remained constant at 1.49 m/sec during the first 50 m of the race. It fell off to 1.38 m/sec during the third 25 m. Her greatest drop-off in velocity occurred during the final 25 m, as she

Table 21.6 A Pace Plan for 100 M Breaststroke, LC

Penny Heyns—100 m breaststroke—1:07.73
First place—1996 Olympic Games
Time for 50 m—30.83

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
25	14.50		1.49	51	1.76
50	31.65	17.15	1.49	51	1.76
75	49.07	17.42	1.38	51	1.61
100	1:07.73	18.66	1.33	52	1.52
Start time	7.77 (15 m)				
Turn time	13.57 (20 m)				

Source: Competition Analyses of Swimming Events, Olympic Games, Atlanta, GA, July 20–26, 1996. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

finished with a velocity of 1.33 m/sec. This sequence is similar to what happens in other 100 events and supports the notion that although swimmers hold back somewhat during the first 25 of these races, they still swim fast early, generating greater velocity than they can maintain to the finish. Apparently, it is better to swim faster in the beginning and accept some drop-off at the end. Holding back too much probably makes it impossible to overtake competitors over such a short distance.

Penny's start time of 7.77 sec for the first 15 m of the race was the best of any competitor in the finals. Most others were between 8.00 and 8.30 sec. Her turn time of 13.57 was also the best in the final. Turn times for the other competitors were between 13.60 and 13.93 sec. Her finishing time was not available.

As with other 100 events, the drop-off from the first to second 50 in breaststroke races will generally be smaller during short-course events. The drop-off is generally between 2.70 and 3.50 sec for short-course 100 breaststroke swims. The speed going out is controlled in the same manner as it is for long-course races. It is generally 0.50 to 0.80 sec slower than the swimmer's best time for a short-course 50 swim. Swimmers should try to maintain nearly constant stroke rates from start to finish in short-course races. Stroke lengths generally will not decline quite as much in short-course races because of the momentum and rest supplied by two additional turns.

100 Backstroke

Jeff Rouse's gold medal swim in the 100 m backstroke at the 1996 Olympic Games has been selected for this event. An analysis is shown in table 21.7. Jeff swam the first 50 of the race in 26.30 sec. His best time for 50 m backstroke was not available, but it was probably in the low 25 sec range. Consequently, his time during the first 50 m of this race was approximately 1.00 to 1.30 sec slower than his best time for 50 m. This compares favorably to the difference in time reported for 100 freestyle swimmers, probably because the first split includes a turn in both events. As in all 100 events, the true difference between a backstroke swimmer's 50 time and the time the athlete swims on the first 50 of a 100 race would be 0.50 to 0.80 if the effect of the turn was excluded.

Jeff's time of 27.80 sec during the second 50 m of this race represents a drop-off of 1.50 sec. Backstrokers do not gain as great an advantage on the start as swimmers in other strokes do, which probably accounts for the slightly smaller drop-off in time between the first and second 50s in their races. Jeff's 25 splits were 11.97, 14.33, 12.87, and 14.93 for the first to the fourth 25s of this race.

Table 21.7 A Pace Plan for 100 M Backstroke, LC

Jeff Rouse—100 m backstroke—54.10
First place—1996 Olympic Games
Time for 50 m—NA

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
25	11.97		1.81	50	2.17
50	26.30	14.33	1.77	50	2.13
75	39.17	12.87	1.79	49	2.18
100	54.10	14.93	1.66	51	1.97
Start time	6.43 (15 m)				
Turn time	10.37 (20 m)				

Source: Competition Analyses of Swimming Events, Olympic Games, Atlanta, GA, July 20–26, 1996. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

The drop-off from the first to second 50 of these races for world-class swimmers will generally be similar to Rouse's, about 1.50 sec or less. But Kristina Egerzegi's drop-off was only 0.57 sec from the first to second 50 m of her 1991 world-record swim in the 100 m backstroke. As mentioned earlier, the drop-off for 100 freestyle and backstroke events is less than it is for 100 butterfly and breaststroke events because the first two events begin with a push-off after the turn, whereas in the latter two strokes the final split includes a turn.

The first 50 of short-course 100 m backstroke races should be swum in the same way it is swum for long-course 100 races. Stroke rates should be held constant, with a slight increase at the end. Swimmers can expect slightly less drop-off, between 0.80 and 1.40 sec, from the first to second 50 splits in short-course races because the extra turns allow them to maintain a slightly greater stroke length during the second 50 of the race.

Summary of Pace Plans for 100 Events

In 100 events, the usual pace pattern that swimmers use is to swim the first 50 m approximately 0.50 to 0.80 sec slower than an all-out effort for that distance. The difference in time between their fastest times for 50 m and their times for the first 50 m of a 100 event are usually greater than 1.00 sec for freestyle and backstroke events because the split for the first 50 m includes a turn in those races.

The drop-off in the second half of freestyle and backstroke races should be about 1.50 to 2.00 sec for freestyle swimmers and between 0.70 and 1.50 sec for backstrokers. In butterfly the drop-off from the first to the second 50 m should be 2.50 to 3.00 sec, and in breaststroke it may be slightly greater at 3.50 to 4.00 sec.

The first 50 of short-course races should also be swum approximately 0.50 to 0.80 slower than a swimmer's best 50 time. Drop-off times from the first to the second half of these races should be less than for long-course races because of additional turns. The difference should be 1.30 sec or less for short-course 100 backstroke events, between 1.30 and 1.70 sec for short-course 100 freestyle events, between 2.40 and 3.00 for short-course 100 butterfly events, and between 2.70 and 3.00 for short-course 100 breaststroke events.

Swimmers should start 100 events with stroke rates that they can maintain throughout the first three-quarters of these races. They should then increase that rate by 1 or 2 cycles/min on the final 25 segment. Starting these races with stroke rates that are too high will cause swimmers to fatigue earlier and slow their velocity so much at the end that their overall times may generally be slower.

Despite what I just said, swimmers must swim at a slightly higher velocity during the first half of 100 events than they can maintain throughout the race. They should expect their velocity to fall off by approximately 0.10 m/sec, or about 0.50 sec over the final 25 m of the race, because of this early speed. If they hold back too much, they may not be able to make up the difference at the end. At the same time, however, they should not swim at maximum speed from start to finish.

200 Freestyle

Successful 200 swimmers generally use two variations of an even-pace plan. Some start the race swimming at the fastest velocity they can maintain to the finish of the event. Others start slightly slower, maintain an even pace for 150 m, and then finish the final 50 with a sprint that is a little faster than their average speed in the middle of the race. More of the recent outstanding 200 m freestyle swims have been performed using an even pace with a faster start.

Swimmers generally swim the first 50 of the race approximately 2.00 sec slower than their best time for a 50 event. Their time at the halfway point is usually 2.50 to 3.00 sec slower than their fastest time for a 100 freestyle swim. They then maintain a relatively constant speed through the remainder of the race. Their drop-off time between the first and second halves of the race is usually between 1.00 and 2.00 sec.

When swimming a 200 freestyle, athletes should select a combination of stroke rate and stroke length that they can maintain throughout the race without decreasing either significantly before the finish. Most swimmers will increase their stroke rates by 1 or 2 cycles/min during the last 50 of the race.

Pieter van den Hoogenband's world-record and gold medal 200 m freestyle swim at the 2000 Olympic Games has been selected as a representative pace plan for this event. Table 21.8 presents the race analysis.

His time for the first 50 m of the race was 24.44, and his time at 100 m was 50.85. Pieter's best times for 50 and 100 m of freestyle were 22.03 and 47.84 at this meet.

Table 21.8 An Even-Pace Plan for 200 M Freestyle, LC

Pieter van den Hoogenband—200 m freestyle—1:45.35
World record and gold medal—2000 Olympic Games
Time for 100 m—47.84

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
50	24.44		1.95	51/46	2.29/2.56
100	50.85	26.41	1.87	48/44	2.37/2.48
150	1:18.21	27.36	1.80	46/43	2.35/2.49
200	1:45.35	27.14	1.80	47/46	2.31/2.26
Start time	6.05 (15 m)				
Turn times	7.40, 7.60, 7.88				
Finish time	2.92				

Source: Competition Analyses of Swimming Events, Olympic Games, Sydney, Australia, Sept. 16–23, 2000. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

Therefore, his time at 50 m was approximately 2.50 sec slower than his best time, and his time at the 100 point was approximately 3.00 sec slower than his best. Pieter was holding back approximately the same amount that a sprinter should hold back during the first 100 of a 200 race. Middle distance and distance swimmers will frequently swim the first halves of their races within approximately 2.0 sec of their best times, probably because they rely more on their aerobic capacity over this race distance.

Pieter's second 50 of his race was approximately 2.00 sec slower than the first at 26.41. His time then fell off to 27.36 during the third 50 segment of the race. He picked his speed up slightly to 27.14 over the final 50 m. Pieter's drop-offs from the first to later 50s of his race were between 2.00 and 3.00 sec, and his drop-off time from the first to the second 100 of the race was 4.50 sec. These drop-offs are slightly greater than recommended. Based on other great 200 freestyle swims, it could be argued that Pieter should have swum the first 100 of the race slightly slower to reduce his drop-off from the first to the second half of the race.

Pieter's swimming velocity, stroke rates, and stroke lengths have been listed for each 25 m segment of his race. His swimming velocity was between 1.87 and 1.95 m/sec during the first 75 m of the race. He maintained his velocity between 1.79 and 1.83 m/sec over the next 100 m and then dropped to 1.74 m/sec over the final 25 m of the race.

His stroke rate on the first 25 m, 51 cycles/min, was slightly higher than it was at any other time during the race. After that he settled into a range between 43 and 48 cycles/min. Again, one could argue that he might have swum the race more economically by maintaining a stroke rate in the range between 44 and 46 cycles/min throughout the race.

His stroke length was at its lowest during the first 25 m of the 200 when his stroke rate was highest. He maintained his stroke length between 2.35 and 2.49 m/cycle through the middle of the race. His stroke length fell off slightly to 2.31 and then to 2.26 m/cycle during the final 50 m of the race as he increased his stroke rate slightly.

His start time of 6.05 sec was excellent. Most male competitors cover the first 15 m of this race in times of 6.10 to 6.70 sec. His times for the three turns were 7.40, 7.60, and 7.88 sec. Those times were slightly better than those of most of his competitors in this race. Turn times ranged from 7.40 to 7.90 sec. His finish time was 2.58 sec, also one of the better times for the group. The range for all competitors was 2.30 to 2.80 sec.

Pieter started this race slightly faster than recommended, and as a result his drop-off was slightly greater.

200 Butterfly

Two hundred butterfly races should also be evenly paced. Swimmers usually swim the first 50 of the race approximately 2.00 sec slower than their best time for a 50 event. Their time at the halfway point is usually 2.50 to 3.00 sec slower than their fastest time for a 100 butterfly swim. They maintain a relatively constant speed throughout the race, although their velocity may be slightly faster on the first 50 and slightly slower on the last 50 than it will be through the middle portion of the race. The drop-off between the first and second halves of the race is usually 3.00 to 4.50 sec, greater than it is in the freestyle event. The greater drop-off is due in part to the fact that the split for the final 100 m begins with a hand-touch turn, whereas the final 100 m split begins with a foot-touch turn in 200 m freestyle races. That accounts for 1.00 sec of the difference. The remainder is probably due to the rigorous nature of this stroke. Intracycle velocity fluctuations are greater in butterfly than they are in freestyle. Therefore, butterfly probably requires more effort than freestyle to maintain a competitive speed through the first half of the race.

Butterfly swimmers, like freestylers, should try to swim with a constant velocity throughout the race rather than starting fast and slowing down. They should select a combination of stroke rate and stroke length that they can maintain throughout the race without decreasing either significantly at the end. Most butterfly swimmers will increase their stroke rates by 1 or 2 cycles/min during the last 50 of the race in an attempt to maintain their swimming velocity in the face of a declining stroke length.

Susan O'Neill's first-place swim at the 1998 World Swimming Championships is representative of the pace plan used by most successful 200 butterfly swimmers. An analysis of her race is shown in table 21.9.

These data show elements of both fast-slow and even-pace patterns. She started the race at a slightly higher stroke rate and speed than she was able to maintain. As a result, her speed dropped off slightly at the end. Her pace was relatively even from the second through the seventh 25 segments of the race. Obviously, she held back some in the beginning. She might have been able to swim a faster time if she had slowed her stroke rate to 50 cycles/min during the first 25 m of the race. Mary T. Meagher followed that plan when she set the previous world record in this event. Her splits are shown in table 21.10. No information was available on stroke parameters for that swim.

Mary T. paced that race by swimming the first 100 m 3.48 sec slower than her best time for 100 m. That slow speed probably enabled her to swim the final 50 m at nearly the same speed that she swam the middle two 50s of the race.

For maximum efficiency, swimmers should probably start 200 races with a stroke rate and velocity that they can maintain to the finish. That pattern may result in a faster finish, as it did for Mary T., and a faster overall time. Starting slower and using a negative-split pace plan is probably not a good idea. Athletes should not swim behind, through the turbulence of their competitors. In addition, the stroke is so rigorous that swimmers would probably have a difficult time increasing their speed enough on the final 50 m to make up for a slow start. For those reasons, I recommend that butterfly swimmers try to hold an even pace throughout, as Mary T. did, or start the race with a slightly faster first half and use a somewhat slower finish, as Susan O'Neill did. They should never try to sprint the race from start to finish.

Susan O'Neill's splits for her world-record 200 m butterfly swim are shown in table 21.11 as another example of an even-pace plan with a strong start. She used a plan similar to the one displayed in table 21.9. Unfortunately, I was not able to get her stroke parameters for this swim. I used the results from her World Championship swim instead of her world-record swim as an example for this race because those parameters were available for the former race.

Susan swam the first 100 of her record swim 1.47 sec faster than she did her swim in the 1998 World Championships. Her time for 100 m had improved nearly 0.50 sec at

Table 21.9 A Typical Pace Plan for 200 m Butterfly

Susan O'Neill—200 m butterfly—2:07.93
First place—1998 World Swimming Championships
Time for 100 m—59.27

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
50	29.08		1.63/1.57	54/50	1.82/1.90
100	1:01.71	32.63	1.52	50	1.85
150	1:34.56	32.85	1.51	50	1.81
200	2:07.93	33.37	1.48	51	1.73
Start time	7.27 (15 m)				
Turn time	9.49 (average of three turns)				

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

Table 21.10 Splits for Mary T. Meagher's Previous World-Record 200 M Butterfly Swim, LC

Mary T. Meagher
200 m butterfly—2:05.96
Former world record—1981
Time for 100 m—57.93

DISTANCE	TIME IN SEC	SPLIT IN SEC
50	29.53	
100	1:01.41	31.88
150	1:33.69	32.28
200	2:05.96	32.27 (drop-off +3.14 sec)

Source: USA Swimming Official Website. **www.usswim.org**

Table 21.11 Splits for Susan O'Neill's World-Record 200 M Butterfly Swim, LC

Susan O'Neill
200 m butterfly—2:05.81
World record—2000
Time for 100 m—58.71

DISTANCE	TIME IN SEC	SPLIT IN SEC
50	28.51	
100	1:00.24	31.73
150	1:32.71	32.47
200	2:05.81	33.10 (drop-off +5.57 sec)

Source: Swimnews Online. **www.swimnews.com**

Table 21.12 Splits for James Hickman's 1998 World-Record 200 M Butterfly Swim, SC

James Hickman
200 m butterfly—1:51.76
Short-course world record—1998
Time for 100 m—51.20

DISTANCE	TIME IN SEC	SPLIT IN SEC
50	25.53	
100	53.91	28.38
150	1:22.71	28.80
200	1:51.76	29.05 (drop-off +3.94 sec)

Source: Swimnews Online. **www.swimnews.com**

that time, so she swam her first 100 segment of that race 1.52 sec slower than her fastest time for the 100 m butterfly. Her drop-off from the first to the second 100 segment of the race was 5.57 sec.

Athletes swim short-course 200 m butterfly races with pace plans similar to those described for long-course races. They tend to swim the first 100 yd or m 2.00 to 3.00 sec slower than their best time for 100 m. Their drop-off from the first to second 100 segment will usually be less than it is for a long-course race because of the extra turns in short-course races. Drop-off times will usually be in the neighborhood of 3.50 to 4.50 sec. The splits for James Hickman's world-record short-course 200 m butterfly swim are displayed as an example in table 21.12.

Hickman's first 100 was 2.71 sec slower than his fastest short-course 100 m swim. This reduction in speed is similar to that used in long-course 200 butterfly races. Hickman swam the remainder of the race at a nearly constant speed with a slight slowing in the final 50 m, matching a pattern that occurs in long-course races. His drop-off time from the first to the second 100 m of this short-course race was 3.94 sec, which is slightly less than we usually see in long-course 200 m butterfly races.

200 Breaststroke

Most successful swimmers also use an even-pace plan in this event. Swimmers usually swim the first 50 of the race about 2.00 sec slower than their best time for a 50 event. Their time at the halfway point is usually 2.00 to 3.00 sec slower than their best time for a 100 breaststroke swim. The drop-off from the first to the second 100 of the race is usually 3.50 to 4.50 sec. Breaststrokers drop off more from the first to the second half of

200 races than do freestyle and backstroke swimmers, for the same reasons mentioned with regard to 200 butterfly races. First, the split at 100 m is taken when the swimmer's hands touch the wall before turning, while the split for the second 100 m includes the time to turn around at the 100 m mark. Second, the breaststroke involves large intracycle velocity fluctuations, which are greater than those of any other competitive stroke.

Breaststrokers should swim at a constant velocity over the first 150 of the race. They should also use a constant stroke rate during the first 150 of the race and do their best to increase that rate on the final 50 segment. Many world-class breaststroke swimmers have increased their stroke rates markedly on the final 50 m of their 200 events in recent meets. Six of eight finalists increased their stroke rates by 2 cycles/min or more during the last 50 of the final heat of the men's 200 m breaststroke at the 1998 World Swimming Championships. All eight female 200 m breaststroke finalists did likewise at that meet. Six of them increased their rates by more than 5 cycles/min.

Stroke lengths should be fairly constant through the first three-quarters of this race. Lengths will decline during the final 50 m when the swimmers increase their stroke rates. Swimming velocity should remain reasonably constant throughout the race.

I can only speculate about why so many present-day breaststrokers are increasing their stroke rates during the final portions of their races. The large intracycle variations of swimming velocity increase the energy cost of breaststroke swimming relative to freestyle and backstroke races even when athletes are pacing. For that reason, breaststrokers may intuitively choose to swim with longer strokes and slower rates in the first half to three-quarters of their races to conserve energy. They then increase their stroke rates markedly in an attempt to maintain their swimming velocity in the face of impending fatigue during the final portion of their races.

A race analysis for Agnes Kovacs's winning swim in the 200 m breaststroke at the 1998 World Swimming Championships has been selected as an example of the pacing plan many swimmers use in this race. An analysis of her race is displayed in table 21.13. She used an even-pace plan. Her stroke rates were fairly constant during the first 150 m of the race. She then increased them dramatically during the final 50 m. I have listed her stroke rates and stroke lengths for each 25 segment of the final 50 m of the race to illustrate how she completed her final sprint.

Kovacs's split was 33.60 sec for the first 50 m of the race. This was probably about 2.26 sec slower than her best time for 50 m. Her time at 100 m was 1:11.66, which was

Table 21.13 A Typical Even-Pace Plan for 200 M Breaststroke Races

Agnes Kovacs—200 m breaststroke—2:25.45
First place—1998 World Swimming Championships
Time for 100 m—1:08.68

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
50	33.60		1.40	36	2.36
100	1:11.66	38.06	1.31	35	2.30
150	1:47.78	36.12	1.38	37	2.18
200	2:25.45	37.67	1.33	40/42	1.99/1.88
Start time	8.67 (15 m)				
Turn time	10.94 (average of three turns)				

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

approximately 3.00 sec slower than her time in the 100 m event at this same meet. She swam the second 100 m of the race in 1:13.79, a drop-off of 2.13 sec from the first 100 m. Her splits were a bit uneven during the middle 100 of the race, splitting 38.06 on the second 50 m and 36.12 on the third 50 m. This distribution of splits suggests that she may have been trying to negative split the race by swimming easy through the first 100 and then picking up her speed dramatically on the third 50. That was a mistake because it resulted in an increase of time to 37.67 during the final 50 m of her race. It would have been better if she had maintained a constant a speed of about 37.00 sec through the middle 100 and then made an effort to increase her speed during the final 50 m. Sudden increases in speed before the final sprint are costly and usually cannot be maintained to the end of the race.

Kovacs used a fairly constant stroke rate between 35 and 37 cycles/min for the first 150 m of the race. Her stoke length was 2.36 m/cycle on the first 50 m and 2.30 m/cycle on the second 50 m and then fell to 2.18 m/cycle during the third 50 m of the race. This loss of stroke length during the third 50 m was probably due to the increase in her stroke rate because her split was fast on that segment of the race.

Her velocity was 1.40 m/sec during the first 50 m and then slowed down, probably too much, to 1.31 m/sec on the second 50 m. Her velocity increased again, also by too much, to 1.38 m/sec on the third 50 m.

She increased her stroke rate progressively to 40 and then to 42 cycles/min over the final 50 m in an effort to sprint home. Her stroke length fell off dramatically and so did her speed. Her stroke lengths were 1.99 and 1.88 m/cycle on the first and second 25s of that final 50 m. Her swimming velocity dropped to 1.33 m/sec during this same segment. She might have been wiser, as far as pacing is concerned, to maintain an even velocity through the middle 100 and then increase her stroke rate on the final 50 m. She may have been able to maintain a greater stroke length during the final 50 m if she had maintained her rate at 35 or 36 cycles/min and had not made an effort to increase her speed during the third 50 m of this race.

Kovacs's start time of 8.67 sec for the first 15 m of the race was average for all finalists. The fastest time was 7.91 sec, and the slowest was 8.99 sec. Her average time for three turns was 10.94 sec, which was the slowest average among all the finalists. The best average was 10.34 sec, and most swimmers had average times between 10.51 and 10.67 sec.

Table 21.14 Splits for Mike Barrowman's World-Record 200 M Breaststroke Swim at the 1992 Olympic Games, LC

Mike Barrowman
200 m breaststroke—2:10.16
World record—1992 Olympic Games
Time for 100 m—1:02.12

DISTANCE	TIME IN SEC	SPLIT IN SEC
50	30.43	
100	1:03.91	33.48
150	1:37.12	33.21
200	2:10.16	33.04

Source: USA Swimming Official Website. **www.usswim.org**

Kovacs's was not a perfectly split race, but it demonstrates a reasonably good distribution of effort over the total distance. The one error that she made is typical of swimmers who try to negative split. This error is less serious than trying to swim too fast early in the race. Mike Barrowman's splits for his 1992 world-record 200 m breaststroke swim, displayed in table 21.14, show a better distribution of effort over the length of the race. Stroke rate, stroke length, and swimming velocity data were not available for that race.

Mike swam the first 50 m in 30.43 sec, which was probably in a range between 2.00 and 2.50 sec slower than his best time for 50 m. His 100 split of 1:03.91 was 1.79 sec slower than his best time for 100 m. This is actually closer to his best 100 time than most swimmers can or should swim the first half of a 200 m race. It was not too fast for Barrowman, however, because he was able to swim the remainder of the race without losing speed. His times of 33.48, 33.21, and 33.04 sec for the next three 50s all represent swimming velocities that were similar to his velocity on the first 50 m of the race because the first split included a dive and did not include a turn. The advantage gained on the start and the absence of a turn probably account for all or nearly all of the roughly 3.00 sec difference between his time for the first 50 m and his times for each of the following 50 segments of this race.

He swam the second half of this 200 breaststroke race in 1:06.25. Thus, his drop-off from the first to second half of the race was 2.24 sec. This was also excellent. Most swimmers drop off between 3.00 and 4.00 sec from the first to second half of this race even when they pace it well.

Athletes should also swim short-course 200 breaststroke races with an even-pace plan. They should swim the first 50 and 100 m approximately 2.00 to 3.00 sec slower than their best times for these distances, as they do in long-course races. The drop-off times from the first to second half of their races will usually be under 3.50 sec because of the velocity and rest they gain from additional turns.

200 Backstroke

The best plan for this race is an even pace, just as it is for other 200 events. Athletes should swim the first 50 m 2.00 to 3.00 sec slower than their fastest time for the 50 m backstroke. The first 100 should be 2.00 to 3.00 sec slower than their best time for that distance. The drop-off from the first to second 100 of the race will be less than it is in other 200 events because backstroke swimmers do not gain as much speed from starting in the water as other swimmers gain from block starts. In addition, the split for the first 100 m of their race includes the time required to make two turns, while the split for the last 100 m includes time for only one turn. The drop-off from the first to the second 100 segment of the 200 backstroke should therefore be in the range of 1.20 to 2.00 sec.

Athletes should try to swim at a constant velocity from the start to the finish of this race. Their velocity will generally fall off just a little in the final 50 m, however, because of fatigue. They should choose the fastest stroke rate they can maintain for the entire race and, if possible, increase that by 2 to 3 cycles/min over the final 50 m. Their stroke length should remain constant over the first three-quarters of the race. It will decline somewhat during the final 50 when they increase their stroke rates. Nevertheless, their splits for the final 50 should be as fast or slightly faster than their 50 splits through the middle of the race.

The information in table 21.15 is for Lenny Krazelburg's first-place 200 m backstroke swim at the 1998 Long-Course World Swimming Championships. It illustrates most of the factors that should be included in an even-pace plan for this event. His stroke rate and stroke length have been indicated for each of the first two 25 portions of the race to show how they changed during the first 50 m. His swimming velocity, stroke rate, and stroke length are displayed for each of the final two 25 m segments of the race to show how he completed his final sprint to the finish.

Krazelburg swam the first 50 m of the race in 28.66 sec, which is approximately 3.50 sec slower than his best time for 50 m backstroke. His time was 58.81 at the halfway point in the race, which was 3.81 sec slower than his winning time in the 100 m backstroke at the same meet. He swam the second 100 m of this race in 1:00.03, so his drop-off time was 1.22 from the first to the second 100 m. His 50 splits were 28.66, 30.15, 29.93, and 30.10 for the first through fourth 50s of the race, respectively.

His swimming velocity was constant through the middle of the race. It was slightly higher on the first 50 m at 1.61 m/sec, but then stayed reasonably similar, between 1.57 and 1.59 m/sec for the next 125 m. His velocity dropped off slightly to 1.54 m/sec on the final 25 m. He probably minimized his loss of velocity on the final 50 m of this race by increasing his stroke rate.

Krazelburg's stroke rate was higher on the first 25 m than it was through the middle of the race. His stroke rate was 46 cycles/min on the first 25 and then dropped to 40 cycles/min for the remainder of the first 100 m. He then increased his stroke rate to

Table 21.15 A Typical Even-Pace Plan for 200 M Backstroke Races

Lenny Krazelburg—200 m backstroke—1:58.84
First place—1998 World Swimming Championships
Time for 100 m—55.00

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
50	28.66		1.61	46/40	2.11/2.41
100	58.81	30.15	1.57	40	2.33
150	1:28.74	29.93	1.59	43	2.23
200	1:58.84	30.10	1.57/1.54	45/46	2.11/1.99
Start time	7.03 (15 m)				
Turn time	7.87 (average of three turns)				

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

43 cycles/min during the third 50 of the race and to 45 and 46 cycles per min on each of the last two 25 m segments. The higher stroke rate at the start may have been because he was nervous or because he was trying to maintain the momentum from his underwater kick when he reached the surface on that 25 segment. He may have been able to save energy without losing time by slowing his rate to approximately 40 cycle/min on the second 25 m. It is difficult to say if increasing his stroke rate to 43 cycles/min on the third 50 was a wise thing to do. He may have been able to finish stronger with a better overall time by maintaining a stroke rate of 40 cycles/min on that 50. On the other hand, he may have felt that his stroke length was declining and thus increased his stroke rate to compensate.

His stroke length was low, 2.11 m/cycle, on the first 25 m of the race and then increased considerably when he slowed his rate to 40 cycles/min. It was 2.41 on the second 25 of the race and 2.33 m/cycle during the second 50 before dropping to 2.23 m/cycle on the third 50. His stroke length fell off dramatically to 2.11 and then to 1.99 m/cycle during the final two 25 m segments of the race, although his velocity remained high because he increased his stroke rate.

Krazelburg's start time of 7.03 sec was the second best of the final competitors. The best time was 6.88 sec; and the other swimmers in the final had start times between 7.16 and 7.52 sec. His average turn time of 7.87 was the best of all the swimmers in the race. The others had average turn times between 7.96 and 8.41 sec.

The pacing plan for short-course 200 m backstroke races should be the same as for long-course races. Swimmers should take the race out about 2.00 to 3.00 sec slower than their best time for a short-course 100 backstroke. Unlike what occurs in other 200 events, the drop-off times of backstrokers from the first to second half of the race are approximately the same, 1.20 to 2.00 sec, regardless of whether the event occurs in long-course or short-course pools.

Summary of Pace Plans for 200 Events

The pacing plans seem to be similar for all 200 events. Ideally, swimmers should start out at the fastest pace they can maintain throughout the race without losing speed at the end. They should swim the first 50 m of these races 2.00 to 3.00 sec slower than their fastest time for 50 m. The first 100 should also be 2.00 to 3.00 sec slower than their best time for that distance. Their drop-off times from the first to the second half of and backstroke events should be between 1.00 and 2.00 sec. Their drop-offs should be 3.00 to 4.50 sec in butterfly and breaststroke events. There are two reasons for the larger drop-off in those events. First, velocity fluctuations are greater in the breaststroke and butterfly strokes than in the other two competitive styles. Thus, more effort is required of breaststroke and butterfly swimmers to accelerate their bodies during every stroke cycle. Second, the split for the first half of the race does not include the time required to make a turn at the 100 m mark in butterfly and breaststroke races, whereas the split for the first 100 m includes the time for a turn in freestyle races.

To distribute their energy evenly over the entire race distance, 200 swimmers should maintain a constant swimming velocity from start to finish. This is difficult to do in competitive situations, and most will swim a little faster in the first three-quarters of the race and a little slower in the last quarter. They may have to swim that way to remain with the leaders and avoid having to swim in their turbulence. But most swimmers would probably do better to distribute their effort in such a way that they could maintain the same velocity on the final 50 that they used on the previous 50s.

Most 200 swimmers start out with a stroke rate that is higher than the rate they can maintain for the entire race. Then they decrease the rate in the middle and increase it again at the end. Sudden changes in speed and effort generally increase the energy requirement disproportionately, so swimmers should save those efforts for the final sprint. Swimmers would probably be more economical in their use of energy by selecting a combination of stroke rate and stroke length that they can maintain for the first three-quarters of the race and still increase their stroke rates by 1 or 2 cycles/min during the final 50 of the race. Breaststrokers may want to start out even more slowly and increase their stroke rates by 3 to 5 cycles/min during the final 50 of their races. They may need to pace more carefully than the others because of the high energy cost of their strokes.

400 M and 500 Yd Freestyle Events

Great swims in these events have been performed with both even-pace and negative-split plans. Some world-record and Olympic and World Championship swims have been done by swimmers who maintained a relatively constant velocity throughout the first 350 m of the race and then turned on a fast sprint to the end. Swimmers who swam the second half of the race at a relatively faster velocity than the first have performed equally outstanding swims. The race analysis for Ian Thorpe's first world-record and gold medal swim at the 2000 Olympic Games, displayed in table 21.16, illustrates an even-pace plan with a fast finish.

Ian's splits were 1:48.86 for the first 200 and 1:51.73 for the second 200 in this race. At first glance these splits appear to be an example of fast-slow splitting rather than even pacing. When the splits are examined by 100s, the even-pace plan becomes more evident. After the first 100 m, which he swam in 52.64, Ian swam at a relatively constant speed of approximately 56 sec for the next two 100s. He picked up the pace on the final 100, which he swam in 55.50.

His time for the first 100 of this race was probably about 3.00 sec slower than his best time for 100 m long course. His time of 1:48.86 at 200 m was approximately 3.50 sec slower than his best time for 200 m freestyle at that point in his career.

His swimming velocity on the first 50 of the race, 1.91 m/sec, was faster than at any other time. He slowed to a velocity between 1.73 and 1.76 for the remainder of the race. As further proof of even pacing, his stroke rate was constant between 35 and 38 cycles/min for the final 350 m of the race. His rate was higher during the first 50 m of the race, at 46 cycles/min.

His distance per stroke on the first 50 m, 2.66 m/cycle, was low, probably because of his high stroke rate. His stroke length was high, at 2.97 m/cycle, on the second 50 of the race when his stroke rate was 35 cycles/min. After that, his distance per stroke remained between 2.79 and 2.89 m/cycle (average 2.86) through the middle of the race.

Table 21.16 | A Typical Even-Pace Plan for 400 M Freestyle Races

Ian Thorpe—400 m freestyle—3:40.59
World record and Gold Medal—2000 Olympic championships
Time for 200 m—1:45.37

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
100	24.48/52.64		1.91/1.75	46/35	2.66/2.97
200	1:48.86	56.22	1.74	35	2.89
300	2:45.09	56.23	1.73	37	2.82
400	3:40.59	55.50	1.76	38	2.76
Start time	NA				
Turn time	7.86 (average of seven turns)				
Finish time	NA				

Source: Biomechanical Analysis, 2000 Olympic Swimming Championships, Sydney, Australia, Sept. 16–23, 2000. Prepared by the Biomechanics Department, Australian Institute of Sport.

His stroke length dropped slightly to 2.76 m/cycle during the final 100 m when his stroke rate increased to 38 cycles/min.

Ian's starting and finishing times were not available for this race. His average time for seven turns was 7.86 sec, one of the best averages among the finalists. Most took over 8.00 sec to cover the 15 m into and out of their turns. Male competitors generally post start times in a range between 6.30 and 7.00 sec in this event. Their finishing times were generally in a range between 2.30 and 2.90 sec.

Ian's pace plans represent an effective way to swim this race. Over the years, most of the great long-course 400 m freestyle swims have been done with even-pace plans similar to this one, although most have paced the first 50 m slightly slower. Consequently, their splits during the first 100 and 200 m segments of 400 races have been approximately 5 to 6 sec slower than their best times for those distances. They then swim the second 200 m in a time that is only 1 to 2 sec slower than the first. Their stroke rates and velocities, like Ian's, have remained constant throughout the race after the first 50, and they have been able to increase their stroke rates slightly, and consequently their swimming speeds, over the final 50 or 100 m.

Distance swimmers can swim closer to their best times in the first half of the race. Many can swim the first 100 and 200 m of this race within 3 to 4 sec of their best times for those distances. Middle distance swimmers usually have to hold back a little more because they get more of their energy from anaerobic metabolism.

In this event, swimmers should select a stroke rate that will allow them to swim at a constant velocity for 350 m and then allow them to increase their speed over the final 50 to 100 m by approximately 1 sec over 100 m. They have been swimming too slowly in the beginning of the race if they are able to swim the final 100 m 2 or 3 sec faster than they were swimming during the middle of the race.

Those swimmers who prefer to negative split this event usually swim the first 200 m a little slower than even-pace swimmers. Then they will increase their speed gradually over the next 150 m and sprint the final 50 m. Negative-split swimmers should not try to increase their speed suddenly at 200 m. The effort to do so will be too costly, and they will have difficulty finishing the race with a strong sprint. Their increase in speed should be gradual from 200 to 350 m, building to a sprint during the final 50 m. Their stroke rates should increase only slightly during the second half of the race. An increase of

1 cycle/min would be satisfactory until the final 50 sprint, when it can increase by 1 or 2 additional cycles/min. Negative-split swimmers can also pull with slightly more force until the final sprint.

Janet Evans's outstanding world-record and gold medal 400 m freestyle swim is an excellent example of negative splitting. She did this swim at the 1988 Olympic championships. Her splits are listed in table 21.17.

She swam the first 200 m of this race in 2:02.14 and the second 200 m in 2:01.71. Her velocity was obviously faster on the second 100 because she did not have the advantage of a block start. Her splits were 59.99 and 1:02.15 for the first two 100 segments of this race. She then increased her pace slightly to 1:01.26 during the third 100 segment. She swam the final 100 m in a fast 1:00.45.

Table 21.17 Janet Evans's World-Record 400 M Freestyle Swim

Janet Evans
400 m freestyle—4:03.85
World record and Gold Medal
1988 Olympic championships
Time for 200 m—NA

DISTANCE	TIME IN SEC	SPLIT IN SEC
100	59.99	
200	2:02.14	1:02.15
300	3:03.40	1:01.26
400	4:03.85	1:00.45

The pace plans for short-course 400 m and 500 yd freestyle events should be similar to the long-course patterns just described. The pace should be even for the first 350 m of the 400 race and for the first 450 yd of the 500 race. The final 50 segments of both races should be swum at a slightly faster velocity than the middle portions. An example of a short-course 400 m freestyle race paced in an excellent manner is Grant Hackett's world-record swim in that event, shown in table 21.18

Hackett swam the first 200 m of this race in 1:47.11, and he swam the second 200 m in 1:47.90. His best time for a short-course 200 m freestyle was not available, but he has swum 1:46.67 in a long-course 200 m race. Consequently, he is certainly pacing early in the race. He probably swam the first 200 m of this race approximately 5 to 6 sec slower than he was capable of swimming for a maximum effort short-course 200 m event.

Hackett's splits for each 200 m segment of this race make it appear that he was using a negative-split pace plan. He gained a 1 or 2 sec advantage on the first 200 m of this race because it began with a block start. Consequently, he swam the second 200 m at a faster average velocity than the first. An analysis of his splits by 100 segments reveals that he swam at approximately the same velocity for 300 m and then finished the race with a sprint. He swam the first 100 in 52.40 sec and the next two in 54.71 and 54.99 sec. He then swam the final 100 m in 52.93 sec, slightly faster than he swam the middle two 100 segments. Hackett's time of 52.40 sec for the first 100 m represents the same velocity that he used in the middle of his race. The time was faster only because of the influence of the start. This distribution of splits represents an even-pace plan for most of the race, with a fast sprint at the finish.

Table 21.18 Splits for Grant Hackett's 1999 Short-Course World-Record 400 M Freestyle Swim

Grant Hackett
400 m freestyle—3:35.01
Short-course world-record swim
1999—Time for 200 m—NA at time

DISTANCE	TIME IN SEC	SPLIT IN SEC
100	52.40	
200	1:47.11	54.71 (drop-off +2.31 sec)
300	2:42.08	54.99
400	3:35.01	52.93 (1:47.90)

Difference between first and second 200s was +0.79.

Source: Swimnews Online. **www.swimnews.com**

The pace used by Tom Dolan during his 1997 American-record 500 yd freestyle swim is displayed in table 21.19. His time was a remarkable 4:08.75 for this race. Dolan used

Table 21.19 Splits for Tom Dolan's American-Record 500 Yd Freestyle Swim at the 1997 NCAA Men's Swimming Championships

Tom Dolan
500 yd freestyle—4:08.75
American-record swim
1997—Time for 200 m—NA at time

DISTANCE	TIME IN SEC	SPLIT IN SEC
100	47.07	
200	1:37.51	50.45 (drop-off +3.44 sec)
300	2:27.93	50.41
400	3:18.33	50.40 (1:50.81)
500	4:08.75	50.42

Source: USA Swimming Official Website. **www.usswim.org**

Table 21.20 Splits for Janet Evans's Long-Course World-Record 800 M Freestyle Swim

Janet Evans
800 m freestyle—8:16.22
World record—1989
Time for 400 m—4:03.85

DISTANCE	TIME IN SEC	SPLIT IN SEC
100	1:00.20	
200	2:02.53	1:02.33
300	3:05.12	1:02.59
400	4:07.92	1:02.80
500	5:10.27	1:02.35
600	6:12.82	1:02.55
700	7:15.54	1:02.72
800	8:16.22	1:00.68

Splits by 200s: 2:02.53, 2:05.39, 2:04.90, 2:03.40
Splits by 400s: 4:07.92, 4:08.30

Source: Swimnews Online. **www.swimnews.com**

an even-pace plan, although he swam the first 100 yd at a slightly faster velocity than he did the remainder of the race. His time was 47.07 sec for the first 100 yd. After that, his speed was reasonably constant at about 50.40 sec for each of the remaining 100s of the race. I suspect that he might have been able to swim slightly faster on the final 100 yd of the race, and perhaps have achieved a slightly faster overall time, if he had swum the first 100 yd at a somewhat slower speed.

Dolan's best 200 yd freestyle time was not available, but it was probably in the neighborhood of 1:33 to 1:34. Therefore, he swam the first 200 yd of his 500 yd swim approximately 4 sec slower than his probable best time for that distance.

800 M and 1,000 Yd Freestyle Events

An even pace throughout with a fast finish seems to be preferred by swimmers in these events. The splits for Janet Evans's long-course 800 m freestyle world-record swim, shown in table 21.20, provide a good example of an even-pace pattern. She swam the first 100 m of this race in 1:00.20. She swam the next six 100 m segments at approximately the same velocity as the first, when the influence of the start is removed. She swam those segments in times between 1:02.33 and 1:02.80. Her time of 1:00.68 for the final 100 m represents her fastest velocity of the race.

Swimmers generally swim the first 200 m of this event between 3 and 5 sec slower than their best time for 200 m freestyle. Their pace over the first 400 m is between 4 and 6 sec slower than their best time for 400 m freestyle. The times for each half of the race should be almost identical.

A race analysis of Brooke Bennett's 1998 World Championship swim for 800 m long course is displayed in table 21.21. This analysis includes data on her stroke length, stroke rate, and swimming velocity, which should help demonstrate the even-paced nature of this race.

Bennett swam the first 400 m of this race 5.50 sec slower than her time for 400 m in the same meet. She swam the next four 100 m segments at times between 1:03.40 and 1:04.60. Her velocity and stroke rate were fairly constant throughout. She maintained a swimming velocity between 1.49 and 1.55 m/sec through the middle of the race. Her stroke rate was between 54 and 55 cycles/min. Her velocity increased to 1.69 even though her stroke rate dropped to an average value of 53 cycles/min during the final 100 m of the race. Her stroke length dropped off slightly from the start to the finish of the race. It began at 1.73 m/cycle and dropped as

Table 21.21 A Typical Even-Pace Plan for 800 M Freestyle, LC

Brooke Bennett—800 m freestyle, LC—8:29.19
First place—1998 World Swimming Championships—Time for 400 m—4:06.85

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
100	1:01.53		1.57	54	1.73
200	2:04.93	1:03.40	1.55	54	1.71
300	3:08.74	1:03.61	1.52	54	1.68
400	4:12.35	1:03.61	1.51	55	1.65
500	5:16.01	1:03.66	1.52	55	1.60
600	6:20.61	1:04.60	1.49	54	1.65
700	7:25.27	1:04.58	1.49	53	1.72
800	8:29.19	1:03.92	1.69	52/54	1.69/1.70
Turn time	8.93 (average of 15 turns)				

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

low as 1.60 m/cycle at 500 m. It increased again to between 1.69 and 1.72 m/cycle when she slowed her stroke rate during the final 150 m.

Her losses of stroke length, velocity, and time in the latter portion of the race suggest that she might have had a better performance if she had swum the first 200 m of the race with slightly less effort. Nevertheless, the race illustrates a well-executed even-pace plan with a strong finish characteristic of most successful swims over this distance.

Brooke's average turn time of 8.93 sec was one of the best among the finalists. The average turn times for all eight swimmers ranged between 8.80 and 9.20 sec. Her starting and finishing times were not available, but a perusal of the 1998 World Championship results showed that female finalists in this event had start times that ranged between 5.48 and 8.17 sec. The range for their finishing times was 2.68 to 3.12 sec.

Swimmers use the same even-pace plan in 1,000 yd freestyle races. They swim at a constant rate of speed for 900 yd, increase their speed gradually during the next 50 yd segment, and sprint the final 50 yd. The splits at 200 and 500 yd are generally between 4.00 and 5.00 sec slower than their best time for those distances. The first 100 yd will usually be approximately 4.00 sec slower than the swimmer's best time for this distance. The other splits for the race will generally be 2.00 sec slower than the first. The time for the final 100 yd of a 1,000 yd race will usually be close to a particular swimmer's time during the first 100 yd of the race.

1,500 M and 1,650 Yd Freestyle Races

As with other distance races, most swimmers use an even-pace plan for almost the entire race and finish with a fast sprint. They swim at approximately the same speed from the start of the race until the final 100 or 200 yd or m, when they increase their speed gradually until they are sprinting to the finish over the final 50 yd or m. Most swim the first 400 m of a 1,500 m race between 8 and 10 sec slower than their best time for a 400 m freestyle. The analysis of Grant Hackett's 1,500 m swim when he won the 1998 World Championship, shown in table 21.22, demonstrates this pattern well.

Grant swam the first 200 m of the race approximately 6 sec slower than his best time for the same distance, and he swam the first 400 m approximately 9 sec slower than his

Table 21.22 A Typical Even-Pace Plan for 1,500 M Freestyle, LC

Grant Hackett—1,500 m freestyle, LC—14:51.70
First place—1998 World Swimming Championships—Time for 400 m—3:44.88

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
100	55.67		1.75/1.66	42/40	2.53/2.49
200	1:54.62	58.95	1.63	40	2.47
300	2:54.04	59.42	1.62	40	2.46
400	3:53.99	59.95	1.60	40	2.43
500	4:53.80	59.81	1.61	39	2.45
600	5:53.69	59.89	1.60	40	2.41
700	6:53.53	59.84	1.60	39	2.45
800	7:53.73	1:00.20	1.59	39	2.44
900	8:53.78	1:00.05	1.59	39	2.44
1000	9:54.84	1:00.06	1.59	39	2.44
1100	10.54.88	1:00.04	1.59	39	2.44
1200	11:54.98	1:00.10	1.59	39	2.43
1300	12:55.04	1:00.06	1.59	39	2.44
1400	13:55.39	1:00.35	1.58	38	2.45
1500	14:51.70	57.31	1.67	40	2.51
Turn time	8.08 (average of 29 turns)				

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

best time for that distance. He swam the first 100 m in a time of 55.67. He swam the remaining 100s of the race approximately 4 sec slower that the first, except for the final 100 m, when he increased his speed to 57.31 sec.

Grant's velocity and stroke rate were slightly higher during the first 50 m than they were later in the race. After that, however, he swam his splits at a relatively constant velocity between 1.59 and 1.60 m/sec and at a constant stroke rate between 39 and 40 cycles/min. He swam the final 100 m faster, at 1.67 m/sec, by increasing his stroke rate slightly to 40 cycles/min and his stroke length to 2.51 m/cycle.

His average time for 29 turns during the race was 8.08 sec. This was the second best average among the finalists at the 1998 World Swimming Championships. The best average was 7.99 sec, and the other finalists had average turn times between 8.12 and 8.64 sec. His start and finish times were not available. Starting times typically range between 6.50 and 7.50 sec for male competitors in this event. Finish times are generally between 2.40 and 3.00 sec.

Short-course 1,500 m freestyle and 1,650 yd freestyle races should also be swum with an even pace and a fast finish. The splits for Tom Dolan's 1997 American-record swim for 1,650 yd, listed in table 21.23, demonstrate the even-pace plan that most successful swimmers have used in this race.

After a fast start on the first 100 when he split 48.96, Dolan swam a steady race with times of approximately 53.00 sec per 100 yd for the first 1,200 yd. At that point, he picked up the pace slightly to about 52.50 sec. His last 50 yd of the race was a fast 24.13.

The first 200 yd of this race was approximately 8 sec slower than his probable best time for 200 yd. His time at 500 yd was approximately 8 sec slower than his best time for that distance. His next two 500 times were 4:27 and 4:23.

Individual Medley Events

Calculating the best pace patterns for individual medley races is difficult because drop-off times are inconclusive when swimmers change strokes during each quarter of the race. Nevertheless, the length of these events makes it imperative that swimmers use some form of pacing to be successful. Based on other events, I believe that an even-pace distribution of effort over the race distance would be the best method to use.

Another problem in determining how athletes pace individual medley races is that it is impossible to tell how much they are pacing each segment based on times, stroke rates, stroke lengths, or swimming velocities. These, of course, differ from stroke to stroke and from athlete to athlete even when they are swimming with the same relative effort. Consequently, my suggestions concerning how fast each stroke should be swum during an individual medley race are based on my experiences with swimmers in these events.

200 Individual Medley Athletes who swim 200 individual medley events usually complete the first 50 yd or m of butterfly about 1.00 sec slower than their best time for a sprint for the same distance. The backstroke split is approximately 3.00 sec slower than their best time for 50 yd or m of that stroke. The breaststroke is 5.00 to 6.00 sec slower, and the freestyle is approximately 4.00 sec slower.

Another way to look at pacing in this event is by considering the difference between times for each segment. These differences will not be the same for all swimmers because each will be relatively stronger or weaker than other athletes in the various strokes. However, experience has demonstrated that these differences are remarkably similar from swimmer to swimmer, even considering that complicating factor. Comparing the differences in time from split to split can therefore provide a guide about the relationship swimmers should expect to have between their splits from one stroke to the next in this race. On this basis, the backstroke split in a 200 individual medley will usually be 3.00 to 4.00 sec slower than the butterfly. The breaststroke will usually be 4.00 to 5.00 sec slower than the backstroke. The final freestyle split will usually be 5.00 to 7.00 sec faster than the time for the breaststroke segment, and it will be similar to the time for the butterfly leg of the race. These relationships between segments hold true for both long-course and short-course events. An analysis of a long-course 200 m individual medley race that fits this pattern is displayed in table 21.24. This analysis is for Yana Klochkova's gold medal swim at the 2000 Olympic Games.

Swimmers tend to use somewhat higher stroke rates for each stroke in the 200 IM than 200 m swimmers in each of those strokes typically use. At the same time, the

Table 21.23 Splits for Tom Dolan's American-Record 1,650 Yd Freestyle Swim at the 1997 NCAA Men's Swimming Championships

Tom Dolan
1,650 yd freestyle—14:29.31
American record—1997 NCAA
Men's Swimming Chamionships
Time for 500 yd—4:08.75

DISTANCE	TIME IN SEC	SPLIT IN SEC
100	48.96	
200	1:41.25	52.29
300	2:34.11	52.86
400	3:27.26	53.15
500	4:20.79	53.53
600	5:14.11	53.32
700	6:07.32	53.21
800	7:00.79	53.47
900	7:54.46	53.67
1,000	8:48.16	53.70
1,100	9:41.56	53.40
1,200	10:34.71	53.15
1,300	11:27.28	52.57
1,400	12:20.04	52.76
1,500	13:12.54	52.50
1,600	14:05.18	52.64
1,650	14:29.31	24.13

Source: USA Swimming Official Website. **www.usswim.org**

Table 21.24 Analysis of Yana Klochkova's Gold Medal Swim in the 200 M Individual Medley at the 2000 Olympic Games

Yana Klochkova—200 m individual medley—2:10.68
First place—2000 Olympic Games

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
Butterfly					
25	13.34		1.65	55	1.81
50	28.70	15.36	1.60	53	1.83
Backstroke					
75			1.47	42	2.09
100	1:01.78	33.08	1.48	42	2.13
Breaststroke					
125			1.33	46	1.74
150	1:40.05	38.27	1.26	46	1.66
Freestyle					
175			1.63	48	2.02
200	2:10.68	30.63	1.61	46	2.08
Turn times	(15 m) 9.20 fly/bk, 10.08 bk/br, 10.08 br/fr				
Start time	7.62 (15 m)				
Finish time	2.70				

Source: Competition Analyses of Swimming Events, 2000 Olympic Games, Sydney, Australia, Sept. 16–23, 2000. Prepared by the IOC Subcommission on Biomechanics and Physiology of Sport.

stroke rates of IM swimmers are slightly slower than the rates used by 100 swimmers. This trend was not evident in each of Klochkova's splits, but it has been characteristic of most world-class 200 individual medley swimmers. Their use of higher stroke rates in this event indicates that athletes swim at a higher level of effort, at least during the first three-quarters of this race, than they would if they were competing in a single-stroke 200 race. The rest afforded to muscle fibers by changing strokes is what probably allows them to swim with more effort during individual medley events.

Yana's time was 9.20 sec for the butterfly to backstroke turn. The range was between 9.10 and 9.50 sec for the other competitors. Her time was 10.08 sec for both the backstroke to breaststroke turn and the breaststroke to freestyle turn. Those were good times. The range among world-class female competitors in this event is 10.00 to 10.50 sec. Start times ranged between 7.30 and 7.80 sec for female swimmers in this event at the 1998 World Championships. Finish times for these swimmers ranged between 2.74 and 3.02 sec.

Unfortunately, no information is available about the stroke rate, stroke length, and swimming velocity that swimmers use in short-course 200 individual medley races. The splits for Summer Sanders's American-record swim, however, indicate a similar pace plan to that of the long-course event. (I suspect that swimmers can afford to take a short-course individual medley out slightly faster than they can a long-course race because they will do more turns.) Sanders's splits are shown in table 21.25.

400 Individual Medley Athletes should swim the butterfly portion of this event approximately 2.50 to 3.00 sec slower than their fastest times for 100 yd or 100 m of butter-

Table 21.25 Splits for Summer Sanders' American-Record 200 Yd Individual Medley Swim at the NCAA Women's Swimming Championships

Summer Sanders
200 yd individual medley—1:55.45
American record—1992 NCAA
Women's Swimming Championships

DISTANCE	TIME IN SEC	SPLIT IN SEC
Butterfly		
50	25.08	
Backstroke		
100	54.59	29.51 (+4.51 sec)
Breaststroke		
150	1:27.70	33.11 (+3.60 sec)
Freestyle		
200	1:55.45	27.75 (–5.36 sec)

Source: USA Swimming Official Website. **www.usswim.org**

fly. The backstroke and freestyle legs are generally 6.00 to 7.00 sec slower than a particular swimmer's best times for those strokes and distances. The breaststroke leg is generally 8.00 to 10.00 sec slower. The freestyle time is generally similar to the time for the opening butterfly leg.

A swimmer with nearly equal ability in all strokes would swim the backstroke leg of this event 4.00 to 5.00 sec slower than his or her time for the opening butterfly leg. The breaststroke would be 5.00 to 12.00 sec slower than the backstroke leg, and the finishing freestyle leg would be 10.00 to 15.00 sec faster than the breaststroke segment. These relationships seem to be true for both long-course and short-course 400 individual medleys.

Tom Dolan's winning swim at the 1998 World Championships was selected as an example of a good pace plan for the 400 IM. Table 21.26 displays an analysis of his race. The data are shown for each 50 segment of the race to demonstrate how evenly he distributed his efforts over each 50 m segment for a particular stroke.

Tom's split for the first 100 m of butterfly was 58.54 sec. His stroke rate was 53 cycles/min for the first 50 m and 50 cycles/min during the second 50 m of the butterfly leg. His velocity and stroke lengths were higher during the first 50 of the butterfly leg, at 1.70 m/sec and 1.94 m/cycle. They dropped to 1.57 m/sec and 1.89 m/cycle during the second 50 m segment. Tom was obviously pacing the butterfly leg of his race. His rates were slightly faster than those of male world-class 200 butterfly swimmers, but they were slower than the rates that world-class swimmers use in 100 m butterfly races.

He swam his backstroke leg in 1:03.77 with stroke rates of 40 and 39 cycles/min for each 50 of that 100 m segment. These rates were approximately the same as those used by many male 200 m backstroke swimmers. His stroke length was 2.29 m/cycle on the first 50 m segment of this split and 2.35 m/cycle on the second. His velocity increased from 1.53 m/sec to 1.60 m/sec on the second 50, when he reduced his stroke rate to 39 cycles/min and increased his stroke length to 2.35 m/cycle.

His split for the breaststroke leg of the race was 1:12.85. His stroke rates were 45 and 46 cycle/min on the first and second 50s of the breaststroke leg, which were considerably faster than those used by most male 200 m breaststroke swimmers. They were, however, 3 to 5 cycles/min slower than the rates used in 100 breaststroke events. His stroke length fell off from 1.79 m/cycle to 1.70 m/cycle from the first to the second 50 m segment of this split. His swimming velocity decreased from 1.34 to 1.30 m/sec as a result.

He swam the final 100 m of freestyle in 59.79 sec. His stroke rate was the same for both 50 m segments of the freestyle split at 43 cycles/min. That rate is similar to that used by many world-class 400 m freestyle swimmers. His stroke length increased from 2.29 to 2.36 m/cycle from the first to second 50 m segment. His swimming velocity also increased from 1.63 to 1.68 m/sec.

Dolan's start, turn, and finish times were not available. A review of the results for the 1998 World Swimming Championships showed that the male swimmers in this event had start times between 6.53 and 6.92 sec. Turn times ranged from 8.72 to 9.36 sec for the butterfly to backstroke turn, from 9.32 to 10.20 sec for the backstroke to

Table 21.26 'Analysis of Tom Dolan's First-Place Swim in the 400 m Individual Medley at the 1988 World Swimming Championships

Tom Dolan—400 m individual medley—4:14.95
First place—1998 World Swimming Championships

DISTANCE	TIME IN SEC	SPLIT IN SEC	VELOCITY IN M/SEC	STROKE RATE IN CYCLES/MIN	STROKE LENGTH IN M/CYCLE
Butterfly					
50	27.29		1.70	53	1.94
100	58.54	31.26	1.57	50	1.89
Backstroke					
150	1:31.14	32.60	1.53	40	2.29
200	2:02.31	31.17	1.60	39	2.35
Breaststroke					
250	2:38.32	36.01	1.34	45	1.79
300	3:15.16	36.84	1.30	46	1.70
Freestyle					
350	3:45.83	30.67	1.63	43	2.29
400	4:14.95	29.12	1.68	43	2.36

Source: Biomechanical Analysis, 1998 World Swimming Championships, Perth, Australia, Jan. 8–18, 1998. Prepared by the Biomechanics Department, Australian Institute of Sport.

breaststroke turn, and from 9.64 to 9.92 sec for the breaststroke to freestyle changeover turn. Finish times were between 2.60 and 2.93 sec for the male competitors in this event.

When competing in the 400 IM, swimmers seem to use stroke rates in each style that are similar to the rates swimmers use for the same strokes in 200 races. This was not always evident with Dolan. He tended to have a slower turnover rate in some strokes. Other finalists in this event, however, used stroke rates for each stroke that were similar to the stroke rates used in 200 events. As in the 200 IM, the change of strokes probably provides some relief that allows athletes to pace this race at a higher intensity than they would use if they were swimming the entire 400 m using only one stroke. Some fatigued muscle fibers probably have an opportunity to rest when swimmers change strokes. Fibers that have been resting then take up the workload.

Teaching Swimmers to Pace

The most common method coaches use to teach pacing is to have athletes swim underdistance repeats at desired race speeds. Unfortunately, they often swim those speeds without distributing their effort evenly over the repeat distance. They commonly swim the first half of the repeat with a higher stroke rate and faster velocity than they do the second half. Swimmers must concentrate on distributing their efforts evenly over the length of paced swims so that they will learn to swim at the correct speed in the most economical manner. They should also experiment with different stroke rates and stroke lengths to find the combination that permits them to swim at their desired pace with the least effort. Swimmers should be able to swim repeats that are one-quarter the race distance or less within 0.20 to 0.50 sec of their ideal pace for an event by the time their most important meets occur.

In the examples of pacing presented in tables 21.1 to 21.26, most athletes swam faster and with higher stroke rates at the beginning of their races. Going out too fast is a common mistake. Athletes should be trained to use stroke rates and velocities that they will use throughout these races. Doing so will delay acidosis and help them finish their races with faster times. For that reason, swimmers should practice the pace for taking a race out from a block start for greater accuracy, and they should restrict their stroke rates and velocities to those they will use throughout each race.

Paced swims for the middle portions of races should begin from a turn in butterfly and breaststroke so that the times accurately reflect their true pace. Swimmers can use a push-off for freestyle and backstroke events, although starting with a turn will provide a better feeling for the pace for the middle of the race in these strokes.

Broken swims also provide an excellent vehicle for teaching pace. Athletes can break the race into parts and practice swimming at the proper pace during each segment. They should also practice swimming with an even distribution of effort or a gradual increase in speed according to the pacing plan they prefer. Swimmers should always sprint the final 50 of their broken swims to condition themselves to increase their speed over the final segment of their races.

Stroke rates can provide another excellent way for swimmers to judge their paces for swimming events. Learning to control one's stroke rate is the quickest and easiest way to learn pacing. The previous chapter covered this topic, so I will review only a few of the suggestions here.

Swimmers should determine the optimum combination of stroke rate and stroke length for each race they compete in. That combination will allow them to swim at their desired race speed with the least effort. After they have determined the best combination of rate and length, they can pace their races efficiently by learning to control and maintain that combination for nearly the entire race distance. Surprisingly few swimmers are conscious of the relationship between maintaining a constant stroke rate and minimizing energy expenditure. Swimming with a constant stroke rate and velocity throughout most of the race will use less energy than changing speed will. The way the body uses energy is analogous to the way an automobile consumes gas. Driving a particular distance at a constant rate of 40 mph will use a small amount of gas. Driving the same distance at the same average rate by varying the speed of the automobile between 25 and 55 mph will use much more gas. Swimmers must learn to cover their race distances in the most economical manner, which should be with an even distribution of effort.

Swimmers can use stroke rates effectively with broken swims to practice distributing effort properly over the entire race distance and to find the optimum combination of stroke rate and stroke length. Calculating stroke rates for each segment of a broken swim can make swimmers more conscious of maintaining a constant rate. They can also experiment with different combinations of stroke rates and stroke lengths to determine the most economical way to swim a particular pace.

I mentioned earlier that swimmers should start their races with a stroke rate that they can maintain from start to finish. An even better method might be to swim the early portions of races with a slightly slower stroke rate and then increase that rate gradually in the latter portions of races as stroke length declines. As shown by the analyses of outstanding swims, stroke lengths do tend to decline late in races as fatigue sets in. Swimmers may be able to counter the tendency of the reduction in stroke length to slow their velocity by training themselves to increase their stroke rates progressively throughout their races.

The method just described is probably a good one to use in races covering distances of 200 yd or m and longer. The best way to swim 100 events may be to use a constant stroke rate throughout because early speed is more important during shorter races. Swimmers should probably experiment with both methods until they know which works best for them.

Strategy

Although pacing usually results in faster times, those times will not always win races. In races between swimmers with similar times, the swimmer who makes an unexpected move that upsets a competitor's race plan often wins. A surprising move can frighten or demoralize a competitor and cause him or her to respond with a poor performance. For that reason, swimmers should know the common offensive and defensive strategies for racing. They should know when to make unexpected moves that will upset their opponents, and they should learn how to counter when an opponent swims his or her race in an unforeseen manner.

Offensive Tactics

Swimmers can use several offensive tactics to help themselves, or their teammates, be successful in races. I will describe these in the following sections.

Taking a Race Out Faster Than Expected

Against opponents who are inexperienced and against those who have a strong finishing sprint, taking a race out faster than expected can work well. This tactic is also useful for swimmers, particularly distance swimmers, who do not have a strong finishing kick when they are swimming middle distance races against athletes who have a strong finishing kick.

Inexperienced swimmers may become demoralized when an opponent takes an unexpected early lead. Although the leader may fatigue earlier because of the sudden increase in speed, he or she may still win the race because the early lead may cause opponents to give up before the finish.

Taking a race out faster than expected also works well against swimmers who like to negative split their races. Often, these swimmers cannot bring a race back fast unless they swim slowly in the beginning. Starting fast can upset the race plan of negative splitters. If they are forced to swim faster than they had planned to early in the race to keep up, they may not have their usual strong finish. Consequently, a swimmer who must rely on aerobic capacity more than speed may be able to match an opponent who is usually faster during the final sprint.

Taking Races Out Slower Than Expected

The tactic of taking races out slower than expected can be used to advantage by a swimmer competing against someone who has a faster time. Swimming slowly at the beginning of races may fool an opponent into swimming slower than he or she had planned. As a result, a slower swimmer may be able to stay with a faster one without becoming fatigued. Consequently, the final sprint to the finish will offer an opportunity to win the race.

Using a Breakaway Sprint in the Middle of Races

Against an opponent who has a similar time, a breakaway sprint in the middle of the race can be a good tactic. This move may demoralize an opponent. He or she may feel the chance to win is nil and slow down.

Taking the Lead

Taking the lead early in a race is an advantage, particularly in turbulent pools and in butterfly races. Leaders can create significant turbulence with any stroke, particularly when lanes are narrow and when the lane lines and gutters of a pool are not well constructed. Swimming in the wake of competitors increases the energy a swimmer must expend to combat wave drag. Therefore, swimmers should take the lead when they feel they can do so without losing too much speed at the end of the race. When the pace seems too fast to take the lead, however, swimmers should remain as close as possible to the leaders to reduce the amount of wake they must swim through, even if that means swimming slightly faster than they had planned.

Drafting

Drafting means swimming in the wake of a competitor. Swimmers say that drafting reduces the energy cost for a race because they are pulled along by the swimmers immediately to the side of them. Due to cavitation, water pressure will be lower close behind an opponent. Accordingly, athletes who swim close to the side of the lane near the legs or just behind the feet of a competitor in an adjacent lane will be stroking in that low-pressure area created by the wake of their opponent's kick. In doing so, they will be pulled along, and they will expend less energy overcoming water resistance. This tactic will leave them with more energy to overtake their competitors during the final sprint. Chatard and his coworker (1998) calculated that drafting behind another swimmer could improve an athlete's time by 9.5 sec over 400 m. Whether such calculations are accurate remains to be seen. Nevertheless, the experience of competitive swimmers has been universal that drafting does save energy.

Shielding a Teammate

In dual-meet competitions, swimmers sometimes use the technique of shielding teammates. A swimmer from one team in the middle of the pool will deliberately swim a slow pace early in a race to get an opponent in an adjacent inside lane to do likewise. In the meantime, one of the first swimmer's teammates in an outside lane will take the lead and try to win the race, or at least beat the swimmers from the other team. This tactic works best when the swimmer doing the shielding is by far the best performer in the pool. The competition is often afraid to take the lead; therefore, they may swim a slow race and lose, not only to the shielding swimmer but also to his or her teammate.

Hiding From an Opponent

Some swimmers will purposely qualify at a slow speed so that they can swim in an outside lane away from their major competition in an invitational or championship event. They are particularly likely to do this when their opponent is known to be a good racer or a swimmer who likes to draft off competitors. Competing in an outside lane allows the swimmer who is hiding to swim the race at his or her best pace. At the same time, the opponent may be racing slower competitors in the middle of the pool, unaware that the swimmer in an outside lane is leading the race.

Defensive Tactics

Swimmers can use several defensive strategies to counter the offensive tactics just described.

Countering a Competitor Who Goes Out Faster Than Expected

A swimmer should never allow a competitor to build a big lead during the early portions of a race. The opponent may become motivated and energized if allowed to establish a substantial lead, and he or she may become more difficult to overtake later. A swimmer should stay close enough to overtake his or her rival, even if it means swimming faster than planned early in the race. If a swimmer and an opponent have similar times, the opponent will be working hard to stay ahead and will not have a strong finish. The fact that the opponent cannot pull away may also demoralize that person. Consequently, if the swimmer stays close behind, he or she may be able to take the lead when the opponent starts to tire.

Countering a Competitor Who Goes Out Slower Than Expected

Swimmers should not be afraid to take the lead when a competitor goes out slower than expected. Some swimmers are so devoted to negative splitting that they expect to be behind in the early stages of races, and they refuse to take the lead even when the pace is too slow. Swimmers with good aerobic endurance, particularly those with marginal sprint speed, should not allow themselves to be tricked into swimming slowly during the early portions of a race. They should know their best pace for each race well enough that they cannot be fooled into making this mistake. They may find themselves outsprinted at the end by a faster but less-enduring opponent if they do not build an early lead when they can.

Countering a Breakaway Sprint in the Middle of a Race

Swimmers should not let a competitor sprint away from them at any point in a race, even if the pace required to stay with the competitor seems too fast. If a swimmer and his or her opponent have similar times, the opponent will probably use more energy trying to move ahead than the first swimmer will use to stay close. An opponent who can get away may gain confidence. On the other hand, an opponent attempting to break away can become discouraged if the attempt fails. In that case, the swimmer who stayed close may be able to overtake the competitor and win the race.

Countering Drafting by a Competitor

Defensively, swimmers should try to swim in the center of their lanes so that competitors cannot draft off them. When an opponent tries to draft, a swimmer should move to the other side of the lane to reduce the draft. That move should take place during a turn when the swimmer can change sides without swimming a greater distance. Swimmers should always be aware of the lane positions of opponents to either side of them.

Countering When an Opponent Tries to Shield a Teammate

Swimmers should be trained well enough to know when they are swimming too slowly in a particular race. They should not be afraid to take the lead when an opponent, even one who has a faster time, swims at a slow pace early in the race. They should get ahead so that they can look for opponents in outside lanes who might be trying to build an early lead.

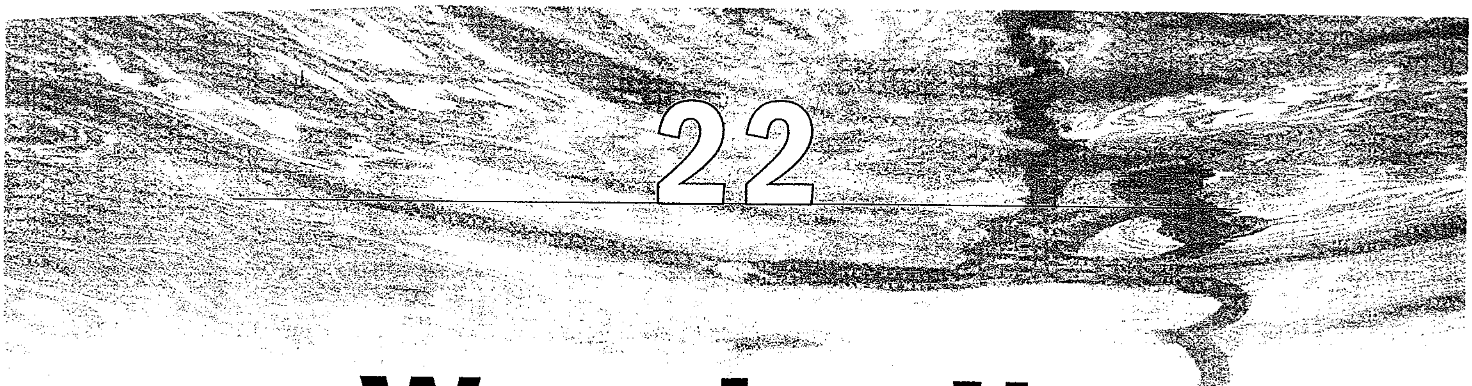
Countering an Opponent's Attempt to Hide

Swimmers should make it their business to know the lanes in which their major competitors are swimming so that they can keep an eye on them during the race. Athletes can do this by reading the published lane assignments for the race or by listening to the announced lane assignments before the race. Swimmers should never go to the block unaware of the position of their major competitors in a race.

Teaching Offensive and Defensive Racing Strategies

A good training procedure for preparing swimmers to use offensive tactics and to counter defensive tactics during races is to have them swim some of their practice repeats at speeds that are both faster and slower than the pace they plan to use for certain races. By swimming faster than race pace in training, they will learn how much they can deviate from their intended pace without losing too much speed later in their races. By the same token, swimming slower than their race pace in practice will help them realize when they are being maneuvered into swimming too slow in races.

Coaches should counsel swimmers when they make offensive or defensive errors during races and then design drills to train them to use proper tactics. Time trials and broken swims are excellent for this purpose.



22

Warming Up and Swimming Down

New in this edition:

- A look at the latest scientific findings on warming up and swimming down

Warming up is a time-honored procedure considered a necessary prelude to all physical activity. The belief is that warming up will help athletes prepare both physiologically and mentally for the upcoming competition or training. Swimming down, or cooling down as it is also known, allows athletes to recover faster after a race or training session.

Warm-Up

In this section I will describe the value of warming up and the procedures swimmers should use to do it. As part of this same topic, I will also discuss the value of massage, both before and after competition, and the value of hyperventilating just before the start of races.

Value of Warming Up

As indicated, warming up has both physiological and mental benefits. Physiologically, a good warm-up prepares the circulatory system to deliver more oxygen to the muscles and prepares the muscles to use that oxygen more rapidly. The warm-up stretches the joints and muscles, increasing their range of motion so that the athlete can perform the skills of swimming more efficiently and skillfully. Warming up increases the speed of muscle contraction so that the swimmer can perform powerful movements immediately when the race begins, and it reduces the possibility of muscle and joint injuries.

The warm-up can serve as a physical and mental rehearsal period for the upcoming competition, and it can help swimmers adjust to the environment of different competition sites. Swimmers can use the warm-up to rehearse physically by working on stroke techniques, refining starts and turns for the upcoming competition, and practicing paces and stroke rates for various events to prepare themselves to perform these procedures accurately and efficiently during the competition.

Swimmers can also mentally rehearse their races during the warm-up. As they swim easily down the pool or swim sprint and paced swims, they can plan their races and focus on aspects of their performance that will lead to success.

Swimmers can become accustomed to their surroundings during the warm-up. Each pool has a different feel and presents distinctive problems with identifying landmarks such as backstroke flags, starting blocks, and other items that swimmers use during races. Swimmers should use the warm-up period to accustom themselves to those surroundings so that they can execute their starts and turns with precision.

Warm-Up Parameters

Coaches and athletes must understand several issues about warming up before they can establish an intelligent protocol. These concern the intensity, length, and timing of the warm-up.

Intensity

At one time the prevailing opinion was that warming up would only be effective if it was vigorous enough to raise muscle temperatures above normal (deVries 1974). We now know that vigorous warm-ups can impair performances if they result in precompetition fatigue. Hermiston and O'Brien (1972) came to this conclusion when they tested a group of subjects for two treadmill-simulated 220 yd runs. The subjects performed one run after 10 min of warming up at 60% of $\dot{V}O_2$max. They did the second run after warming-up at an intensity of 30% of $\dot{V}O_2$max. The oxygen cost of the run after the more intense warm-up was greater than it was for the run preceded by the low-intensity warm-up.

Houmard and associates (1991) also reported that a warm-up consisting of low-intensity swimming worked better than more vigorous procedures for competitive swimmers. They compared the effects of the following warm-up procedures on performance during 400 yd time trials: (1) no warm-up, (2) a warm-up consisting of a low-intensity 1,500 m swim, and (3) a warm-up consisting of 4 × 50 m sprints on 1 min, and (4) a combination of a low-intensity 1,500 m swim and 4 × 50 m on 1 min. They concluded that the low-intensity swim improved performance most and that including some high-intensity swimming did not improve the effect. Several other studies (DeBruyn-Prevost and Lefebvre 1980; Genovely and Stanford 1982) have reported similar results.

Based on these and other pieces of research, the opinion of most contemporary researchers is that athletes should perform warm-ups at moderate effort. The effort should be sufficient to encourage blood flow, heating of the skin, and warming of surface blood vessels without being so vigorous as to cause fatigue. Warm-ups designed to raise muscle temperatures will cause fatigue because they must be so intense that they cause lactic acid to accumulate in the muscles. That, in turn, may reduce muscle pH below its neutral level of 7.0 so that athletes will be slightly acidotic when they start their races, hastening the decline of muscle pH to levels that cause fatigue and interfere with performance. For that reason, athletes should complete the warm-up at a pace below their aerobic thresholds. That should be intense enough to increase blood flow without causing lactic acid to accumulate in their muscles.

The ideal intensity for such a warm-up seems to be between 30% and 50% of $\dot{V}O_2max$, which is similar to easy efforts at 20% to 40% of maximum speed (Chwalbinska-Moneta and Hanninen 1989; Ingjer and Strommer 1979; Martin et al. 1975).

Although athletes should perform the bulk of a warm-up at low intensity, some vigorous race-pace swimming should be included for rehearsal purposes even if that swimming causes some lactic acid to accumulate. Rehearsing the proper pace for races is important enough to performance to make an exception to the rule of keeping warm-ups at low intensity. But athletes should keep race-pace swimming to a minimum and complete it at least 20 min before the start of their first event so that they will have adequate time to remove the lactic acid that accumulated.

Length

Little scientific information is available to help determine the optimum length of time that athletes should spend warming up. DeVries (1974) and other experts recommend a duration of 15 to 30 min. I recommend 30 min or longer because it will take that long to finish all the procedures that should be part of a good warm-up.

Nearness to Competition

Swimmers should complete the vigorous portions of a warm-up, the sprints and pace work, 15 to 30 min before the start of an event. Doing so will provide enough time to remove lactic acid from the muscles and restore muscle pH to normal. They should continue the less vigorous portions of the warm-up until no more than 5 min remains before competition. The best method may even be to continue swimming easy until their event is called to the blocks.

Warm-Up Procedures

The major portion of the warm-up should be a reasonable period of easy swimming. This activity will allow swimmers' oxygen consumption mechanisms to respond faster when the race begins so that they will more quickly reach an optimum level of oxygen consumption. As a result, they should be able to swim farther and faster before becoming fatigued.

Besides increasing blood flow and oxygen consumption, swimmers should include activities in their warm-up that will increase their range of motion, their stroke mechanics, and their sense of pace. Another purpose is to focus on strategy for the race. Available research and the reported experiences of successful coaches and athletes suggest the following warm-up procedures. They include low-intensity swimming to increase blood flow and oxygen consumption as well as activities to increase range of motion and stroke efficiency. Attention is also given to the practice of starts and turns. Finally, they include a physical rehearsal for the race in the form of paced swims.

1. *Stretching.* Before entering the water, athletes should spend 5 or 10 min doing some flexibility exercises. They should pay particular attention to increasing their range of motion in the joints of their ankles, shoulders, and lower back. Breaststrokers should also stretch their groins and knees.

2. *Easy swimming.* The next step is to swim easy for 10 to 20 min, at 20% to 40% effort. Swimming, pulling, kicking, and stroke drills that help them rehearse stroke mechanics should be included during this swim. Athletes should swim until they feel loose, efficient, and powerful. This is a good time for them to rehearse their races mentally. They should plan the pace they intend to use, be it even or fast-slow. They should also plan any offensive strategies they intend to use and review their procedures for countering defensive strategies their opponents may use. They should see themselves swimming the race properly and successfully. They should concentrate intently, narrowing their focus to the impending race while blocking out factors that may interfere with their goal of performing well.

3. *Starts and turns.* Swimmers should practice both of these skills at some time early in the warm-up. They should also practice relay starts if they are swimming on a relay. They should perform the starts with proper streamlining, dolphin kicking if used, and a good pull to the surface. Swimming from the flags into and out of turns is not the best way to practice that skill. The swimmers can learn to adjust their approach for turns while swimming easy early in the warm-up. Then they should do their paced swims with good starts and turns. They should not leave the pool until they feel confident that they will be able to start and turn well at race speeds.

4. *Pace and sprint swims.* Next, the athletes should do some paced swims to rehearse the paces they will swim in their races. Distances of 25 m are ideal for 50 and 100 races, and swims of 50 to 100 m are sufficient to practice their paces for longer events. Stroke rates and stroke counts should be taken during these swims if athletes use those measures to help them in pacing their races. The usual ritual of swimming a few 25 sprints is not necessary. Nevertheless, many swimmers like to sprint fast before competing. They should complete all paced and sprint swimming at least 15 min before the first race begins.

5. *Maintaining the warm-up effect.* The suggested procedure is to finish the warm-up just before reporting to the starting blocks for the event. The last portion of the warm-up should consist of easy swimming. Finishing a warm-up just before swimming is not always possible. This is unfortunate because the warm-up effect can diminish if an extended time passes after the warm-up period ends and the swimmer's first event starts. Therefore, when possible, swimmers should reenter the water for about 5 or 10 min of easy swimming before race time. This activity will prepare them for the race by increasing their blood flow and oxygen consumption without causing fatigue.

Massage

Prerace and postrace massages, or rubdowns, are popular among swimmers. Scientific evidence, however, has not universally supported the benefits of these procedures (Asmussen and Boje 1945; Karpovich 1965). Nevertheless, a strong theoretical case can be made for the benefits of massage. A list of some reasons for using massage as a precompetition procedure follows:

- Muscle temperature can be increased without fatigue through the heat generated from the balm and the friction from the hands of the person giving the massage.
- The manipulation of the athletes' limbs by the massage therapist should increase flexibility.
- Muscle tension and prerace anxiety may decrease from the relaxing combinations of increased body heat and joint manipulation.

Massage has also been used to facilitate recovery after competitions in the belief that it increases the removal of lactic acid from the muscles and bloodstream to other parts of the body where it can be metabolized. This seems a reasonable conclusion. Massage, when properly performed, should aid in "squeezing" lactic acid out of the muscles and moving it away from its site of origin. Research, however, has not supported the value of massage as a recovery procedure. In one study, researchers compared active recovery, passive recovery, and mas-

Suggested Warm-Up Procedures

1. Stretch ankles, shoulders, and lower back for 5 or 10 min. Breaststrokers should also stretch their groins and knees.
2. Swim long and easy for 10 to 20 min. Use stroke drills to rehearse skills.
3. Practice starts and turns.
4. Swim 25s, 50s, or 100s at race pace.
5. Swim a few sprint 25s if you wish.
6. Swim down long and easy for 2 to 5 min. Finish 15 min before race time.
7. Reenter the water 5 or 10 min before race time and swim easy until called to the block.

sage for their rates of lactic acid removal after exercise (Gupta et al. 1996). Active recovery removed half the accumulated blood lactate in approximately 15 min. Massage and passive recovery required approximately 22 min to achieve the same result. Consequently, the authors reported that massage was no more effective for lactate removal than simply resting after exercise. Despite the lack of scientific support, the possible benefits of massage are impressive. Therefore, I would advise using it both before and after competitions. Massage may also be useful in promoting recovery after training.

Hyperventilation

Many swimmers and coaches believe that hyperventilating aids performance. Therefore, they take several deep breaths while waiting for their races to start. There is some physiological support for this practice, although not for the reasons usually stated.

Deep breathing does not increase the oxygen supply before races. The oxygen inhaled before a race starts cannot be stored. Instead, it is simply exhaled with the next breath. Hyperventilation is beneficial because it reduces the carbon dioxide level in the blood so that athletes do not feel the need to breathe until later in their races. This allows them to swim sprint races with fewer breaths, and because breathing can increase drag, reducing the number of breaths may result in faster times. A reduction in the need to breathe may also aid performance by reducing the stress that swimmers feel. Carbon dioxide accumulation, not oxygen deprivation, precipitates the feelings of breathlessness and the need for air that swimmers experience early in their races.

Athletes can reduce the carbon dioxide content of the blood by taking several forced, long exhalations immediately before the start of a race. If swimmers start a race with a low concentration of carbon dioxide in their blood, more time will pass before it increases to the level at which they feel a distressing urge to breathe. Hyperventilating before the start should be particularly beneficial for 25 and 50 races of freestyle and butterfly because athletes try to swim these races with one to three breaths. It may also be beneficial in 50 backstroke races because many swimmers are now using an underwater dolphin kick for a sizable portion of that race. Athletes who compete in 100 freestyle, butterfly, and backstroke races may also benefit from hyperventilating before their races begin, particularly if they plan to restrict their breathing early in those races.

Swimmers should begin hyperventilating while waiting behind the block and continue as they step to the back of the starting platform. They should take several large, but not massive, inhalations, followed by long and complete exhalations. Five or six such exhalations should be sufficient. They should not overdo it. Athletes can become dizzy and may even faint from too much hyperventilating.

Swimmers should not hold their breaths when they are called to the block after hyperventilating. Instead, they should breathe normally after they are called to their mark. At the starting signal, they should take one large breath as they dive into the water. That breath, plus the reduction in carbon dioxide from hyperventilating, should allow them to swim farther before they feel the need to breathe.

Although hyperventilating should provide some benefit in 25, 50, and even 100 races, it probably has no beneficial effect in longer races. Swimmers should begin breathing in a normal rhythm just after diving into the water when they swim longer races. Consequently, they have no need to hold their breaths at any time during the race except just before finishing.

Swimming Down

One of the most important and most often neglected postrace and posttraining procedures for swimmers is swimming down. Athletes should always swim easy for 800 to 1,200 yd or m (10 to 20 min) after they finish a race. They will recover faster by doing so. Several studies have shown that they will recover twice as fast by swimming easy instead of simply stopping and resting at the side of the pool (Bond et al. 1987; Bonen and Belcastro 1976; Krukau, Volker, and Liesen, 1987). Swimming easy after an event is termed *active recovery* as compared with resting, which is called *passive recovery*.

The graph in figure 22.1 demonstrates that athletes can recover in nearly half the time if they use active recovery instead of passive recovery procedures.

As shown by the graph, blood lactate fell to near resting levels in 30 min when the athletes performed some mild exercise immediately following exercise. When the athletes simply rested without exercising, it required 60 min to remove the same amount of lactic acid.

Recovery is more rapid with mild exercise because the rate of lactic acid removal increases through a mechanism called the *muscle pump*. The contraction of muscles exerts a squeezing effect on the veins that pushes blood back to the heart at an accelerated rate. Because of this action, lactic acid will be removed from the blood to the heart, liver, and other muscles where it can be metabolized. More lactic acid thus leaves the muscles where it was produced and enters the blood, where it can be removed more rapidly.

Mild exercise also permits faster recovery by removing carbon dioxide from the muscles and delivering oxygen to them at a faster rate. The elevated rate of flow maintained through mild exercise will cause more blood to reach the lungs each minute, where it will give up its carbon dioxide and take on oxygen. The oxygen can then be transported to the muscles, where it will increase the rate of lactic acid removal by aiding in the metabolism of that substance to glucose.

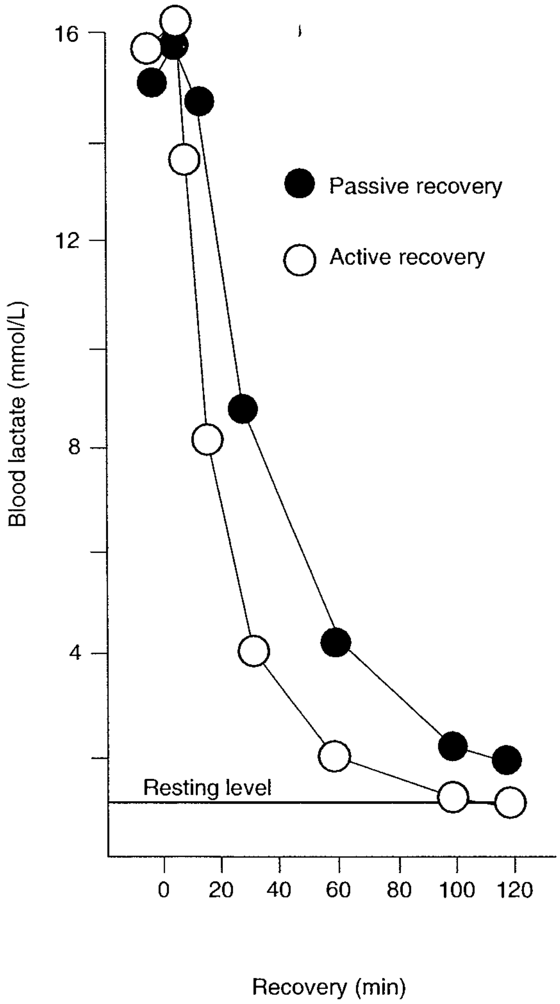


Figure 22.1 The effects of active and passive recovery on removal of blood lactic acid.

Adapted from Wilmore and Costill 1988.

Although 30 min of active recovery was required to return the blood lactic acid to its resting level, the information in figure 22.1 shows that most of the lactic acid can be removed within the first 10 to 20 min after a race. Consequently, muscle pH is probably normalized or nearly so in that length of time. For that reason, 10 to 20 min is the recommended length for recovery swims.

Coaches have difficulty persuading athletes to swim for this long after races when their teammates are swimming other events and when awards are being given. Nevertheless, swimmers should be encouraged to do so because their chances of swimming well in their next competition will improve. One study showed that swimmers tended to stop before they had fully recovered unless they were required to swim down for a long period (Strozberg and Klar 1998). Therefore, coaches should impress on them how important it is to complete a full swim-down.

The speed during the swim-down should be sufficient to maintain a high rate of blood flow without causing additional muscle glycogen use and lactic acid production. Well-conditioned athletes can probably swim at 30% to 50% of their maximum speed without producing additional lactic acid and without using any significant amount of glycogen. Selecting any particular speed for swimming down is probably unnecessary. A study by Bonen and Belcastro (1976) indicated that athletes will generally choose the proper speed for swimming down if left to their own devices.

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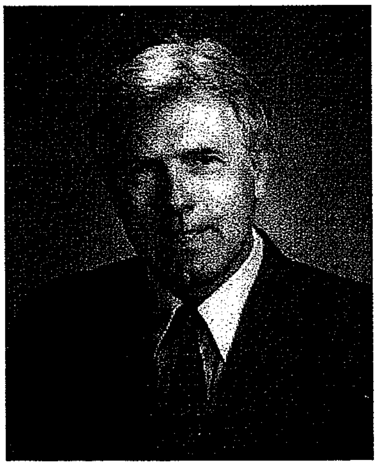
About the Author



Ernest W. Maglischo has coached swimming for 38 years, working at four universities and two swim clubs. He has won 13 NCAA national championships at the Division II level and 19 conference championships. In 1996 he was honored as the Pacific 10 Conference Swimming Coach of the Year, and he has been named NCAA's Division II coach of the year an unprecedented eight times. He has also received the highest coaching award, the National Collegiate and Scholastic Swimming Trophy.

Maglischo holds a PhD in exercise physiology from Ohio State University. He's a member of the College Swimming Coaches Association, the American Swimming Coaches Association, and USA Swimming, where he serves on the Sports Medicine Committee. Now retired, Maglischo lives in Phoenix, Arizona.