



Aerobic Capacity for Endurance

Jack Daniels

Aerobic capacity refers to the greatest amount of oxygen an individual can consume while performing physical exercise. The form of physical exercise that a person might perform can vary greatly, of course, from a simple act involving just a few small muscles to a gross motor movement that demands the use of large muscle groups. With this in mind, an individual's aerobic capacity can range from a limited consumption of oxygen to one that is 20 or more times greater than that associated with rest. For example, running and cross-country skiing are forms of exercise that involve large muscle groups. The amount of oxygen an elite runner or skier can use when exercising at a high intensity can easily be 70 or 80 milliliters per kilogram of body weight per minute, which is clearly over 20 times the resting metabolism of 3.5 milliliters per kilogram per minute. On the other hand, the amount of oxygen that could be consumed while operating an eggbeater may not exceed twice that consumed at rest. Therefore, aerobic capacity is specific to a group of muscles, although we tend to think of it as the most oxygen an individual can consume while engaged in an exercise that brings into play as many muscles as possible.

Aerobic involvement during exercise actually has two major components. The first is the central component, which refers to the oxygen delivery system. The ability of the lungs to oxygenate the blood that is pumped through the pulmonary vessels, the ability of the blood to carry oxygen, and the ability of the heart to pump blood to the exercising muscles are all parts of the oxygen delivery system. The second is the peripheral component, which refers to the ability of the exercising muscles to take in and use the delivered oxygen to convert fuel aerobically to energy for muscular contractions.

Factors of importance here are the degree of vascularization of the exercising muscles and the number, size, and distribution of mitochondria (the intracellular structures in the exercising muscles where oxygen is used to convert fuel—fat and carbohydrate—to energy). In addition, the status of oxidative enzymes (chemicals that aid in the consumption of oxygen at the cellular level) is important in just how much oxygen can be consumed in a given time. In effect, the central component delivers oxygen, and the peripheral component uses some, or possibly all, of the oxygen that it receives.

Clearly, the ideal situation would be to have a central component capable of delivering as much oxygen as the muscles might ever need and for the peripheral component to be able to use as much oxygen as can be delivered. But this is not the case. If it were, we would have no need for the term *aerobic capacity*, which implies that there is a limit to how much oxygen can be consumed by any particular group of muscles.

ENDURANCE AND AEROBIC CAPACITY

Endurance is the relative intensity (to the individual's aerobic capacity) of exercise that an individual can maintain for a period of time. It is better to think of endurance as a *relative* factor rather than an *absolute* one. An improvement in endurance refers to either being able to endure a particular intensity of exercise for a longer period or being able to endure an increased intensity for the same period. Most often endurance is described as the ability to maintain a certain fraction of aerobic capacity for a specific period.

Naturally, an athlete can improve endurance either by increasing aerobic capacity (because even the same fraction of an improved aerobic capacity will lead to performance at greater intensity) or by increasing the fraction of the same aerobic capacity that he or she can maintain for any particular period. For example, early in a season of training a distance runner may be able to sustain a pace that demands 80 percent of his or her aerobic capacity for a period of one hour. Later that season the same runner may be able to endure a pace that demands 84 percent of the same aerobic capacity for the same amount of time. Alternatively, an increase in aerobic capacity may result in an 80 percent intensity being related to a faster pace for one hour.

In a sense, aerobic capacity can be viewed as a somewhat absolute, yet variable, factor and endurance as a relative and variable factor.

Energy Production

To perform any type of physical activity, energy must be provided to the muscles involved. The necessary energy is provided either anaerobically (without oxygen) or aerobically (with oxygen).

Anaerobic Metabolism

The *anaerobic* metabolism of fuel results in the production of pyruvic acid, which later is converted to lactic acid. Both of these by-products of anaerobic metabolism are eventually removed from the body *aerobically*, either during recovery from exercise or, if the intensity is low enough, during continued exercise. Both anaerobic and aerobic processes are going on at the same time, all the time. Anaerobic energy production is more rapidly available than aerobic energy, and athletes rely on it heavily at the beginning of any bout of exercise and during exercise at high intensity. Note that the body also uses lactic acid as fuel that can be burned aerobically.

Aerobic Metabolism

Both carbohydrate and fat are metabolized aerobically in skeletal muscles, with water and carbon dioxide being the waste products of aerobic metabolism. The longer the bout of exercise, the more heavily the body relies on aerobic metabolism for the production of energy. It takes a couple of minutes for the body to adjust to a continuous bout of exercise. While this adjustment is occurring, anaerobic metabolism carries a diminishing share of the load (see figure 10.1). Think of the start of exercise as a rocket taking off. At the start of the process, powerful booster engines produce the bulk of the energy necessary for flight. But the

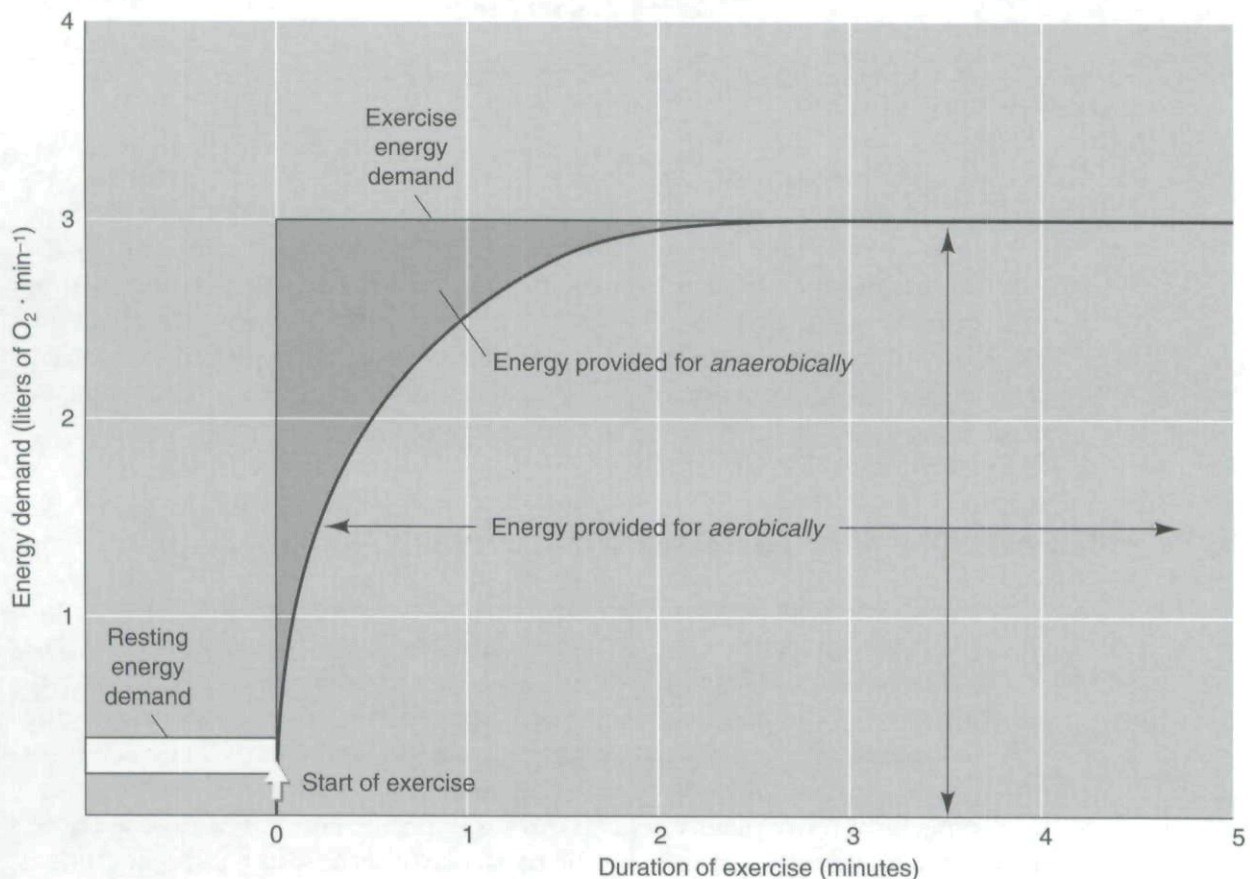


Figure 10.1 It takes a couple of minutes for the body to adjust to a continuous bout of exercise. While this adjustment is occurring, anaerobic metabolism carries a diminishing share of the load.

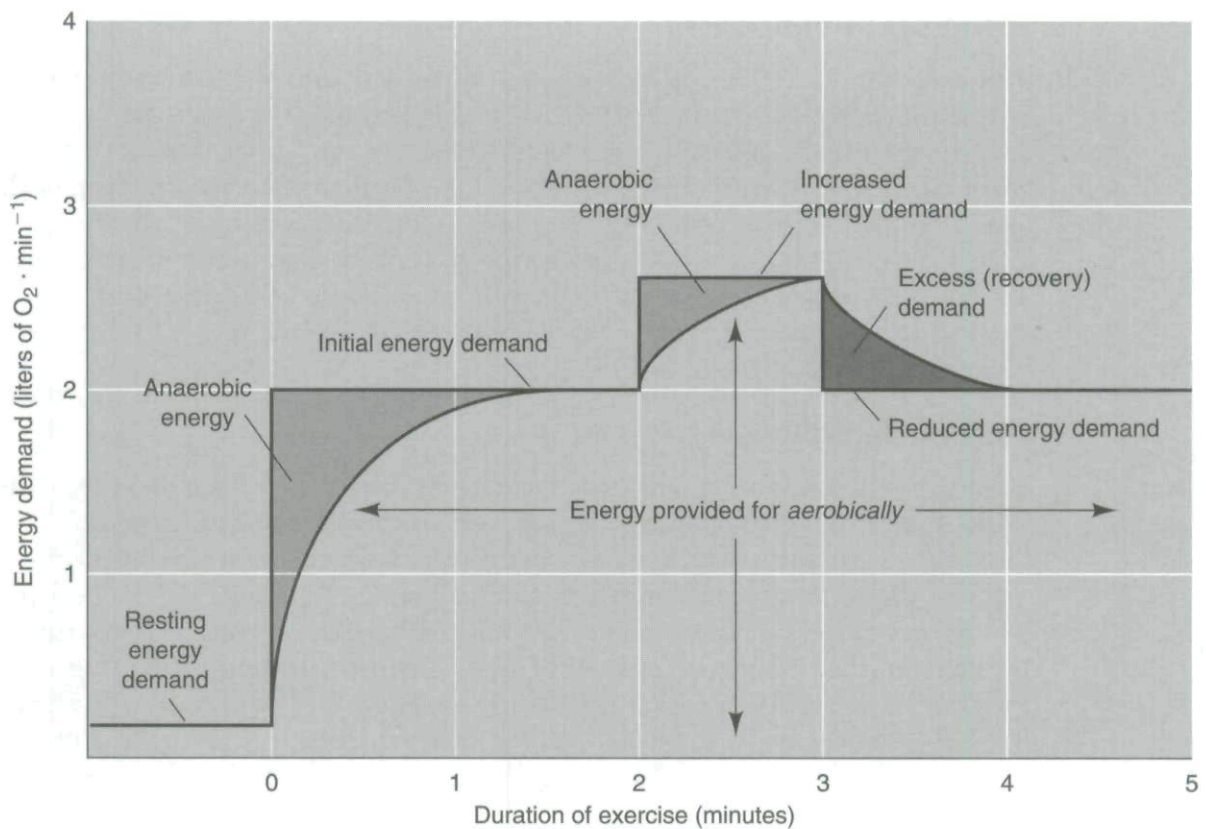


Figure 10.2 If given time to be rejuvenated, the body's "booster engines" can provide considerable power any time it is needed.

boosters can provide power for only so long. Once under way, the main engines take over as the primary energy providers. These engines are capable of functioning more continuously. With adequate fuel and when operating within their capabilities, they can go on for a long time. Still, the booster engines can be called on for sudden bursts of energy at almost any time during the flight. If given time to be rejuvenated, they can produce considerable power whenever it is needed, as depicted in figure 10.2. Furthermore, any time the energy demand exceeds an individual's $\dot{V}O_{2\max}$, anaerobic metabolism must provide all the additional energy.

Aerobic Power for Anaerobic Events

But what about the benefits of high aerobic power in more anaerobic sports or in sports that are intermittent in nature, such as football? Pyruvic acid and lactic acid are removed aerobically, which means that good aerobic capability will have a positive effect on recovery, even from high-intensity exercise. Being able to tolerate repeated bouts of high-intensity exercise is beneficial not only in competition but also in training. An athlete with good aerobic capacity can perform more quality repeats during a specific amount of practice time. So, although a given sport may not be particularly aerobic in nature, additional quality practice time can certainly help produce better performance in a competitive situation.

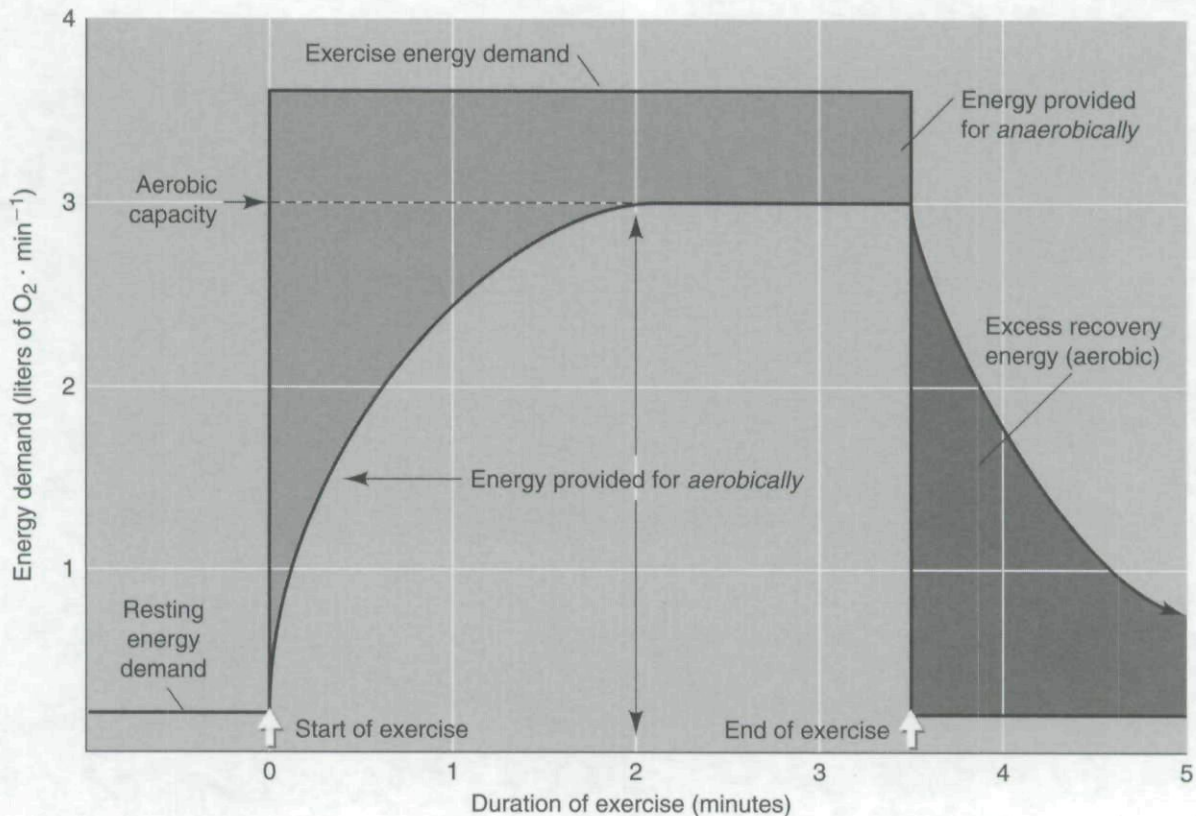


Figure 10.3 Aerobic power plays the dominant energy-production role in competition and serves the competitor well during long practice sessions as well as competitions in which he or she competes in more than one event.

Aerobic Power for Aerobic Events

It should be obvious that a high aerobic capacity is of tremendous importance in sporting events that require prolonged exercise. In aerobic sports the participant relies heavily on his or her aerobic capacity. Aerobic power plays the dominant energy-production role in competition and serves the competitor well during practice sessions in which repeated bouts of exercise are often the goal of training. Furthermore, in track and swimming meets it is common for a competitor to race in more than one event. The enhanced recovery rate associated with a high aerobic capacity plays a significant role in how well the athlete can deal with a second or third event (see figure 10.3).

Relationship of Aerobic Capacity and Economy of Exercise

An athlete with a high aerobic capacity who is not economical when performing his or her sport may not match the performance of an athlete with less aerobic capacity but more economical form. Figure 10.4 shows a typical economy curve generated by the steady-state oxygen consumption ($\dot{V}O_{2\text{submax}}$) of a runner running at 230, 250, 270, and 290 meters per minute ($\text{m} \cdot \text{min}^{-1}$). The aerobic capacity of this runner is placed on an extension of the economy curve, and from this,

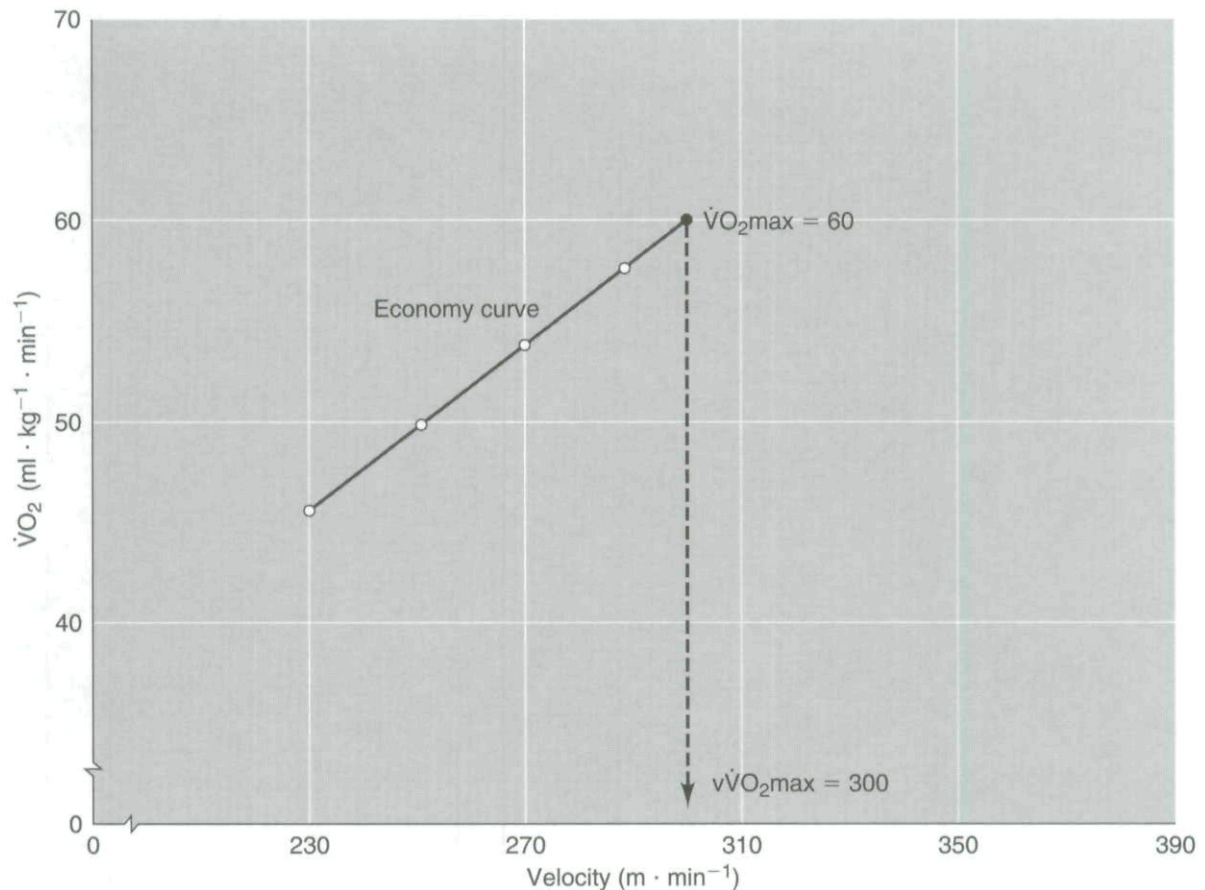


Figure 10.4 The aerobic capacity, economy curve, $\dot{V}O_{2max}$, and a $v\dot{V}O_{2max}$ of a runner.

a corresponding velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) can be determined (see figure 10.4). The aerobic capacity for this runner ($60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) corresponds to a $\dot{V}O_{2max}$ of 300 meters per minute ($\text{m} \cdot \text{min}^{-1}$). This $v\dot{V}O_{2max}$ value can be considerably more revealing about this runner's distance-racing capability than the $\dot{V}O_{2max}$ value by itself because it includes the added variable, running economy.

As an example, figure 10.5 shows the economy curve, $\dot{V}O_{2max}$, and $v\dot{V}O_{2max}$, for two elite female distance runners. Both these runners raced 3,000 meters in nearly identical times, yet $\dot{V}O_{2max}$ varied by about 20 percent. Notice that $v\dot{V}O_{2max}$, which adds running economy to the picture, varied only slightly between the runners.

Of course, variations in $\dot{V}O_{2max}$ and economy will occur during different phases of training, and the same athlete may show a marked change in $\dot{V}O_{2max}$ or economy during a single year (or even a single season) of training. The point is that changes in performance may occur in the absence of changes in aerobic power or any other variable chosen as a performance marker.

In keeping with my definition of endurance—being able to endure a particular intensity (running speed, for example) longer, or an increased speed for a specific time—it becomes obvious that a change in economy of exercise also affects

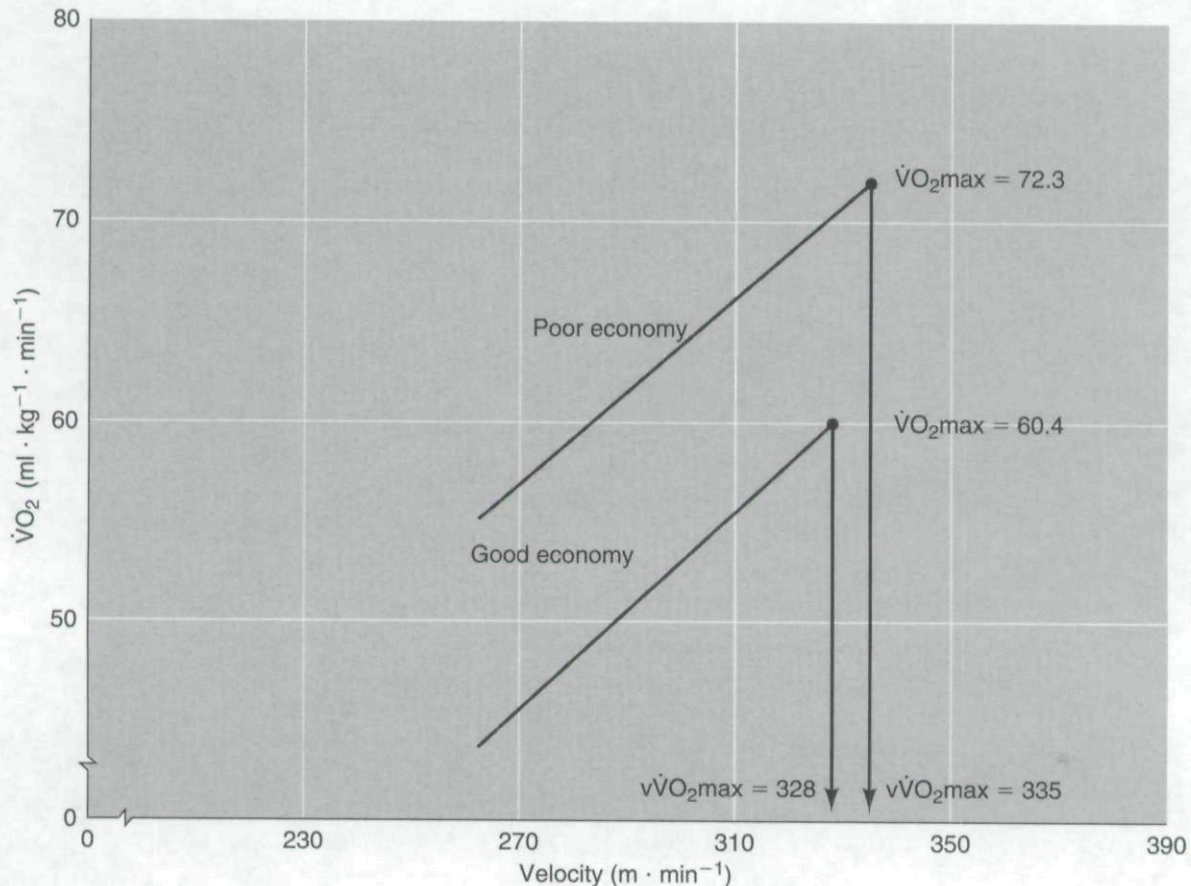


Figure 10.5 The economy curve, $\dot{V}O_{2\max}$, and $v\dot{V}O_{2\max}$ for two elite female distance runners. From Daniels et al. 1984, page 70.

endurance. For example, a distance runner with a $\dot{V}O_{2\max}$ of 60 who races at a 6:00-per-mile pace ($268 \text{ m} \cdot \text{min}^{-1}$) for 30 minutes at 90 percent of his or her $\dot{V}O_{2\max}$ ($54 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) will increase race speed if improved economy leads to this $\dot{V}O_{2\max}$ ($54 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) being associated with a faster speed ($280 \text{ m} \cdot \text{min}^{-1}$, for example). Figure 10.6 illustrates this.

So, aerobic capacity, endurance, and economy all play major roles in performance, particularly in sports that demand prolonged, steady exercise at relatively high intensity.

PRINCIPLES OF TRAINING

Before discussing specific training designed to develop or improve aerobic capacity, endurance, or economy, it is useful to understand some of the basic principles of conditioning that affect these components of performance.

Principle 1: Body Reaction to Stress

Actually, two general reactions to stress can be considered. The first is the reaction to an acute bout of exercise, for example, getting up from a bench and running

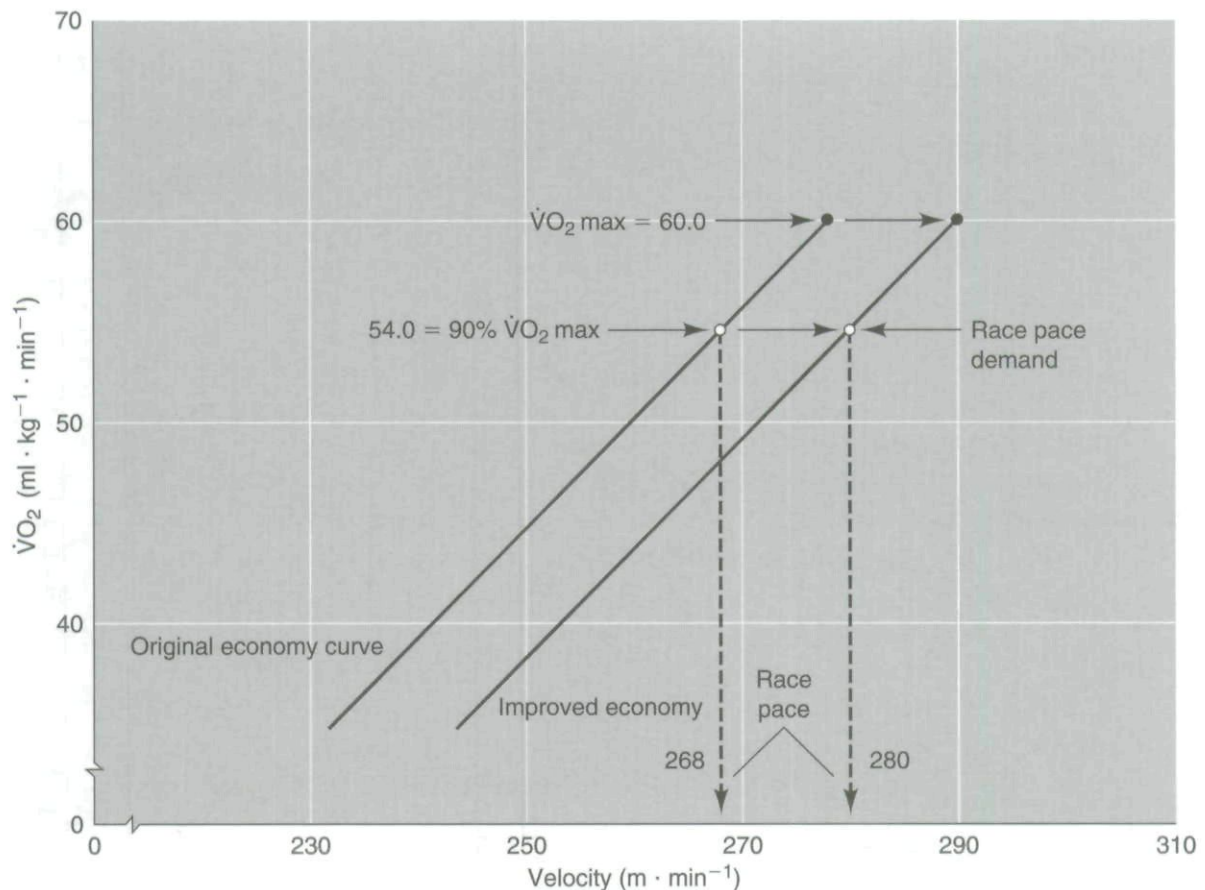


Figure 10.6 A change in economy of exercise also affects endurance.

several hundred meters to the other side of a park. On arriving there, the individual would notice some immediate reactions to this stress: an increase in heart rate, increased breathing, and possibly some leg-muscle fatigue. If some blood were collected, a rise in the lactic-acid level of the blood might be detected. Noticeable sweat might have started to accumulate on parts of the skin. All these reactions would take place any time the individual attempted such a bout of exercise, regardless of his or her level of fitness.

The second type of reaction to physical stress is in the form of changes that take place in the body as a result of chronic stress—undergoing a particular stress repeatedly, maybe in a single session of exercise but perhaps with regular frequency on different days. For example, one might get up from the same park bench and run to the other side of the park five times each week for several weeks. When chronic stress of this type (which we would usually refer to as *training*) is imposed on the body, the body makes changes that will allow the individual to perform the same bout of exercise with greater ease. The heart muscle will get stronger, as will the running muscles and the ventilatory muscles. Changes will take place in the muscle cells that will result in lower accumulations of lactic acid in the blood. The soreness associated with earlier bouts of exercise will disappear as the body strengthens itself against this particular activity. A desirable training effect will take place; the individual will attain a new fitness level.

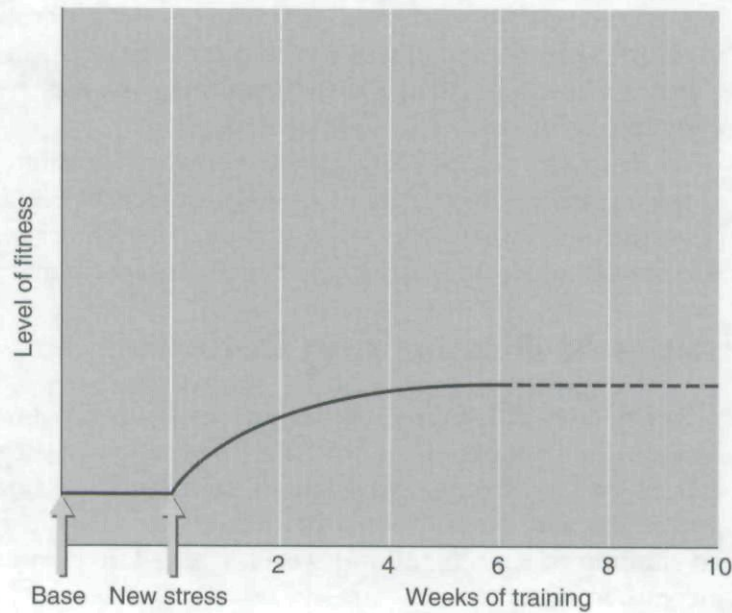


Figure 10.7 Exercising at a greater degree of stress produces an increase in fitness that levels off after a period of time.

From Daniels 1998, page 19.

Principle 2: Predictable Rate of Improvement

A person at a stable level of fitness who begins to exercise at a greater degree of stress will reach a higher level of fitness. The rate at which the individual will achieve this new fitness, however, is not linear. Rather, as weeks of performing the same routine go by, the benefits become less until the person reaches the new fitness level. Further training at this particular stress will not produce further improvements in fitness. Figure 10.7 depicts how a person might achieve a new level of fitness by regularly performing a consistent schedule of training.

A beginning runner might train three days each week, running two one-mile runs in 12 minutes each, with a 5-minute recovery between the two runs (written as 2×1 mile at 12:00 with 5:00 rest, $3 \times$ week). Each training session involves a *workload* (two miles in this case), an *intensity* of training (12:00 pace for the miles being run), and an amount of *recovery* time between individual work bouts (5 minutes). *Frequency* of performing this training (three times each week) is also indicated. All training can be described in this manner: workload, intensity, recovery (sometimes there is a single work bout so recovery between bouts is not a consideration), and frequency. Furthermore, increasing the stress of any of these factors will lead to achieving a new level of fitness.

Principle 3: Limits to Improvement

Principle 2 suggests that as long as a person keeps increasing the stress of training, fitness will continue to improve. Everyone, however, has limits. These limits are often seasonal. A young beginning runner may have an immature body that can take only so much stress before it starts to break down. A college student

may try to add additional training time to an already crowded schedule, resulting in insufficient rest and illness. For numerous reasons, an individual might not be able to go beyond a particular state of fitness one season and then move to much greater heights in the next season of training.

We must also accept that each individual has absolute limits to how much he or she can achieve in any sport. Certainly, differences exist in body structure, degree of motivation, level of opportunity, and quality of direction (coaching) available. All these factors play a part in the degree of success that an individual can reach.

Principle 4: Diminishing Returns

This principle of training implies that as the stress of training continuously increases, the benefits of the training become less. A beginning runner who increases training from 20 to 40 miles each week will not realize as great an improvement with the additional 20 miles as he or she did when training went from no running to running 20 miles each week. The greater the stress, the less the increase in benefit.

At some point of increased stress, a decrease in fitness may occur if accompanying rest and recovery time are inadequate, a condition typically referred to as *overtraining*. A good approach to avoiding overtraining is to be aware of how training feels to the athlete, not just how fast the training sessions are going. Also, if an increase in training stress is not associated with better performance, the athlete should reevaluate what he or she is doing; it may be time to back off for a while.

Principle 5: Accelerating Setbacks

This principle goes hand in hand with principle 4. It states that relatively minimal training stress is associated with few problems (injuries, illnesses, overtraining, loss of interest, etc.), but, at some point of increased stress, even a small amount of additional stress can result in a much greater chance of something going wrong. Figure 10.8 depicts how principle 4 (upper curve) and principle 5 (lower curve) appear if fitness potential and chance of a setback are both plotted against increased training stress.

Principle 6: Specificity of Training

This principle refers to the fact that the part of the body that is stressed is the part that stands to benefit from that stress. The running muscles must be stressed to become more efficient during the act of running, the heart must be stressed for it to become stronger, and so forth. This principle does not deny the benefits of cross-training, but it does suggest that an athlete carefully consider the consequences to avoid producing undesirable results (for example, too much gain in muscle mass that is nonproductive in the sport of primary interest).

Principle 7: Ease of Maintenance

The ease of maintenance principle states that once an individual achieves a certain level of fitness, the degree of stress necessary to maintain it is not as great as was necessary to reach that level of fitness in the first place. Part of this effect

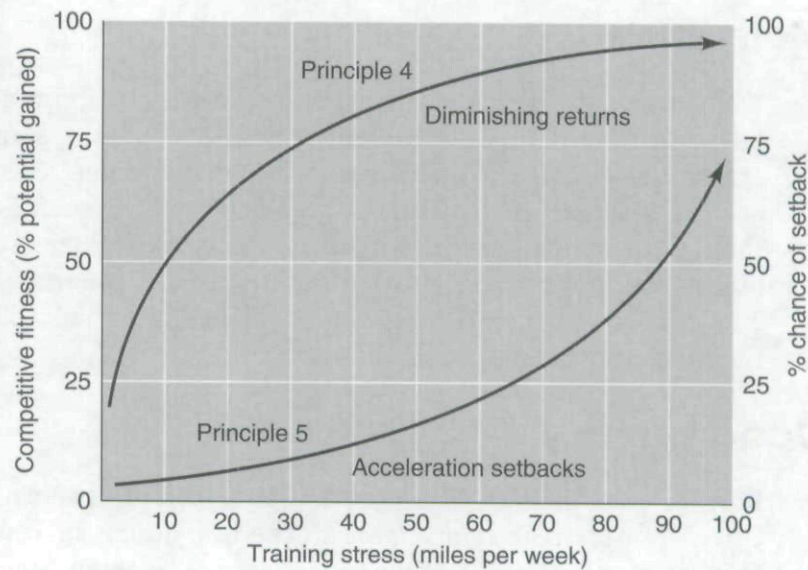


Figure 10.8 Increasing training stress beyond a certain point can lead to diminishing returns and a greater chance of injuries and overtraining.

From Daniels 1998, pages 26 and 28.

comes from an elevated level of confidence achieved through specific performances, but part of it is strictly physiological. Various systems of the body will continue to perform at an achieved level with only occasional stress, allowing the individual to attend to another, possibly weaker, system with greater enthusiasm.

INGREDIENTS OF SUCCESS

In addition to an understanding of the basic principles of conditioning there are several other attributes that are necessary for athletic success.

Ability

Every individual is born with specific physical characteristics that largely determine potential success in a given sport. It is easy to see that a very tall person may have good potential for a sport like basketball but not necessarily for gymnastics. On the other hand, small individuals are designed more for gymnastics than for throwing the discus. In many sports like boxing, wrestling, and weightlifting differences in body size are so important to competitive success that weight classes have been established to level the playing field.

Although not as obvious as differences in anatomical design—height and weight—physiological makeup varies greatly among individuals. Some people have systems ideally designed to perform endurance activities. Others seem to be put together to excel at sprinting. Add to these variations that an immature body is different from a fully developed one, that males differ from females, that physical characteristics vary across a wide range of ages, and it is apparent that addressing the issue of training for sport is not always straightforward. It is difficult to say that a set amount of stress will produce the optimum training effect for anyone.

Motivation

Even among individuals with equal or nearly equal ability to perform a particular physical activity, vast differences exist in the desire shown toward the same activity. Being tall and coordinated doesn't guarantee success on the basketball court if the person's motivation is in another area, such as music or art. With thoughtful and enthusiastic direction, an outside influence can sometimes instill motivation, but intrinsic motivation is normally essential to achieving real success in any sport or physical endeavor. The athlete involved must be the one with the motivation, not a parent or coach.

Opportunity

Further muddying the waters of developing an ideal approach to training is the extent of opportunity available to the individuals involved. In many sports, climate, facilities, and equipment are major concerns. Skiers need snow, swimmers need water, rowers and paddlers need water and boats. Money can be an obstacle, as in sports like yachting and equestrian events. Naturally, just having the opportunity to compete against others is a factor in how far an individual can develop in any sport.

Direction

Another ingredient that should be addressed is the matter of having a coach or teacher, or at least a training plan to follow. Possessing this ingredient may be a detriment if the plan or person directing the training of an individual or team is not in tune with proper training principles or is not patient enough to let the athletes progress at a reasonable rate. The most serious fault that someone in charge of the conditioning of others can make is not being sensitive to individual differences and needs.

Age and Body Composition

Before reaching physical maturity (in the late teens for most individuals), age can be a major factor in the success that an endurance athlete might achieve. When one realizes the important role that muscle mass plays in oxygen consumption—the greater the mass of exercising muscle, the greater the need for oxygen to feed that mass and the greater the weight the runner must carry—it is easy to accept the various degrees of success that youngsters reach as distance runners. Some late-maturing individuals have light bodies to carry around and often have great success when they start out as distance runners. When they mature, many have a rapid growth spurt, adding not only additional muscle mass but also fat deposits and larger bones. An immediate effect is a drop in endurance as the body struggles with its new dimensions.

On the other hand, some individuals grow steadily, and the adjustment is gradual enough for them that performance may never take a backward slide, even temporarily. In either case, once the body has had a chance to adjust to its new dimensions, performance will usually continue to progress as long as training continues.

Actually, over time, from very young ages to about 18, the major physiological change that accompanies an improvement in performance is better economy. $\dot{V}O_{2\max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) often remains nearly constant as increases in total oxygen consumption are matched by increases in body mass. The improvement in running economy appears to be partly associated with normal growth and partly with training that may take place during the growth years. Even in the absence of an increase in relative $\dot{V}O_{2\max}$, the improvement in economy results in $\dot{V}O_{2\max}$ becoming significantly better. This change is directly associated with a change in performance, as described earlier. Figure 10.9 shows the changes that took place in relative $\dot{V}O_{2\max}$ and running economy among a group of young runners who were followed over a period of five years.

A word of caution is appropriate regarding body mass as it relates to the performance of a distance runner. First, oxygen consumption ($\dot{V}O_2$) can be expressed in either *absolute* or *relative* terms. Absolute oxygen consumption refers to the actual amount of oxygen that an individual consumes each minute, usually expressed in liters or milliliters per minute. For example, a runner might be consuming 3,000 milliliters of oxygen per minute while running at a maximum aerobic effort. If this runner weighs 60 kilograms (132 pounds), then he or she will have a relative $\dot{V}O_2$ of 50 milliliters per kilogram per minute ($3,000 \text{ ml} \div 60 \text{ kg} = 50 \text{ ml per kg}$). If this represents the individual's $\dot{V}O_{2\max}$, it can be improved in either of two ways—by increasing the absolute 3,000-milliliter maximum or by reducing the body mass, which is divided into the absolute $\dot{V}O_2$ to arrive at a relative $\dot{V}O_{2\max}$. Remember that relative $\dot{V}O_{2\max}$ is the one more closely associated with running performance.

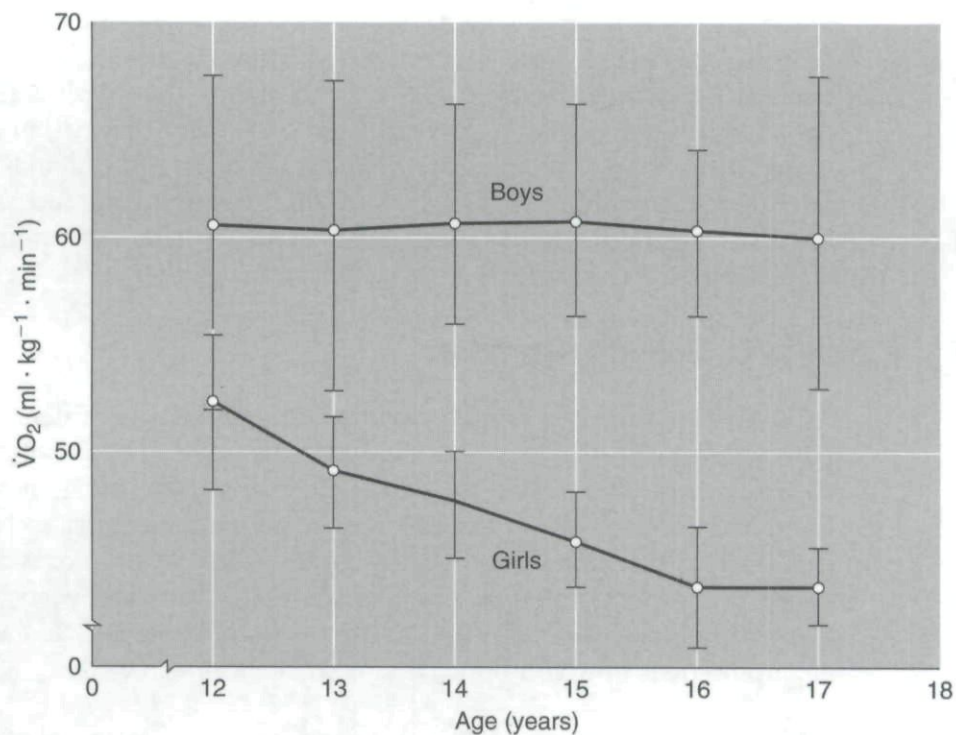


Figure 10.9 The changes in muscle mass, fat deposits, and bone size that occur as athletes reach physical maturity affect their relative $\dot{V}O_{2\max}$.

From Daniels et al. 1978, page 202.

The danger comes in getting overzealous in an attempt to reduce body mass (in hopes of increasing relative $\dot{V}O_{2\max}$). If the body is carrying unnecessary body fat, some drop in body mass will improve performance. But if one curtails nutrition to the extent that muscle mass or energy stores are reduced, the result will be a reduction in *absolute* $\dot{V}O_{2\max}$. Continued loss of weight will not improve performance and, in fact, can degrade performance. Growing youngsters sometimes try to avoid growing up “too much” by reducing their food intake so much that muscle growth is held back and nutrients are not adequate to sustain nutritional needs.

COMMON PROBLEMS IN GAINING ENDURANCE AND AEROBIC POWER

Given the many factors that influence success in sport, it is not difficult to appreciate that some individuals have much greater success than others do in particular sports. Unlike sports in which skill plays a dominant role, some sports that rely on high aerobic capacity or superior endurance actually have rather limited skill components. Of all competitive sports, distance running probably demands the least from its participants in skill development. Conditioning is the most important element in the success of runners. Even in endurance sports with a high technique component, such as cross-country skiing and distance swimming, at some point conditioning the aerobic system becomes of primary importance.

Rushing to a Goal

Nothing can become a greater problem for an endurance athlete than shortcutting a sound, consistent training plan. Not adhering to the simple training principles presented earlier in this chapter can lead to a setback that curtails training for an undetermined time. Training setbacks are a particular problem because they not only stop steady progress toward a goal but often motivate the participant, once he or she regains health, to try to make up for lost time by training even harder. This increase in training stress usually leads to further setbacks.

Copying the Champion

The careers of many potentially outstanding endurance athletes have undoubtedly been cut short by trying to duplicate the training habits of a current champion or record holder. This is particularly true among young, inexperienced athletes, who idolize the outstanding individuals in their sport and will attempt to do exactly what their hero does in training. A key word here is *does* because beginners in a sport often don't realize the many hours and years of training that the current stars went through as youngsters. They just read about what the champion does now and figure that is what they need to do.

Not Listening to the Body

Not even the best thought-out training plan in the world will always be right for everyone. It seems so simple to lay out a training program and conscientiously

follow it to the letter. How can a person go wrong? How can a person overtrain if the program is a proven, successful approach to greatness? The answer is that no matter how perfect the plan, things go wrong now and then. People become injured, people become ill, people have other things to do in their lives that sometimes limit the rest or nutrition they get. Some days don't go so well, and this is when it pays for an athlete to listen to his or her body. A variety of methods are available to examine the effects of training, such as monitoring heart rate, timing segments of a training session, taking blood samples to check on blood-lactate levels, and so forth. But the simplest and most often overlooked method is learning to read the body. Most great athletes excel at this (which is probably why they became so great), but enthusiastic beginners often overlook this important aspect of training. Endurance athletes need to learn to *feel* how things are going. They need to know when to end a workout and when to change a workout to something that may be just as stressful but of a different nature. Learning to read the body takes some time but is well worth the effort.

Assuming Everyone Is the Same

Not recognizing individual differences is often the weakest part of a training program for youngsters and older individuals. Youngsters mature at far different rates, and some oldsters age rapidly. But this problem is not limited to the young and old. Besides normal physiological changes that take place among individuals, a variety of psychological factors come into play. Because people react differently to the same training stresses, it is not uncommon to see two distance runners, for example, attain quite different race times even though they have followed the same program and are equally motivated. Recognizing individual differences goes hand in hand with learning to listen to the body.

Not Caring for Illness and Injury

In the heat of training for an important competition, it is tempting to try to train through an injury or illness. Some injuries will clear up just as fast during normal training as they will by taking time off; other injuries need true rest, at least from specific stresses. Learning which injuries fall into which categories is not easy, but experience and a good coach can go a long way in making the determination.

Lacking Flexibility

Just as trying to train through an injury or illness is not always desirable, not being willing to alter training or competition schedules can be counterproductive. Situations sometimes dictate a change in plans. A typical example is when an important planned training session with a specific time goal coincides with adverse environmental conditions that negate any chance of meeting the hoped-for time. Two ways to deal with this situation are to change the workout completely or to move the same workout to another day in the same week when conditions may be more conducive to success. A third possibility would be to go on with the planned workout but to go by feel rather than time for the various stages of the session.

Lacking Confidence in the Training Plan

An athlete will usually achieve better results by following a less-than-ideal training scheme presented by a person in whom the athlete has complete confidence than he or she would by adhering to a sound plan set up by a coach in which the athlete has less confidence. Clearly, the ideal situation is having confidence in someone who is presenting a good program. It is always beneficial to commit to a program, but if results are not reasonable for the effort put forth, the athlete may want to try a different approach.

Underestimating Aerobic Fitness and Endurance

It is not uncommon for an endurance athlete who has lost a couple of races during the final "sprint" to the tape to feel that he or she must do more speed training. Spending more time on speed (anaerobic) training may actually detract from aerobic fitness, which can cause the athlete to be so far behind the leaders that he or she receives no benefit from a kick to the finish. Often, a better explanation for losing races in the final minute is not being aerobically fit enough to run away from an opponent during the middle part of a race. A strong finishing kick is accomplished by athletes who arrive at that part of a race with high energy reserves, not necessarily superior all-out speed.

MEASURING AEROBIC CAPACITY

An athlete's aerobic capacity, or $\dot{V}O_{2\max}$, can be measured by a "max" test. During a max test the subject should be constantly monitored to evaluate the stress being imposed so that the test can be terminated if necessary. Tests of less-fit individuals should include monitoring of the subject's heart rate, blood pressure, and ventilatory responses. The electrical activity of the heart may also be monitored with an electrocardiograph. The tester should ask the subject periodically how he or she is feeling and whether it is possible to go on another minute or half minute before the test ends. With fit individuals (those involved in regular, strenuous training and competitions), it is good to monitor these variables, but in field tests it may be possible only to ask the subject to express his or her feelings. An important consideration is that with most trained endurance athletes the individual will reach $\dot{V}O_{2\max}$ before he or she feels that the test must be terminated. Thus it is best to be able to monitor the rate of carbon dioxide produced ($\dot{V}CO_2$) as well as the rate of oxygen uptake ($\dot{V}O_2$) throughout the test. The ratio of these two respiratory values provides a good measure of how hard the subject is working and when it is appropriate to stop the test.

Regardless of the extent to which a max test is being monitored, the subject should first perform a normal warm-up (as if getting ready to compete in a race) and then be fitted with any equipment necessary for the test itself. If the test is being conducted on a treadmill and the person is unfamiliar with treadmill running, let the subject perform at least some of the warm-up on the treadmill.

If resting values are to be recorded before the test gets under way, it is best to take them while the subject is sitting and has recovered from any warm-up rou-

tine. The tester should make sure the subject understands how the test will be conducted and when it will be terminated. Then the actual test can begin. With runners, I prefer the following protocol.

1. Start the treadmill at the speed of the individual's 10,000-meter race pace (if only a 5,000 time is known, use a pace just a little slower than 5,000-meter race pace, which is 30 to 40 seconds per mile slower than current one-mile race pace).
2. The individual runs at this speed throughout the entire test but on a level (0 percent) grade for only the first two minutes.
3. Each minute after the second minute has been completed, the treadmill will be elevated 1 percent. The speed stays the same.
4. Any physiological variables that are being monitored should be recorded during the final 15 seconds of each minute.
5. About 10 seconds before the end of *each* minute, the tester asks the subject if he or she can go on for another minute. If the answer is yes (indicated by a thumbs-up sign), then the current treadmill grade is increased by 1 percent and the test continues. If the answer is no (indicated by a back-and-forth horizontal waving of the hand), then the tester may ask the subject if a half minute more is possible. Based on the response, the test is either terminated or continued for a final half minute.
6. If recovery data are to be collected, the subject should be seated (on a chair on the treadmill), with the feet elevated or the legs moving somewhat to stimulate circulation. Final blood collection for determination of maximum lactate accumulation should be made about two to three minutes after the test ends.

If a running max test is being conducted *over ground* on a running track or road (to simulate race conditions more closely), then the following protocol is used.

1. For the first 400 meters of the test, the subject runs at about 10,000-meter race pace or a little slower.
2. After completing 400 meters of running, the subject increases the pace to one that is equal to his or her most current 5,000-meter race pace.
3. The subject holds the 5K race pace for three more 400-meter laps of a track (or equivalent distance on a road) with 30-second expired-air collections beginning with the third of these three laps.
4. Upon completion of lap four (1,600 meters of running), the subject increases the pace to one that is as hard as he or she can go for a final 400 meters of running. Expired-air collections (lasting about 30 seconds each) are continually collected during this final all-out run.
5. Heart rates can be monitored and recorded during the final 400 meters of running (or immediately upon termination of the final 400 meters if a heart-rate monitor is not available).
6. If recovery data are to be collected, the subject should sit quietly with the feet elevated or with the legs moving around somewhat to stimulate circulation. Blood samples for maximum lactate determination should be taken about two to three minutes after the test ends.

In over-ground running tests, the test administrators must be driven alongside the subject throughout the test to make the expired-air collections. Figure 10.10 shows an over-ground running test being administered.

MEASURING ENDURANCE AND ECONOMY

A good test for endurance is one that measures blood-lactate accumulation upon termination of a series of increasingly faster submaximal runs. Economy is often measured during a similar series of submax runs, but it can also be evaluated using just one or two submaximal efforts.

Blood samples and expired-air samples can both be collected during the same series of runs. Following a normal warm-up, use the following protocol, which is practical for either a treadmill test or an over-ground test. Hook up the subject for collecting expired air samples and for monitoring heart rates.



Figure 10.10 Test administrators collect data during an over-ground running test.

1. From the following chart of running velocities (in meters per minute) and corresponding mile paces, pick the *fastest* velocity that is *slower* than the current 5,000-meter race pace.

190	210	230	250	270	290	310	330	350	370
8:28	7:40	7:00	6:26	5:58	5:33	5:11	4:53	4:36	4:21

2. Count back three or four paces, depending on whether a four- or five-stage test is used, to determine the first (slowest) test speed.
3. The subject runs for five minutes at the first test speed, and an expired-air sample is collected for the final 60 seconds of the five-minute run. Heart rate is also monitored during the final 15 seconds of the run.
4. After the five-minute run, a blood sample is collected during a 60-second break that the subject receives after each run.
5. Heart rate is recorded, expired air is analyzed for determination of $\dot{V}O_2$ and $\dot{V}CO_2$, and the blood sample is used to determine blood-lactate accumulation.
6. A similar five-minute run is performed at each progressively faster test speed (selected from the preceding chart), until the fastest speed identified in step 1 has been completed.
7. $\dot{V}O_2$, blood lactate, and heart rate are determined and recorded for each of the four or five submaximal tests that are completed.

Plotting these data will generate a heart-rate response curve, a blood-lactate profile, and an economy curve.

Using Economy Data

The resulting economy curve can be used to compare running economies among athletes or for the same athlete at different stages or seasons of training. This is accomplished by comparing the $\dot{V}O_2$ values at identical test speeds. In addition, by extending the economy curve out to the individual's $\dot{V}O_{2\max}$, a value for $v\dot{V}O_{2\max}$ can be determined. Figure 10.11, on page 212, illustrates.

A single value for running economy can be calculated by converting the $\dot{V}O_2$ at any measured velocity to a standard value that represents the "cost" of running one kilometer. For example, a $\dot{V}O_2$ of 50 milliliters per kilogram when running at a velocity of 250 meters per minute would result in one kilometer of running costing 200 milliliters per kilogram per kilometer ($1,000 \div 250 \times 50 = 200$). Similarly, running at 300 meters per minute with a $\dot{V}O_2$ of 60 milliliters per kilogram would also cost 200 milliliters per kilogram per kilometer ($1,000 \div 300 \times 60 = 200$). This method of expressing running economy has the advantage of comparing an individual's economy over a variety of velocities.

Using Blood-Lactate Data

The blood-lactate profile can be used as a measure of endurance. A simple way to accomplish this is to connect the lactate data points and determine the $\dot{V}O_2$ and running velocity that correspond to a standard lactate value. This is done in figure 10.11, using a blood-lactate value of 4.0 millimoles per liter ($\text{mmol} \cdot \text{L}^{-1}$) of blood. The corresponding $\dot{V}O_2$ and running velocities can then be expressed as a percentage of $\dot{V}O_2$ and $v\dot{V}O_{2\max}$, respectively. The values for percentage of

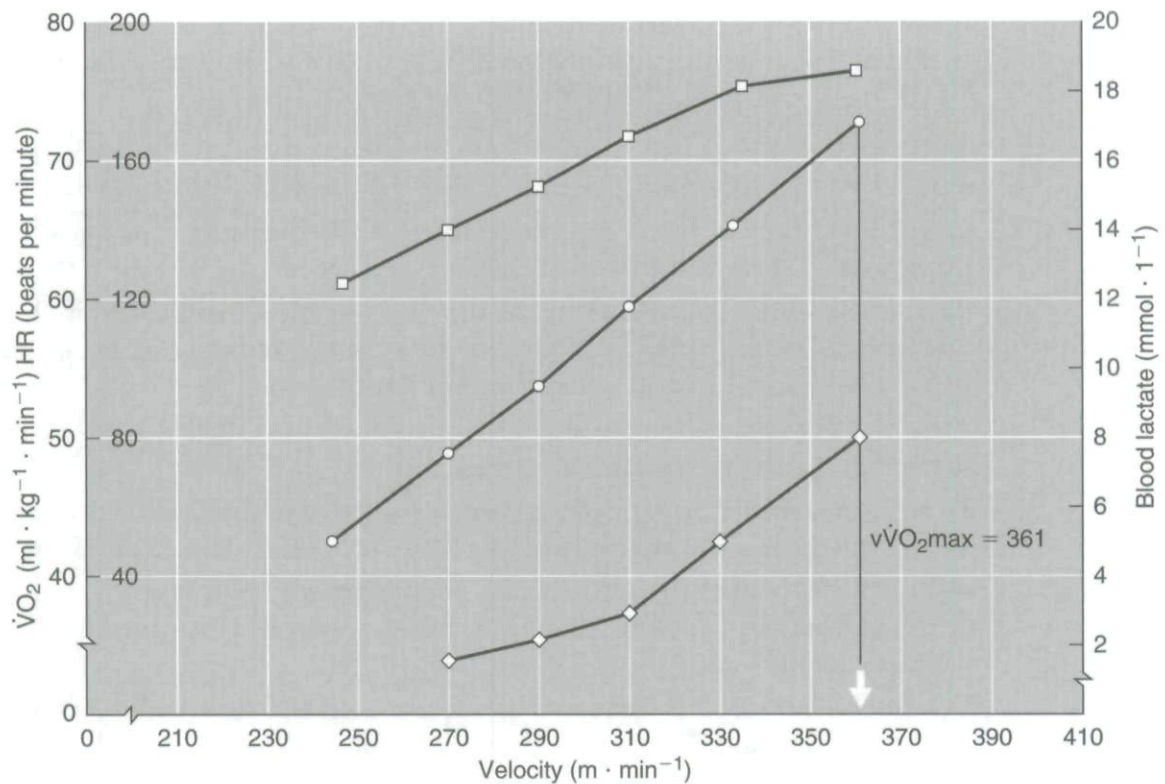


Figure 10.11 A comparison of the oxygen consumption ($\dot{V}O_2$ —circles), heart rate (HR—squares), and blood-lactate level (Bla—triangles) of an elite runner.
From Daniels 1998, page 50.

$\dot{V}O_{2\max}$ and $v\dot{V}O_{2\max}$ are 85 and 89 in figure 10.11, which are typical values for a trained distance runner.

Heart-Rate Data

The heart-rate data collected during the submaximal and maximal tests can be compared with data from subsequent test sessions. In addition, a percentage of max heart rate can be determined that corresponds to the blood-lactate value of 4.0 millimoles per liter (about 90 percent in figure 10.11).

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