THE RIGHT STUFF:
THE PHYSIOLOGY OF SPEED
AND ENDURANCE

What’s inside the bodies of runners who are able to run fast and far? How much of what they have comes from training, and what’s the best way to train to develop whatever it is they have? Exercise physiologists (scientists who study what makes our bodies move) are working hard to answer these questions in laboratories around the world. In recent years, they have learned quite a lot about the physiology of speed and endurance, and they learn more almost every day. Yet the athlete’s body remains very much an open frontier in science. We won’t have a complete picture for some time yet. Nevertheless, what we do know has great practical value for all runners.

You don’t need to be an expert in exercise physiology to run fast, but you’ll surely run faster if your training program is shaped by the most recent sports science—and if you continually keep up to date. Elite runners are usually fortunate enough to have coaches with expertise in exercise physiology who tailor their training based on the newest thinking in athletic performance. On the other hand, self-coached runners—like the rest of us—are required to make our own training decisions. To make good decisions, we need to understand the basic physiological ob-
jectives of training and the cause-effect relationships between the various types of training and these objectives.

There are two general types of exercise physiology research that you can use to improve your training. Some studies shed new light on the physiological characteristics—such as muscle fiber types and oxygen-carrying capacity—that contribute to running performance and that we should enhance in our training. Other studies give us a measurable view of how a specific training method or pattern affects one or more of these characteristics. Together, these two types of research can help you decide the proper format for your workouts and the best way to incorporate them into a training program.

If you're wondering how all this can help you run faster, consider the following practical example of exercise physiology. Studies of runners dating back to the 1960s established that faster distance runners tend to have a high aerobic capacity, or VO₂max, and superior energy economy. Aerobic capacity is the maximum rate (adjusted for weight) at which a runner can use oxygen during running. Economy is the amount of energy a runner uses while running (the less the better, of course). When you put the two together, you get one of the best predictors of running performance: namely, velocity at VO₂max—or vVO₂max. This is the slowest sustained running pace at which a runner reaches 100 percent VO₂max. For example, suppose that during a standard exercise test, it is discovered that your VO₂max is 55 liters per minute per kilogram of body weight. If this rate of oxygen consumption is first achieved at a running velocity of 10 miles per hour (mph) and shows no increase at higher running speeds, then your vVO₂max is 10 mph.

An improvement in either your VO₂max or your running economy will increase your vVO₂max (as well as the amount of time you can sustain this pace), and this in turn will improve your running performance in races. So what’s the best workout to increase your vVO₂max?

This is the question that Veronique Billat, Ph.D., an exercise physiologist at the University of Paris-Evry in France, set out to answer several
years ago. Specifically, she challenged herself to create workout formats that would allow runners to spend the greatest total amount of time at VO₂max and would therefore presumably produce the most powerful boosting effect on VO₂max and economy.

Billat deduced that runners seeking to maximize workout time spent at VO₂max should run at exactly vVO₂max and no faster because they would fatigue more quickly at faster speeds. (Remember, vVO₂max represents the slowest running pace at which VO₂max is reached.) Her next move was most clever. Billat knew that a runner’s rate of oxygen consumption remains at or near 100 percent VO₂max for as long as 15 to 20 seconds after he or she stops running at vVO₂max, or slows down from this pace. She realized that a well-designed workout could exploit this lag phenomenon to allow runners to further increase time spent at VO₂max.

The best way to do this would be to alternate short intervals run at vVO₂max with short “floats” (jogging recoveries) at perhaps half of vVO₂max. Keeping the hard intervals short would delay fatigue by preventing neuromotor fatigue (exhaustion that results when electrical nerve signals no longer reach muscle cells easily) from getting out of hand. (More on that below.) Keeping the floats short would prevent oxygen consumption from falling very far before hard work resumed.

The workout format she settled on was highly unorthodox, consisting of 30-second bursts at vVO₂max separated by 30-second floats and repeated to failure (that is, until vVO₂max can no longer be sustained for 30 seconds). In testing this format, Billat found that some runners were able to amass more than 18 total minutes at VO₂max, almost a third of it occurring during their jogging recoveries! A group of moderately fit runners increased their VO₂max by 10 percent (that’s huge) in just 8 to 10 weeks when they added twice weekly 30-30 sessions to their training. Influential running coaches and writers who pay attention to the sports science journals have since begun to promote Billat’s 30-30 workout, and before long, it may become a standard-issue weapon in the competitive runner’s training arsenal.
Again, you don’t need to read the sports science journals yourself in order to take advantage of cutting-edge training methods such as Billat’s 30-30 workout. But understanding their basic physiological underpinnings might allow you to incorporate these methods into your training more effectively, because you get the best fitness results by customizing the generally prescribed training methods to your own particular needs.

According to the latest science, there are roughly eight characteristics (the precise number depends on exactly how you choose to parse them) that make up distance-running ability. In the remainder of this chapter, I will describe them and explain which types of training have proved most effective in developing each.

CHARACTERISTIC #1: IMPACT-PROOF LEGS

Perhaps the most important early adaptation to running is an improvement in the capacity of the bones, muscles, and tendons in your legs to absorb ground impact forces without breaking down. When subjected to regular foot-to-pavement pounding, the bones of the lower extremities restructure themselves to become stronger and denser. This remodeling process is essentially a healing response to impact trauma, which works out for the best as long as you always increase running volume gradually and allow adequate recovery time. If you subject your bones to too much stress too soon, damage will outpace remodeling and a bone strain will result. Strains in the tibia (the larger of the two shin bones) are the most common injury in beginning runners. A severe bone strain can develop into a stress fracture.

Muscles and tendons adapt to impact forces in a similar injury-response fashion. The muscles, especially your calves and quadriceps, help your body absorb impact forces by contracting eccentrically—that is, by resisting their own lengthening. Eccentric contractions pull muscles in two directions simultaneously, often rupturing and damaging muscle fibers. But the damaged tissue responds by remodeling itself in such a way as to become more resistant to future eccentric rupturing.
Key tendons of the lower extremities absorb impact by stretching and recoiling. They, too, adapt to this repetitive strain with a remodeling process that increases their density, stiffness, and tensile strength (how far they can stretch without tearing).

Like the bones, the muscles and tendons are especially vulnerable to injury during the early stages of a new running program as tissue remodeling struggles to keep up with the tissue damage that stimulates it. And these same impact forces also contribute to muscle fatigue. Conventional wisdom holds that “hitting the wall” in a marathon or long training run is caused by depletion of stored energy—specifically glycogen. A more important cause of declining performance in long runs is impairment of the muscles’ capacity for elastic recoil due to the effects of repetitive impact forces. The damage that accumulates in the muscle fibers reduces their stretching capacity and ability to contract. Then, to top it off, nerves send information about this damage to the brain, which responds by essentially shutting the muscles down to protect them from further damage. The net effect is that the physical cost of maintaining your desired speed increases dramatically. Your legs become increasingly sore, which reduces your desire to continue running at the current pace.

The same muscle and tendon adaptations that allow runners to run farther and more often without getting injured also increase resistance to this type of neuromuscular fatigue. The best way to train for impact tolerance is to begin with a small volume of running and increase it gradually, reducing volume every third or fourth week to give your legs a chance to recover, or “catch up.”

**CHARACTERISTIC #2: A BIG, STRONG HEART**

As I explained above, one of the major factors that affects running performance is your aerobic capacity, or VO$_2$max. This is your maximum capacity to consume oxygen (relative to your body mass) while running. Why is this so important? Because your muscle fibers need oxygen to
release the energy that allows them to contract repeatedly at the moderate work intensities associated with distance running.

There are two components of aerobic capacity: the delivery of oxygen to the muscles, and how oxygen is metabolized within the muscles. Because oxygen is transported in the blood, there is a close relationship between your maximum rate of blood circulation and your VO2max. A strong heart is the cornerstone of good circulation—better runners tend to have larger, more powerful, and more efficient hearts than do lesser runners. Training increases the size, power, and efficiency of the heart muscle.

Oxygen consumption begins, of course, with the lungs, which draw oxygen from the air you breathe. (Interestingly, the lungs themselves do not adapt to training.) Much of the oxygen drawn into the lungs is trapped by capillaries and absorbed through them into the bloodstream. Hemoglobin proteins attached to red blood cells transport oxygen molecules to every cell throughout the body, where oxygen is used to break down fats, carbohydrates, and to a much lesser extent, amino acids (the building blocks of proteins) to release energy. The heart's role in this process is to keep the blood (and the oxygen within it) flowing throughout the body. When you're running, your body needs more oxygen to keep it moving, so the rate and force of the heart's muscle contractions must increase so that bloodflow and oxygen delivery to the working muscles can also increase. When you sustain very high running speeds long enough, your heart will reach its maximum pumping capacity, which, again, is determined by its size, strength, and efficiency. It's perhaps also determined by a protective mechanism that is regulated by the brain and may just prevent us from exercising to death (as inadequate oxygen flow to the heart itself would cause a heart attack).

The major adaptation of the heart to training is an increase in its size; in fact, it becomes more powerful and more efficient primarily by growing. The heart's maximum pumping capacity is a function of the amount of blood it pumps per contraction (stroke volume) and its maximum rate of contraction. Training does not increase maximum heart
rate, but it does increase stroke volume. As the size of the heart increases, its blood storage capacity increases, allowing the heart to pump more blood per contraction. The maximum stroke volume of an average sedentary adult is 70 to 80 milliliters per contraction, while in elite endurance athletes, it can be as high as 160 to 170 milliliters per contraction. This adaptation allows the heart to perform any given amount of work at a lower heart rate. Consequently, trained runners can achieve a faster running speed before reaching their maximum heart rate (which remains unchanged) and maximum rate of bloodflow (which is now greater). A larger heart can also contract with greater force than a smaller one, which further reduces the rate of contraction needed to sustain any given work rate.

Heart growth happens relatively slowly and is believed to continue for years in runners who train consistently. However, there is a related training adaptation that happens much more quickly. Within days of the onset of training, blood plasma volume begins to increase (plasma is the fluid component of the blood). This change allows for greater blood pressure in the pumping chamber (left ventricle) of the heart, resulting in greater stroke volume. Ultimately, training can increase blood plasma volume by nearly 10 percent. There is also evidence that the blood vessels of trained runners have a greater dilating capacity, which allows for higher rates of bloodflow as well.

All types of training provide circulatory benefits. However, research shows that high-intensity intervals performed at or near 100 percent VO$_2$max are the most effective way to increase cardiovascular adaptations, and to increase VO$_2$max itself. Runners can achieve substantial gains in the pumping capacity of their hearts with as little as 8 weeks of training, especially if it features vVO$_2$max intervals. But structural changes in the heart cannot happen fast enough to account for such rapid improvement. So what’s behind these fitness gains? It appears that...
neurological factors account for much of this early improvement. The brain actively limits the work rate of the muscles in order to protect the heart from oxygen deprivation. When you make it through your first bouts of hard training unharmed, the brain learns to relax a bit and allows the heart to work harder, so that the skeletal muscles can work harder too.

That’s the first half of the VO₂ max equation. The other half is the capacity of the muscles to draw oxygen from the blood and use it to break down fuel molecules and release energy. The muscles of faster distance runners have a very large capacity to use the oxygen that is delivered to them, and training can greatly increase this capacity.

As mentioned above, oxygen is transported to the muscles by hemoglobin molecules in the blood and passes into individual muscle cells through tiny blood vessels called capillaries. Myoglobin proteins located inside the muscle cell bind to oxygen molecules and store them until they are needed. Mitochondria, also located within the muscle cell, serve as the site of aerobic metabolism. In the mitochondria, oxygen and special enzymes break down carbohydrates (individual glucose molecules and long chains of glucose molecules called glycogen), fats (triglycerides), and some amino acids to produce molecules of adenosine triphosphate (ATP), which is the fundamental energy currency of the muscles. It is the splitting of ATP that ultimately fuels every muscle fiber contraction. Fats and carbohydrates are broken down not to provide energy directly but to replenish ATP, which the muscle cell stores in very small amounts (enough to fuel a few seconds of high-intensity work). The breakdown of one glucose molecule, for example, which requires two long series of reactions, yields 38 ATP molecules. This process takes only a fraction of a second.

Training increases the density of capillaries in the muscles, their myoglobin concentration, the number of mitochondria within the muscle cells, and the concentration of mitochondrial enzymes. In addition, it increases the number of glucose and fatty acid transporters in the muscle.
cell membranes, which in turn increases the efficiency with which the muscle cells can draw carbohydrate and fat fuel from the blood. These adaptations, which happen to the greatest degree in slow-twitch muscle fibers (one of two general classes of muscle fibers, which I'll describe below), add up to significant increases in oxygen consumption capacity. This allows the muscles to produce work aerobically at high rates.

Muscle cells are also able to break down glucose outside the mitochondria and without the help of oxygen, through a process known as anaerobic glycolysis. This process produces ATP less efficiently—only two or three ATP molecules per glucose molecule—yet much faster than aerobic metabolism. Therefore, as the intensity of work increases, the muscle cells depend more and more on anaerobic metabolism. For example, at a comfortable jog, more than 99 percent of your muscle energy is produced aerobically. During a 90-second sprint, aerobic and anaerobic pathways contribute energy about equally. And during a 10-second sprint, about 95 percent of your muscle energy comes from anaerobic metabolism.

The larger your aerobic capacity is, the less you have to rely on anaerobic metabolism at higher running speeds. Or, put another way, the larger your aerobic capacity is, the faster you can run before you begin to rely heavily on anaerobically produced energy. This is beneficial because the fast-twitch muscle fibers that specialize in anaerobic energy production fatigue much faster than the slow-twitch fibers that specialize in aerobic energy production. While runners with a lot of fast-twitch muscle fibers can often produce more total energy for running, and therefore sprint faster, runners with a lot of well-developed slow-twitch muscle fibers can maintain a relatively high running speed for a much longer duration.

How should you train to maximize the aerobic energy capacity of the muscles? Research tells us that the overall volume of training has the greatest influence on these adaptations. Since moderate aerobic-intensity running is conducive to high training volume, this type of running is
probably most beneficial as a foundation for aerobic development. However, highly trained runners need to mix in some high-intensity running in order to stimulate further adaptations. Workouts performed at or near anaerobic threshold pace (explained below) seem to offer the greatest “bang for the buck” in terms of stimulating adaptations that increase this threshold.

**CHARACTERISTIC #3: MAGNETIC MUSCLES**

Until recently, scientists believed that fatigue during high-intensity exercise was related to lactic acid buildup. The theory went like this: In anaerobic glycolysis, described in the previous section, one of the intermediates of glucose metabolism, pyruvate, is produced faster than it can be used by the mitochondria to make ATP. Unused pyruvate quickly breaks apart into lactic acid and hydrogen ions, which accumulate in the muscle cells and “leak” into the bloodstream. The buildup of lactic acid and hydrogen ions in the muscle cells causes them to become more acidic and interferes with further energy production. It also stimulates nerve endings, causing the “lactic acid burn” sensation familiar to every competitive runner. The end result (said the theory) is plummeting performance—it becomes harder and harder, and eventually impossible, to sustain the desired running pace.

The latest research suggests that lactic acid buildup (known as acidosis) is a relatively weak contributor to muscle fatigue at high intensities. It now seems that a much stronger cause is a type of neuromotor fatigue, specifically, depolarization of the muscle cells resulting from a shift in calcium-potassium balance.

Here’s the new theory: Muscle contractions are stimulated by electrical currents that flow throughout the body via minerals including sodium and potassium. Each muscle cell contraction involves a lightning-fast exchange in which potassium molecules inside the muscle cell and sodium molecules outside the muscle cell switch places. These exchanges are most efficient when there is a high degree of polarization (a
difference in the strength of the electrical charge) between the spaces inside and outside the cells. At the beginning of high-intensity exercise, the inside of the muscle cell has a much stronger positive charge than the area outside the muscle cell. This difference in charge strength makes it easy for sodium and potassium to cross the cell membrane. During sustained high-intensity activity, potassium is released from the muscle cells faster than it can be taken up outside the muscle cells. The resulting buildup of potassium outside the muscle cells causes a progressive lessening of the difference in charge strength between the intracellular and intercellular spaces, hence weaker and less efficient muscle contractions (i.e., fatigue).

Picture the nerve signals that cause muscle contractions as little marbles rolling down a sand hill. Each grain of sand is a potassium molecule. The top of the hill is the inside of the muscle cell, and the bottom of the hill is the outside of the muscle cell. Each time a marble (nerve signal) rolls down the hill, a small avalanche of sand (potassium molecules) follows it. Consequently, as marble after marble rolls down the hill, the hill becomes less and less steep as sand shifts from the top to the bottom. So the marbles roll down slower and slower until eventually they don’t roll at all. That’s neuromotor fatigue.

Training leads to several adaptations that enhance a runner’s resistance to muscle cell depolarization. One of them is an increase in slow-twitch muscle fiber characteristics. Fast-twitch muscle fibers are more susceptible to depolarization. Training also increases potassium storage within muscle cells and the density and efficiency of the so-called calcium-potassium pumps that are responsible for those lightning-fast calcium-potassium exchanges.

An interesting wrinkle is that muscle cell depolarization almost always occurs at the same time as muscular acidosis (lactic acid buildup) even though the mechanisms are distinct. This is what led scientists to believe for so long that acidosis was a major cause of fatigue. One of the strongest predictors of distance running performance is the ability to
keep blood lactate levels low at higher running speeds (a phenomenon referred to as a high lactate threshold, or a high anaerobic threshold). One study found that a high anaerobic threshold speed explained 87 percent of the variability in 3,000-meter running performance in a group of high-level runners. However, it is now understood that this is mostly a coincidence. It’s not the low lactic acid levels themselves but the corresponding low levels of intercellular potassium buildup that matter. Nevertheless, since it’s not possible to measure potassium buildup in humans during exercise, and since lactic acid buildup and potassium buildup correspond so closely, blood lactate measurements will probably continue to be used to assess aerobic strength and performance potential.

**CHARACTERISTIC #4: RAW SPEED**

The importance of raw speed to distance running performance is often underestimated. In fact, studies have shown that maximum sprint speed is a strong predictor of performance in distance running events. In other words, the fastest runners over long distances are typically also faster than other distance runners in short sprints. Clearly then, certain physiological characteristics that underlie raw speed are not incompatible with the fatigue resistance characteristics that are also critically important to distance runners.

But the very best sprinters tend to have rather poor fatigue resistance, so it’s also clear that some other speed characteristics are incompatible with endurance.

Research has demonstrated that sprint speed comes not so much from the ability to move one’s legs quickly but from the ability to push off the ground with tremendous force: that is, to produce great power. This ability, in turn, derives mainly from certain properties of muscle fibers.

The most celebrated physiological difference between sprinters and distance runners is in muscle fiber types. The muscles of top sprinters are
known to contain a very high number of type II, or fast-twitch, muscle fibers. These have greater contraction speed (or “contractility”), elasticity, and anaerobic energy capacity than type I, or slow-twitch, muscle fibers, which have greater aerobic energy capacity and fatigue resistance.

Recent findings have given us a more nuanced understanding of muscle fibers and their relation to sprint and distance running performance. We now know that the characteristics of the two basic muscle fiber types can vary by degrees. For example, there are type I muscle fibers that are able to contract as quickly as some type II muscle fibers; it is likely that talented distance runners have a lot of these “fast slow-twitch fibers.” Also, at least five subtypes of type II fibers are now recognized. For example, type IIa fibers are the “classic” fast-twitch fibers: very powerful but not very fatigue-resistant. Type IIb fibers are another borderline fiber type that possesses both fast-twitch and slow-twitch characteristics, and top distance runners tend to have a lot of these as well. Type IIc fibers can adapt to training to serve as either fast-twitch or slow-twitch fibers, and better distance runners tend to have plenty of these too. So it appears that fast distance runners have a nice blend of muscle fiber types that support raw sprint speed and fatigue resistance.

There is also evidence that muscle fibers of the same type can have different degrees of contractility. Faster distance runners tend to be extremely powerful for their size. Since the muscles of these runners are small and contain many slow-twitch fibers, we can infer that what muscle they do have is highly contractile for its type.

Besides a very high number of fast-twitch muscle fibers, another characteristic that supports sprint speed but not sustained speed is muscle size. Large muscles can produce more force, hence greater speed, than smaller ones, but they consume a lot of energy, so they quickly change from an advantage to a hindrance with increasing race distance. This becomes very clear when you look at the musculature of runners competing in the various race distances from 100 meters to 10,000 meters in a track meet.
Should distance runners train to increase their maximum sprint speed? The answer is no. While it is highly beneficial for a distance runner to have loads of natural sprint speed, training should focus on increasing the fraction of maximum speed that can be maintained over race distances. The types of training that most effectively produce this result also tend to slightly decrease maximum sprint speed (mainly by enhancing the slow-twitch properties and diminishing the fast-twitch properties of adaptable muscle fibers). A small amount of sprint and power (plyometrics) training is appropriate to develop the raw speed aspect of sustained speed capacity. Runners who lack natural speed and power may benefit from doing a bit more speed and power training than other runners. Natural sprinters training for distance running should avoid this type of training.

**CHARACTERISTIC #5: A BIG "FUEL TANK"**

Carbohydrate stored in the muscles and liver as glycogen is the principal fuel for race-pace running for most runners at most distances. Because carbohydrate fuel stores in the body are relatively small, depletion of these stores and the resulting fatigue is an important limiter in longer races (and,
for that matter, in some long workouts). Training can greatly increase the amount of glycogen stored in the muscles and thereby substantially increase endurance. The graph on page 14 shows the effect of training on glycogen storage as compared to its effect on three other physiological characteristics important to running. The leg muscles of an elite marathon runner might contain three times as much glycogen as those of a sedentary person of the same weight. Training can also slow the rate at which muscles use carbohydrate at any given running pace by increasing running economy (i.e., lowering the overall energy cost of running) and by increasing the body’s capacity to utilize other fuels (fat, amino acids, and lactate).

Training also enhances a runner’s ability to create glucose from lactate and amino acids during running. First, training increases the activity of lactate transporters. These bind to lactate molecules and hydrogen ions inside the muscle cell and carry them across the cell membrane into the bloodstream, through which lactate travels to other tissues of the body where it is stored or converted. For example, the liver can convert lactate back into glucose through a process called gluconeogenesis. Training also enhances the liver’s capacity to absorb lactate from the bloodstream and convert it to glucose. In addition, training boosts the body’s ability to deliver additional carbohydrate fuel to the active leg muscles from the less active muscles of the upper body through a mechanism called the lactate shuttle. In this process, glycogen in the less active muscles is converted into lactate and then carried through the bloodstream to the legs, where it can be metabolized further in the mitochondria. Finally, training also leads to adaptations that increase the efficiency with which muscle proteins are broken down into amino acids, transported to the liver, and converted into glucose through gluconeogenesis.

The best training for most of these adaptations is long runs that deplete the muscle glycogen stores. These workouts begin to increase glycogen storage levels in the muscles almost immediately. By the same token, this adaptation will start reversing itself very quickly in the absence of long runs that continually challenge fuel supply. For this reason,
frequent and progressive long runs are essential in training. Long runs also enhance the body’s ability to metabolize fats and amino acids after glycogen stores run low, and they reduce the degradation of running economy that develops with fatigue. Very high intensity intervals are probably the strongest enhancers of lactate shuttling capacity.

Certain nutritional practices are also helpful. Maintaining a diet with adequate carbohydrate intake is an important way to maximize carbohydrate storage. Timing is especially important. Consuming carbohydrate before workouts and races tops off liver glycogen stores and helps to prevent hypoglycemia (low blood glucose). Consuming carbohydrate in a sports drink or gel while running decreases reliance on muscle glycogen stores, thus conserving them. And consuming carbohydrate immediately after running results in more rapid glycogen replenishment than does waiting to consume carbohydrate. Also, tapering—that is, drastically reducing training volume—in the days before a long race greatly increases glycogen stores. I’ll talk about fueling strategies and the relationship between carbohydrate depletion and fatigue in greater detail in chapter 11.

**CHARACTERISTIC #6: AN ENERGY-SAVING STRIDE**

The terms *running biomechanics* and *running technique* are often used interchangeably. Both refer to how a runner runs, but the two are not quite the same. Biomechanics refers specifically to the aspects of a runner’s stride that are determined by individual body structure. Technique refers to aspects of the stride that are (at least somewhat) independent of body structure. For example, perhaps you have tight hamstrings, and as a result you run with short strides. That’s biomechanics. But perhaps you’ve also fallen into the habit of shuffling, and if you worked at it, you could run with slightly longer strides than you do. That’s technique. As you can see by this example, biomechanics and technique are mutually influencing, which is why it’s not impractical to use them interchangeably. I’ll use the term *running form* to refer to the
combination of biomechanics and technique.

Good running form is efficient running form. A certain minimum rate of energy consumption is required for a runner of a certain weight to run at any given speed. A runner with efficient form will consume energy at a rate that is not much above this minimum, while a runner with inefficient form will consume a lot more energy due to wasteful movements. Various studies have provided evidence of the economical value or cost of various biomechanical and technique characteristics. For example, it has been shown that runners who produce higher impact forces (independent of body weight) tend to be less economical.

Effective ways to improve your stride efficiency include conscious control (using body awareness to practice a specific form alteration with every stride until it’s automatic), stretching and resistance training to diminish biomechanical limiters, using orthotics when necessary to reduce the energy waste of poor foot biomechanics, uphill and downhill running, high speed running, and form/power drills. I’ll describe the details of “correct running form” and how to achieve it in chapter 7.

Understand, however, that you can’t change certain physical characteristics that affect efficiency. Characteristics that are likely to positively influence economy include average or slightly smaller than average height for men and slightly greater than average height for women, an ectomorphic physique, tapering thighs (thicker near the hip, narrow near the knee), a narrow pelvis, and smaller than average feet.

It is also believed that the muscles and tendons of some runners are better able to absorb, store, and return ground impact forces than those of other runners. Such springiness in the soft tissues of the lower extremities is especially beneficial in longer races, when muscle damage resulting from repetitive impact becomes a major performance limiter.

Besides efficiency, the other great advantage of good running form is that it reduces the likelihood of injuries by reducing impact forces and dispersing them better. Most running injuries are caused not by impact forces alone but by the combination of impact forces and joint instability.
(specifically in the ankle, knee, and hip). When joints lack adequate stability, running impact forces cause them to collapse or move abnormally with each foot strike, creating damage that steadily accumulates.

Superior joint stability is therefore an important characteristic of good running form. Some runners have it naturally, but all runners can enhance it through strength training and making small but crucial gait modifications. Running itself tends to decrease rather than increase joint stability, so it’s very important that you make these special efforts to counteract this effect.

**CHARACTERISTIC #7: LIGHT WEIGHT**

Did I have to bring up the topic of body weight? Unfortunately, yes. Being light is as beneficial to performance in long-distance running as any other physical characteristic. As body weight increases, so does the energy cost of running at any given speed. Running is a form of weight lifting—and the more weight you carry, the more weight you must lift. In one study, the addition of 1 kilogram of weight was shown to increase the energy cost of running by 3.5 percent. This loss of economy would turn a 40-minute 10-K runner into a 41:28 10-K runner.

How do you train to lose weight? You don’t. If your primary goal is to lose weight, see a weight loss counselor. If your primary goal is to become a better runner, and you happen to be carrying a few extra pounds, you’re best off training and eating for maximum performance. That is, training and eating the same way you would if you were already at an ideal weight. Your weight will take care of itself. Ultimately, quality training is more beneficial than caloric restriction for body composition (i.e., body fat percentage, a truer measure of health and fitness than weight, which is linked to height and body type). In fact, numerous studies have shown that caloric restriction negatively affects training.
Well-fueled muscles are able to work harder—and hard work burns fat and preserves lean muscle. My own sports nutritionist has told me that she improves her clients’ body composition, performance, and overall health more often by increasing their caloric intake (along with the quality of those calories) than by decreasing it.

**CHARACTERISTIC #8: A SOUND MIND**

The sport of running involves a variety of significant mental challenges—including race suffering, fear of performing poorly, and the frustration of injury—that some runners overcome better than others. Mental fitness is a collection of psychological attributes that help runners surmount the mental challenges of training and racing. Over the past several decades, sports psychologists have intensively studied the mind’s influence on sports performance and have found the same set of attributes and strategies occurring time and again in the most successful athletes.

One such study was conducted by Martin Seligman, Ph.D., professor of psychology at the University of Pennsylvania in Philadelphia. Seligman used a questionnaire to categorize individual swimmers on the University of California at Berkeley’s swim team as “optimists” or “pessimists” prior to the competitive season. The swimmers and their coaches then rated each race performance of each swimmer throughout the season as either “better than expected” or “worse than expected.” By the end of the season, the pessimists had twice as many “worse than expected” performances as the optimists.

Besides optimism, other key attributes that sports psychologists have found to characterize mental fitness are confidence, focus, resilience, emotional control, motivation, and discipline. Sports psychologists have also identified a set of powerful mental techniques that are routinely practiced by those who possess a high degree of mental fitness. These techniques include effective goal setting and imaging. The systematic cultivation of mental fitness and practice of proven mental techniques is called mental training. Cutting-edge mental training is the topic of chapter 12.
HIGH-TECH HELP

RACE TIME CALCULATORS

When scientists make a big discovery, they sometimes get caught up in the excitement of it and confer greater significance upon the object of their discovery than it actually deserves. This is what happened when exercise physiologists learned how to measure VO₂max and subsequently discovered that elite endurance athletes always have an exceptionally large aerobic capacity. It wasn’t long before the practice of testing runners and other athletes to determine their VO₂max and therefore their racing potential became widespread.

It has since become apparent that while a large aerobic capacity is a significant factor in running ability, other physiological characteristics (as discussed in this chapter) are also important. All great runners have at least a relatively high VO₂max, but not all runners with a high VO₂max are great. Two runners with the same VO₂max seldom run the same times in races, and two runners who run the same times in races seldom have the same VO₂max.

Because so many physiological characteristics underlie running ability, no single one of them is an exact predictor of race times. The best predictor of a runner’s finishing time at any given race distance is actually his or her race time at another distance. It is widely documented that runners who run the same time at any distance over a mile tend to run more or less the same time at every distance straight up through the marathon.

In the 1960s, statisticians, sports scientists, and running coaches began to gather data on runners’ best times at standard race distances, analyzed it, and found clear, consistent mathematical relationships among average paces maintained over the various distances. Finally, they created formulas that runners could use to obtain a finish time prediction for a particular race distance based on a recent result at another race distance. Digital technology has allowed programmers to create simple calculators that make this process even easier. These calculators are very handy for establishing goal times and also for quantifying your
potential for improvement. For example, one of the athletes I coach recently set a 10-K personal record of 33:55. According to a formula developed by renowned running coach and exercise physiologist Jack Daniels, Ph.D., who has worked with elite runners such as Alberto Salazar and Joan Benoit Samuelson, this is the equivalent of a 16:20 5-K. Since this athlete has already run a 16:01 5-K, I have reason to believe that he can further improve his 10-K time.

While fun and practical, race time calculators are not perfect. If they were perfect, they would all produce the same results, and they do not. Therefore if you choose to use them, you should use more than one of them to produce predicted time ranges instead of specific predicted times. It’s also important to note that all of the calculators assume appropriate training for each distance. According to one calculator, if you’ve run a recent 5-K in 21:02, you can expect to run a marathon in 3:21:00. But it’s very unlikely that you’ll run the predicted marathon time on the same training you did for the 5-K.

Here are some Web sites with race time prediction calculators.

>> www.marathonguide.com
>> www.runnersweb.com
>> www.runnersworld.com
>> www.runningtimes.com

**KEY POINTS**

>> It’s best to train in ways that take advantage of the latest science.
>> Developing impact-resistant bones and soft tissues is the first priority of training.
>> A strong aerobic system is the most important performance characteristic in runners.
>> While sprinting ability is beneficial to distance runners, there’s no need to train to increase your top-end speed.
>> Your brain is as crucial as your lungs and muscles to running performance and should not be neglected in your training approach.