Introduced in 2001, the Segway revolutionized personal transport. Through a complex interaction of gyroscopes, electronics, and human control, the unusual upright contraption remains an eye-catcher a decade later. It allows vigilant security guards to zip about shopping malls or college campuses and tour groups to dash through parks and urban landscapes with barely any exertion.

Technology is a means of simplifying tasks. Even animals use “tools” of one sort or another to minimize the expenditure of energy: Chimpanzees poke sticks into anthills to gather a meal rather than exhaustively dig into the hill; sea otters break open shellfish with rocks. As human technology has produced more and more labor-saving devices, physical exertion has decreased for larger and larger segments of the population. Concurrently—
particularly in the developed world—the amount of food consumed per capita has increased.

As the Segway and other technological innovations continue to ease the daily physical challenges and exertions we face, we have to pay a lot more attention to what we eat and to how much activity we need to remain healthy. If we do not, and simply let machines do the work, we may no longer be able to move without them.

CHAPTER OUTLINE

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- Exercise and Weight Management

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CHAPTER PLANNER

- Stimulate your interest by reading the introduction and looking at the visual.
- Scan the Learning Objectives in each section:
- Read the text and study all figures and visuals. Answer any questions.

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End of chapter
- Review the Summary, Online Resources, and Key Terms.
- Answer the Critical and Creative Thinking Questions.
- Answer What is happening in this picture?
- Complete the Self-Test and check your answers.
Physical Activity, Fitness, and Health

LEARNING OBJECTIVES
1. Describe the characteristics of a fit individual.
2. Explain what is meant by the overload principle.
3. Evaluate the impact of exercise on health.
4. Discuss the role of exercise in weight management.

Exercise improves your fitness and overall health. This is true whether your fitness goal is to be able to walk around the block easily or to perform optimally in athletic competitions. Exercise, along with an adequate diet, is important in maintaining health and reducing the risk of chronic diseases such as cardiovascular disease and obesity.

When you exercise, changes occur in your body: You breathe harder, your heart beats faster, and your muscles stretch and strain. If you exercise regularly, you adapt to the exercise you perform and as a result can continue for a few minutes longer, lift a heavier weight, or stretch a millimeter farther. This is known as the overload principle: The more you do, the more you are capable of doing. For example, if you run a given distance three times a week, in a few weeks you can run farther; if you lift heavy books for a few days, by the next week you have more muscle and can lift more books more easily. These adaptations improve your overall fitness.

The Four Components of Fitness
A person’s fitness is defined by his or her endurance, strength, flexibility, and body composition (Figure 10.1). A fit person can continue an activity for a longer period than an unfit person can before fatigue forces him or her to stop, but fitness is more than just stamina. Being fit also reduces the risk of chronic disease and makes weight management easier.

Cardiorespiratory endurance How long you can jog or ride your bike depends on the ability of your cardiovascular...
and respiratory systems, referred to jointly as the cardiorespiratory system, to deliver oxygen and nutrients to your tissues and remove wastes. **Cardiorespiratory endurance** is enhanced by regular aerobic exercise (Figure 10.1a).

Regular aerobic exercise strengthens the heart muscle and increases the amount of blood pumped with each heartbeat. This in turn decreases **resting heart rate**, the rate at which the heart beats when the body is at rest to supply blood to the tissues. The more fit you are, the lower your resting heart rate and the more blood your heart can pump to your muscles during exercise. In addition to increasing the amount of oxygen-rich blood that is pumped to your muscles, regular aerobic exercise increases the ability of your muscles to use oxygen to produce ATP. Your body’s maximum ability to generate ATP using aerobic metabolism is called your **aerobic capacity**, or VO₂ max. Aerobic capacity is a function of the ability of the cardiorespiratory system to deliver oxygen to the cells and the ability of the cells to use oxygen to produce ATP. The greater your aerobic capacity, the more intense activity you can perform before lack of oxygen affects your performance.

**Muscle strength and endurance** Greater **muscle strength** enhances the ability to perform tasks such as pushing or lifting. In daily life, this could mean lifting a gallon of milk off the top shelf of the refrigerator with one hand, carrying a full trash can out to the curb, or moving a couch into your new apartment. Greater **muscle endurance** enhances your ability to continue repetitive muscle activity, such as shoveling snow or raking leaves. Muscle strength and endurance are increased by repeatedly using muscles in activities that require moving against a resisting force. This type of exercise is called **muscle-strengthening exercise**, strength-training exercise, or resistance-training exercise and includes activities such as weight lifting and calisthenics (Figure 10.1b).

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**Cardiorespiratory endurance** The efficiency with which the body delivers to cells the oxygen and nutrients needed for muscular activity and transports waste products from cells.

**Aerobic exercise** Endurance exercise that increases heart rate and uses oxygen to provide energy as ATP.

**Aerobic capacity** The maximum amount of oxygen that can be consumed by the tissues during exercise. Also called maximal oxygen consumption, or VO₂ max.

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c. Flexibility makes everyday tasks easier and can improve athletic performance. Too-tight muscles, tendons, and ligaments restrict motion at the joints, decreasing stride or stroke length and increasing the amount of energy needed to move the joints. Regularly moving limbs, the neck, and the torso through their full range of motion helps increase and maintain flexibility.

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d. A fit person has more muscle mass than an unfit person of the same height and weight. Engaging in aerobic exercise and muscle-strengthening exercise has a positive impact on body composition, reducing body fat, and increasing the proportion of lean tissue.
chronic conditions such as cardiovascular disease, hypertension, type 2 diabetes, breast and colon cancer, and bone and joint disorders (Figure 10.2). The health benefits of exercise are so great that they can even overcome some of the health risks of carrying excess body fat. Exercise reduces overall mortality, regardless of whether the person is lean, normal weight, or obese. So even if you can’t take off the pounds, you’ll still benefit from continuing to exercise.

In addition to decreasing the risk of disease, exercise improves mood and self-esteem and increases vigor and overall well-being. Exercise has also been shown to reduce depression and anxiety, as well as to improve the quality of life. The mechanisms involved are not clear, but one hypothesis has to do with the production of endorphins. Exercise stimulates the release of these chemicals, which are thought to be natural mood enhancers that play a role in triggering what athletes describe as an “exercise high.” In addition to causing this state of exercise euphoria, endorphins are thought to aid in relaxation, pain tolerance, and appetite control.

**Flexibility** When you think of fitness, you may picture someone with bulging muscles, but fitness also involves flexibility. Flexibility determines your range of motion—how far you can bend and stretch muscles and ligaments. If your flexibility is poor, you cannot easily bend to tie your shoes or stretch to remove packages from the car. Improving flexibility improves performance in certain activities and may reduce your risk of injuries such as pulled muscles and strained tendons (Figure 10.1c).

**Body composition** Individuals who are physically fit have a greater proportion of muscle and a smaller proportion of fat than do unfit individuals of the same weight (Figure 10.1d). The amount of body fat a person has is also affected by gender and age. In general, women have more stored body fat than men. For young adult women, the desirable amount of body fat is 21 to 32% of total weight; in adult men, the desirable amount is 8 to 19%.

**Exercise and the Risk of Chronic Disease**

Regular exercise not only makes everyday tasks easier but can also prevent or delay the onset of chronic conditions such as cardiovascular disease, hypertension, type 2 diabetes, breast and colon cancer, and bone and joint disorders (Figure 10.2).

**Health benefits of physical activity**

- Exercise improves strength and endurance, reduces the risk of chronic disease, aids weight management, reduces sleeplessness, improves self-image, and helps relieve stress, anxiety, and depression.

- Exercise improves flexibility and balance.

- Exercise increases the sensitivity of tissues to insulin and decreases the risk of developing type 2 diabetes.

- Exercise reduces the risk of cardiovascular disease because it strengthens the heart muscle, lowers blood pressure, and increases HDL (good) cholesterol levels in the blood.

- Regular exercise reduces the risk of colon cancer and breast cancer.

- Exercise increases muscle mass, strength, and endurance.

- Weight-bearing exercise stimulates bones to become denser and stronger and therefore reduces the risk of osteoporosis. The strength and flexibility promoted by exercise can help improve joint function.
Exercise Recommendations

LEARNING OBJECTIVES

1. **Describe** the amounts and types of exercise recommended to improve health.
2. **Classify** activities as aerobic or anaerobic.
3. **Plan** a fitness program that can be integrated into your daily routine.
4. **Explain** overtraining syndrome.

Most Americans do not exercise regularly, and 32% of American adults get no physical activity at all during their leisure time.\(^3\) To reduce the risk of chronic disease, public health guidelines, including the 2010 Dietary Guidelines, advise at least 150 minutes of moderate-intensity or 75 minutes of vigorous-intensity aerobic physical activity each week or an equivalent combination of both.\(^6,7\) Greater health benefits can be obtained by exercising more vigorously or for a longer duration. Moderate-intensity exercise is the equivalent of walking 3 miles in about an hour or bicycling 8 miles in about an hour. Vigorous-intensity exercise is equivalent to jogging at a rate of 5 miles per hour or faster or bicycling at 10 miles per hour or faster.\(^7\) Adults should also include muscle-strengthening activities on two or more days per week, but time spent in muscle-strengthening activities does not count toward meeting the aerobic activity guidelines.

If you can’t find the time or motivation to exercise for an hour a day, do not give up. Even a small amount of exercise is better than none.\(^7\)
What to Look for in a Fitness Program

A complete fitness program includes aerobic exercise for cardiovascular conditioning, stretching exercises for flexibility, and muscle-strengthening exercises to increase muscle strength and endurance and maintain or increase muscle mass. The program should be integrated into an active lifestyle that includes a variety of everyday activities, enjoyable recreational activities, and a minimum amount of time spent in sedentary activities (Figure 10.4).

Exercise recommendations • Figure 10.4

A healthy lifestyle minimizes sedentary activities and includes a variety of everyday activities as well as exercise that improves muscle strength and at least 150 minutes of aerobic exercise, which increases heart rate. Achieving the recommended amounts of aerobic activity, muscle-strengthening exercise, and stretching recommended will help improve and maintain fitness and health. In general, more exercise is better than less.
Moderate or vigorous aerobic exercise should be performed most days of the week. An activity is aerobic if it raises your heart rate to 60 to 85% of your **maximum heart rate**; when you are exercising at an intensity in this range, you are said to be in your **aerobic zone** (Figure 10.5). For a sedentary individual who is beginning an exercise program, mild exercise such as walking can raise the heart rate into the aerobic zone. As fitness improves, an exerciser must perform more intense activity to raise the heart rate to this level.

Aerobic activities of different intensities can be combined to meet recommendations and achieve health benefits. The total amount of energy expended in physical activity depends on the intensity, duration, and frequency of the activity. Vigorous physical activity, such as jogging, that raises heart rate to the high end of the aerobic zone (70 to 85%) improves fitness more and burns more calories per unit of time than does moderate-intensity activity, such as walking, that raises heart rate only to the low end of the zone (60 to 69%).

Individuals should structure their fitness program based on their needs, goals, and abilities. For example, some people might prefer a short, intense workout such as a 30 minute run, while others would rather work out for a longer time, at a lower intensity, such as a 1-hour walk. Some may choose to complete all their exercise during the same session, while others may spread their exercise throughout the day, in shorter bouts. Three short bouts of 10-minute duration can be as effective as a continuous bout of 30 minutes for reducing the risk of chronic disease. It is preferable to spread your aerobic activity throughout the week rather than cram it all into the weekend. Exercising at least 3 days produces health benefits and reduces the risk of injury and fatigue. A combination of intensities, such as a brisk 30-minute walk twice during the week in addition to a 20-minute jog on 2 other days, can meet recommendations.

Muscle strengthening and stretching can be performed less often than aerobic exercise. Muscle strengthening is needed only 2 to 3 days a week at the start of an exercise program and 2 days a week after the desired strength has been achieved. Muscle strengthening should not be done on consecutive days. The rest between sessions gives the muscles time to respond to the stress by getting stronger. Increasing the amount of weight lifted increases muscle strength, whereas increasing the number of repetitions improves muscle endurance. Flexibility exercises can be performed 2 to 7 days per week. Time spent stretching does not count toward meeting aerobic or strength-training guidelines.

### Finding your aerobic zone • Figure 10.5

**Maximum heart rate** The maximum number of beats per minute that the heart can attain.

**Interpreting Data**

**What is the aerobic zone for someone who is 30?** What happens to this range when the person turns 40?

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a. You can calculate your aerobic zone by multiplying your maximum heart rate by 0.6 and 0.85. Maximum heart rate depends on age; it can be estimated by subtracting your age from 220. For example, if you are 20 years old, you have a maximum heart rate of 200 (220 – 20) beats per minute. If you exercise at a pace that keeps your heart rate between 120 (0.6 x 200) and 170 (0.85 x 200) beats per minute, you are in your aerobic zone.

b. You can check your heart rate by feeling the pulse at the side of your neck, just below the jawbone. A pulse is caused by the heart beating and forcing blood through the arteries. The number of pulses per minute equals heart rate.
Creating an Active Lifestyle

Incorporating exercise into your day-to-day life may require a change in lifestyle, which is not always easy. Many people avoid exercise because they do not enjoy it, think it requires them to join an expensive health club, have little motivation to do it alone, or find it inconvenient or uncomfortable. Finding an exercise you enjoy, setting aside a time that is realistic and convenient, and finding a place that is appropriate and safe are important steps in starting and maintaining an exercise program (Table 10.1). Riding your bike to class or work rather than driving, taking a walk during your lunch break, and enjoying a game of catch or tag with your friends or family are all effective ways to increase your everyday activity level. The goal is to gradually make lifestyle changes that increase physical activity.

Before beginning an exercise program, check with your physician to be sure that your plans are appropriate for you, considering your medical history (Figure 10.6). If you choose to exercise outdoors rather than in a gym, reduce or curtail exercise in hot, humid weather in order to avoid heat-related illness. In cold weather, wear clothing that allows for evaporation of sweat while providing protection from the cold. Start each exercise session with a warm-up, such as mild stretching or easy jogging, to increase blood flow to the muscles. End with a cool-down period, such as walking or stretching, to prevent muscle cramps and slowly reduce heart rate.

Don’t overdo it. If you don’t rest enough between exercise sessions, fitness and performance will not improve. During rest, the body replenishes energy stores, repairs damaged tissues, and builds and strengthens muscles. In athletes, excessive training without sufficient rest to allow for recovery can lead to overtraining syndrome. The most common symptom of this condition is fatigue that limits workouts and is felt even at rest. Some athletes experience decreased appetite, weight loss, muscle soreness, increased frequency of viral illnesses, and increased incidence of injuries. They may become moody, easily irritated, or depressed; experience altered sleep patterns; or lose their competitive desire and enthusiasm. Overtraining syndrome occurs only in serious athletes who are training extensively, but rest is essential for anyone who is working to increase fitness.

Suggestions for starting and maintaining an exercise program  Table 10.1

Start slowly. Set specific, attainable goals. Once you have met them, add more

- Walk around the block after dinner.
- Get off the bus or subway one stop early.
- Use half of your lunch break to exercise.
- Do a few biceps curls each time you take the milk out of the refrigerator.

Make your exercise fun and convenient

- Opt for activities you enjoy: Bowling and dancing may be more fun for you than using a treadmill at the gym.
- Find a partner to exercise with you.
- Choose times that fit your schedule.

Stay motivated

- Vary your routine: Swim one day and mountain bike the next.
- Challenge your strength or endurance once or twice a week and do moderate workouts on other days.
- Track your progress by recording your activity.
- Reward your success with a new book, movie, or workout clothes.

Keep your exercise safe

- Warm up before you start.
- Cool down when you are done.
- Don’t overdo it: Alternate hard days with easy days and take a day off when you need it.
- Listen to your body and stop before an injury occurs.

Exercise is for everyone

Almost anyone of any age can exercise, no matter where they live, how old they are, or what physical limitations they have.
Fueling Exercise

The body runs on energy from the carbohydrate, fat, and protein in food and body stores. These fuels are needed whether you are writing a term paper, riding your bike to class, or running a marathon. Before they can be used to fuel activity, their energy must be converted into the high-energy compound ATP, the immediate source of energy for body functions. ATP can be generated both in the absence of oxygen, by anaerobic metabolism, and in the presence of oxygen, by aerobic metabolism (Figure 10.7). The type of metabolism that predominates during an activity determines how much carbohydrate, fat, and protein are used to fuel the activity.

### LEARNING OBJECTIVES

1. **Compare** the fuels used to generate ATP by anaerobic and aerobic metabolism.
2. **Discuss** the effect of exercise duration and intensity on the type of fuel used.
3. **Describe** the physiological changes that occur in response to exercise.

### Anaerobic versus aerobic metabolism • Figure 10.7

ATP is produced in the cells by anaerobic metabolism when no oxygen is available. Anaerobic metabolism produces ATP very rapidly but uses only glucose as a fuel. The **lactic acid** that is produced can be used as a fuel for aerobic metabolism. The majority of ATP is produced by aerobic metabolism. Aerobic metabolism requires oxygen, takes place in the mitochondria, and can use carbohydrate, fat, or protein to produce ATP. It is slower but more efficient at generating ATP than anaerobic metabolism.
The availability of oxygen determines whether ATP is produced predominantly by anaerobic versus aerobic metabolism. Oxygen is inhaled by the lungs and delivered to the muscle by the blood (Figure 10.8). When you are at rest, your muscles do not need much energy, and your heart and lungs are able to deliver enough oxygen to meet your energy needs using aerobic metabolism. When you exercise, your muscles need more energy. To increase the amount of energy provided by aerobic metabolism, you must increase the amount of oxygen delivered to the muscles. Your body accomplishes this by increasing both heart rate and breathing rate. The ability of the circulatory and respiratory systems to deliver oxygen to tissues is affected by how long an activity is performed, the intensity of the activity, and the physical conditioning of the exerciser.

Exercise Duration and Fuel Use

When you take the first steps of your morning jog, your muscles increase their activity, but your heart and lungs have not had time to step up their delivery of oxygen to them. To get the energy they need, the muscles rely on the small amount of ATP that is stored in resting muscle. This is enough to sustain activity for a few seconds. As the stored ATP is used up, enzymes break down another high-energy compound, creatine phosphate, to convert ADP (adenosine diphosphate) to ATP, allowing your activity to continue. But, like the amount of ATP, the amount of creatine phosphate stored in the muscle at any time is small and soon runs out (Figure 10.9).

Short-term energy: Anaerobic metabolism After about 15 seconds of exercise, the ATP and creatine phosphate in your muscles are used up, but your heart rate and breathing have not increased enough to deliver more oxygen to the muscles. To get more energy at this point, your muscles must produce the additional ATP without oxygen (see Figure 10.7 on previous page). This anaerobic metabolism can produce ATP very rapidly but can use only glucose as a fuel (Figure 10.10). The amount of glucose is limited, so anaerobic metabolism cannot continue indefinitely.
Changes in the source of ATP over time • Figure 10.9

The source of the ATP that fuels muscle contraction changes over the first few minutes of exercise.

Instant energy
During the first few seconds of exercise, the muscles get energy from stored ATP. Then, for the next 10 seconds or so, creatine phosphate stored in the muscles is broken down to form more ATP.

Short-term energy
Anaerobic metabolism of glucose, obtained either from the blood or from muscle glycogen, becomes the predominant source of ATP when creatine phosphate stores have been depleted. Thirty seconds into the activity, anaerobic pathways are operating at full capacity.

Long-term energy
After about two to three minutes, oxygen delivery to the muscles has increased enough to support aerobic metabolism, which uses fatty acids and glucose to produce ATP.

Fueling Exercise

Muscle contraction is fueled by glucose from muscle glycogen breakdown or blood glucose. Blood glucose is supplied by the breakdown of liver glycogen, glucose synthesis by the liver, and carbohydrate consumed during exercise. Some of the fatty acids used as fuel come from triglycerides stored in the muscle, but most come from adipose tissue. The amino acids available to the body come from the digestion of dietary proteins and from the breakdown of body proteins.

Interpreting Data
After about 10 minutes, most of the ATP used to fuel moderate exercise is produced by ___________.

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Long-term energy: Aerobic metabolism  After you have been exercising for two to three minutes, your breathing and heart rate have increased to supply more oxygen to your muscles. This allows aerobic metabolism to predominate. Aerobic metabolism produces ATP at a slower rate than does anaerobic metabolism, but it is much more efficient, producing about 18 times more ATP for each molecule of glucose. As a result, glucose is used more slowly than in anaerobic metabolism. In addition, aerobic metabolism can use fatty acids, and sometimes amino acids from protein, to generate ATP (see Figure 10.10 on previous page).

In a typical adult, about 90% of stored energy is found in adipose tissue; this provides an ample supply of fatty acids. When you continue to exercise at a low to moderate intensity, aerobic metabolism predominates, and fatty acids become the primary fuel source for your exercising muscles (see What a Scientist Sees). When you pick up the pace, the relative amount of ATP generated by anaerobic versus aerobic metabolism and the fuels you burn will change.

Protein as a fuel for exercise  Although protein is not considered a major energy source for the body, even at rest, small amounts of amino acids are used for energy. The amount increases if your diet does not provide enough total energy to meet needs, if you consume more protein than you need, or if you are involved in endurance exercise (see Chapter 6).

When the nitrogen-containing amino group is removed from an amino acid, the remaining carbon compound can be broken down to produce ATP by aerobic metabolism or, in some cases, used to make glucose (see Figure 10.7 on page 361). Exercise that continues for many hours increases the use of amino acids both as an energy source and as a raw material for glucose synthesis. Strength training does not increase the use of protein for energy, but it does increase the demand for amino acids for muscle building and repair.

WHAT A SCIENTIST SEES

The Fat-Burning Zone

Have you ever jumped onto a treadmill and chosen the workout that puts you in the “fat-burning zone” rather than the one that puts you in the “cardio zone” because your goal was to lose weight? The fat-burning zone is a lower-intensity aerobic workout that keeps your heart rate between about 60 and 69% of maximum. The cardio zone is a higher-intensity aerobic workout that keeps heart rate between about 70 and 85% of maximum.

However, do you really burn more fat during a slow 30-minute jog in the fat-burning zone than during a vigorous 30-minute run in the cardio zone? A scientist sees that you do burn a higher percentage of calories from fat during a lower-intensity aerobic workout, but that’s not the whole story. When you pick up the pace and exercise in what the treadmill calls the cardio zone, you continue to burn fat. The graph shows that 50% of the calories burned come from fat during the lower-intensity workout (that is, in the fat-burning zone) and only 40% come from fat during the higher-intensity workout. Looking at the actual numbers of calories burned, however, the scientist sees that at the higher intensity, you burn just as much fat (about 150 Calories/hour) but a much greater number of calories overall.

Think Critically  Which workout will help you lose the most weight: 30 minutes in the cardio zone or 30 minutes in the fat-burning zone? Why?
Exercise Intensity and Fuel Use

The energy contributions made by anaerobic and aerobic metabolism combine to ensure that your muscles get enough ATP to meet the demands you place on them. The relative contribution of each type of metabolism depends on the intensity of your activity. With low-intensity activity, sufficient ATP can be produced by aerobic metabolism. With intense exercise, more ATP is needed, but oxygen delivery to and use by the muscles becomes limited, so the muscles must get the additional ATP they need by using anaerobic metabolism (Figure 10.11).

Lower-intensity exercise relies on aerobic metabolism, which is more efficient than anaerobic metabolism and uses both glucose and fatty acids to produce ATP. The body’s fat reserves are almost unlimited, so if fat is the fuel, exercise can theoretically continue for a very long time. For example, it is estimated that a 130-pound woman has enough energy stored as body fat to run 1000 miles. However, even aerobic activity uses some glucose, which means that if exercise continues long enough, glycogen stores are eventually depleted, causing fatigue.

Fatigue occurs much more quickly with high-intensity exercise than with lower-intensity exercise because more intense exercise relies more on anaerobic metabolism, which can use only glucose for fuel. Glycogen stores thus are rapidly depleted (Figure 10.12). Anaerobic metabolism

Fatigue: “Hitting the wall” • Figure 10.12

Glycogen depletion is a concern for athletes because the amount of stored glycogen available to produce glucose during exercise is limited. When athletes run out of glycogen, they experience a feeling of overwhelming fatigue that is sometimes referred to as “hitting the wall” or “bonking.”

Between 60 and 120 grams of glycogen are stored in the liver; glycogen stores are highest just after a meal. Liver glycogen is used to maintain blood glucose between meals and during the night. Eating a high-carbohydrate breakfast will replenish the liver glycogen used during sleep.

There are about 200 to 500 g of glycogen in the muscles of a 70-kg (154-lb) person. The glycogen in a muscle is used to fuel that muscle’s activity.
Aerobic training causes physiological changes in the cardiovascular system that increase the delivery of oxygen to cells. It also causes changes in the muscle cells that increase glycogen storage and the ability to use oxygen to generate ATP.

Training causes blood volume and the number of red blood cells to expand, increasing the amount of hemoglobin so that more oxygen can be transported. It also causes the number of capillary blood vessels in the muscles to increase so that blood is delivered to muscles more efficiently.

In the muscles, training enhances the ability to store glycogen and increases the number and size of muscle-cell mitochondria. Because aerobic metabolism occurs in the mitochondria, the greater size and number of mitochondria increases the capacity of cells to burn fatty acids to produce ATP.

Also produces lactic acid. With low-intensity exercise, the small amounts of lactic acid produced are carried away from the muscles and used by other tissues as an energy source or converted back into glucose by the liver. During high-intensity exercise, the amount of lactic acid produced exceeds the amount that can be used by other tissues, and the lactic acid builds up in the muscle and subsequently in the blood. Until recently, it was assumed that lactic acid buildup was the cause of muscle fatigue, but we now know that although lactic acid buildup occurs with high-intensity exercise, it is not a major factor in muscle fatigue. Fatigue most likely has many causes, including glycogen depletion and changes in the muscle cells and the concentrations of molecules involved in muscle metabolism.

**Fitness Training and Fuel Use**

When you exercise regularly to improve your fitness, the training causes physiological changes in your body. The changes caused by repeated bouts of aerobic exercise also produce lactic acid. With low-intensity exercise, the small amounts of lactic acid produced are carried away from the muscles and used by other tissues as an energy source or converted back into glucose by the liver. During high-intensity exercise, the amount of lactic acid produced exceeds the amount that can be used by other tissues, and the lactic acid builds up in the muscle and subsequently in the blood. Until recently, it was assumed that lactic acid buildup was the cause of muscle fatigue, but we now know that although lactic acid buildup occurs with high-intensity exercise, it is not a major factor in muscle fatigue. Fatigue most likely has many causes, including glycogen depletion and changes in the muscle cells and the concentrations of molecules involved in muscle metabolism.

1. **What** fuels are used in anaerobic metabolism?
2. **What** type of metabolism does a marathon runner rely on?
3. **Why** is a trained athlete able to perform at a higher intensity for a longer time than an untrained person?
Energy and Nutrient Needs for Physical Activity

LEARNING OBJECTIVES

1. Compare the energy and nutrient needs of athletes and nonathletes.
2. Explain why athletes are at risk for dehydration and hyponatremia.
3. Discuss the recommendations for food and drink during extended exercise.
4. Plan pre- and post-competition meals for a marathon runner.

Good nutrition is essential to performance, whether you are a marathon runner or a mall walker. Your diet must provide enough energy to fuel activity, enough protein to maintain muscle mass, sufficient micronutrients to metabolize the energy-yielding nutrients, and enough water to transport nutrients and cool your body. The major difference between the nutritional needs of a serious athlete and those of a casual exerciser is the amount of energy and water required.

Energy Needs

The amount of energy expended for any activity depends on the intensity, duration, and frequency of the activity and the weight of the exerciser (Figure 10.14). Whereas casual exercise may burn only 100 additional Calories a day, the training required for an endurance athlete, such as a marathon runner, may increase energy expenditure by 2000 to 3000 Calories/day. Some athletes require 6000 Calories a day to maintain their body weight. In general, the more intense the activity, the more energy it requires, and the more time spent exercising, the more energy is expended (see Appendix H). Running for 60 minutes, for instance, involves more work than walking for the same amount of time and therefore requires more energy.

Gaining or losing weight

Body weight and composition can affect exercise performance. In sports such as football and weight lifting, having a large amount of muscle is advantageous, and athletes may try to build muscle and increase body weight. Healthy weight gain can be achieved through a combination of increased energy intake, adequate protein intake, and muscle-strengthening exercise to promote an increase in lean tissue rather than fat.

In sports such as ballet, gymnastics, and certain running events, small, light bodies offer an advantage, so athletes may restrict energy intake in order to maintain a low body weight. While a slightly leaner physique may be beneficial in these sports, dieting to maintain an unrealistically low weight may threaten health and performance. An athlete who needs to lose weight should do so in advance of the competitive season to prevent the calorie restriction from affecting performance. The general guidelines for healthy weight loss should be followed: Reduce energy intake by 200 to 500 Calories/day, increase activity, and change the behaviors that led to weight gain (see Chapter 9).

Unhealthy weight-loss practices

Athletes who participate in sports that require weight restriction to optimize performance are vulnerable to eating disorders. The motivation and self-discipline characteristic of successful athletes contributes to their increased risk of anorexia and bulimia (see Chapter 9). In athletes who develop anorexia, the restricted food intake can affect growth and maturation and impair exercise performance. In athletes who develop bulimia, purging can cause dehydration and electrolyte imbalance, which affect performance and endanger overall health. In addition to using restricted food intake or purging to keep body weight low, athletes are more likely than nonathletes to engage in compulsive exercise behaviors in order to increase energy expenditure.

Factors affecting energy expenditure

This graph illustrates the impact of running pace and body weight on energy expenditure per hour. The longer an individual continues to run, the greater the amount of energy expended. Body weight affects energy needs because moving a heavier body requires more energy than moving a lighter one. Therefore, if the pace is the same, a 170-lb woman requires more energy to run for an hour than does a 125-lb woman.
Women with female athlete triad typically have low body fat, do not menstruate regularly, and may experience multiple or recurrent stress fractures. Neither adequate dietary calcium nor the increase in bone mass caused by weight-bearing exercise can compensate for the bone loss caused by low estrogen levels. Treatment involves increasing energy intake and reducing activity so that menstrual cycles resume.

Disordered Eating

- Low energy intake reduces the intake of calcium and other nutrients important for bone health.

Osteoporosis

- Estrogen is needed for calcium homeostasis in the bone and for calcium absorption in the intestines. Low levels lead to low peak bone mass, premature bone loss, and increased risk of stress fractures.

Amenorrhea

The extreme energy restriction of an eating disorder combined with exercise creates a physiological condition that is similar to starvation, which contributes to a drop in estrogen levels. Low estrogen causes amenorrhea.

Female athlete triad • Figure 10.15

Think Critically Why is bone loss accelerated in young girls who are not menstruating?

Think Critically

- Why is bone loss accelerated in young girls who are not menstruating?

Making weight • Figure 10.16

After three young wrestlers died while exercising in plastic suits in order to sweat off water, wrestling guidelines were changed to improve safety. Weight classes were altered to eliminate the lightest class, plastic sweat suits were banned, weigh-ins were moved to one hour before competition, and mandatory weight-loss rules were instituted. The percentage of body fat can be no less than 5% for college wrestlers and 7% for high school wrestlers.
Carbohydrate, Fat, and Protein Needs

The source of energy in an athlete’s diet can be as important as the amount. To maximize glycogen stores and optimize performance, a diet providing about 6 to 10 g of carbohydrate/kg of body weight per day is recommended for athletes in training (Figure 10.17). The recommended amount of fat is the same as that for the general population—between 20 and 35% of energy. To allow for enough carbohydrate, fat intakes at the lower end of this range may be needed for some athletes. Diets that are very low in fat (less than 20% of calories) do not benefit performance. Protein is not a significant energy source, accounting for only about 5% of energy expended, but dietary protein is needed to maintain and repair lean tissues, including muscle. A diet in which 15 to 20% of calories come from protein will meet the needs of most athletes.

As discussed in Chapter 6, competitive athletes participating in endurance or strength sports may require extra protein. In endurance events, such as marathons, protein is used for energy and to maintain blood glucose. Athletes participating in these events may benefit from 1.2 to 1.4 g of protein/kg of body weight per day. Athletes participating in strength events require amino acids to synthesize new muscle proteins and may benefit from 1.2 to 1.7 g/kg per day. While this amount is greater than the RDA (0.8 g/kg per day), it is not greater than the amount of protein habitually consumed by athletes. For example, an 85-kg man consuming 3000 Calories, of which 15 to 20% is from protein, would be consuming 1.6 g of protein/kg of body weight.

Vitamin and Mineral Needs

An adequate intake of vitamins and minerals is essential for optimal performance. These micronutrients are needed for energy production, oxygen delivery, protection against oxidative damage, and repair and maintenance of body structures.

Exercise increases the amounts of many vitamins and minerals used both in metabolism during exercise and in repairing tissues after exercise. In addition, exercise may increase losses of some micronutrients. Nevertheless, most athletes can meet their needs by consuming the amounts of vitamins and minerals recommended for the general population. Because athletes must eat more food to satisfy their higher energy needs, they consume extra vitamins and minerals with these foods, particularly if they choose nutrient-dense foods. Athletes who restrict their intake in order to maintain a low body weight may be at risk for vitamin and mineral deficiencies.

Antioxidants and oxidative damage

Exercise increases the amount of oxygen used by the muscles and the rate of ATP-producing metabolic reactions. This increased oxygen use increases the production of free radicals, which can lead to oxidative damage and contribute to muscle fatigue. To protect the body from oxidative damage, muscle cells contain antioxidant defenses, some of which may interact with dietary antioxidants such as vitamin C, vitamin E, β-carotene, and selenium. Despite the importance of antioxidants for health and performance, there is little evidence that supplementation with antioxidants improves human performance.

Proportions of energy-yielding nutrients in an athlete’s diet • Figure 10.17

The proportions of carbohydrate, fat, and protein recommended in the diets of athletes, shown in the pie chart to the right, are within the ranges recommended for the general public: 45 to 65% of total energy from carbohydrate, 20 to 35% of energy from fat, and 10 to 35% of energy from protein.
Water Needs

Exercise increases water needs because it increases losses in sweat and from evaporation through the respiratory system. During exercise, most people drink only enough to assuage their thirst, but this amount typically is not enough to replace water losses. Therefore, they end their exercise session in a state of dehydration and must restore fluid balance during the remainder of the day.

The risk of dehydration is greater in hot than cold environments. However, dehydration may also occur when exercising in the cold because cold air tends to be dry, so evaporative losses from the lungs are greater. In addition, insulated clothing worn in cold weather may increase sweat loss, and fluid intake may be reduced because a chilled athlete may be reluctant to drink a cold beverage. Female athletes training in cold weather may also limit fluid intake in order to avoid the inconvenience of removing clothing in order to urinate.12

Even when fluids are consumed at regular intervals throughout exercise, it may not be possible to drink enough to compensate for losses. During exercise, water is needed to cool the body and to transport both oxygen and nutrients to the muscles and remove waste products from them. Not consuming enough water to replace losses can be hazardous to the performance and health of even the most casual exerciser (Figure 10.19).

Dehydration and heat-related illnesses

Dehydration occurs when water loss is great enough for blood volume to decrease, thereby reducing the ability of the circulatory system to deliver oxygen and nutrients to exercising muscles (see Chapter 8). A decrease in blood volume also reduces blood flow to the skin and the amount of sweat produced, thus limiting the body’s ability to cool itself. As a result, core body temperature can increase, and with it the risk of various heat-related illnesses.
Heat cramps are involuntary muscle spasms that occur during or after intense exercise, usually in the muscles involved in the exercise. They are a form of heat-related illness caused by an imbalance of electrolytes at the muscle cell membranes. They can occur when water and salt are lost during extended exercise.

Heat exhaustion occurs when water loss causes blood volume to decrease so much that it is not possible both to cool the body and to deliver oxygen to active muscles. It is a form of heat-related illness characterized by a rapid but weak pulse, low blood pressure, disorientation, profuse sweating, and fainting. A person who is experiencing symptoms of heat exhaustion should stop exercising and move to a cooler environment.

Heat exhaustion can progress to heat stroke, the most serious form of heat-related illness. It occurs when core body temperature rises above 105°F, causing the brain’s temperature-regulatory center to fail. When this occurs, the individual does not sweat even though body temperature is rising. Heat stroke is characterized by elevated body temperature; hot, dry skin; extreme confusion; and unconsciousness. It requires immediate medical attention.

Exercising in hot, humid weather increases the risk of heat-related illnesses. As environmental temperature rises, the body has more difficulty dissipating heat, and as humidity rises, the body’s ability to cool through evaporation decreases (Figure 10.20).

As the severity of dehydration increases, exercise performance declines. Even mild dehydration—a water loss of 1 to 2% of body weight—can impair exercise performance. A 3% reduction in body weight can significantly reduce the amount of blood pumped with each heartbeat because the blood volume is decreased. This, in turn, reduces the circulatory system's ability to deliver oxygen and nutrients to cells and remove waste products.

Dehydration and performance • Figure 10.19

Heat index

As the severity of dehydration increases, exercise performance declines. Even mild dehydration—a water loss of 1 to 2% of body weight—can impair exercise performance. A 3% reduction in body weight can significantly reduce the amount of blood pumped with each heartbeat because the blood volume is decreased. This, in turn, reduces the circulatory system’s ability to deliver oxygen and nutrients to cells and remove waste products.

Exercise in extreme conditions increases the risk of heat-related illness. Heat index, or apparent temperature, is a measure of how hot it feels when the relative humidity is added to the air temperature. To find the heat index, find the intersection of the temperature on the left side of the table and the relative humidity across the top. The colored zones correspond to heat index levels that contribute to increasingly severe heat illnesses with continued exposure and/or physical activity.
Fluid recommendations for exercise

Anyone who is exercising should consume extra fluids. Because thirst is not a reliable short-term indicator of the body’s water needs, it is important to schedule regular fluid breaks. To ensure hydration, adequate amounts of fluid should be consumed before, during, and after exercise.

Exercisers should drink generous amounts of fluid in the 24 hours before an exercise session and about 2 cups of fluid 4 hours before exercise. During exercise, whether casual or competitive, exercisers should try to drink enough fluid to prevent weight loss. Drinking 6 to 12 ounces of fluid every 15 to 20 minutes for the duration of the exercise should maintain adequate hydration. To restore lost water after exercise, each pound of weight lost should be replaced with 16 to 24 oz (2 to 3 cups) of fluid.

The best type of beverage to consume during exercise depends on the duration of the exercise. For exercise lasting an hour or less, water is the only fluid needed, particularly if one of your exercise goals is weight management. A typical 16-ounce sports drink provides about 100 Calories, so it will replace about half of the calories expended during a 40-minute ride on a stationary bicycle.

For exercise lasting more than 60 minutes, sports drinks or other beverages containing a small amount of carbohydrate (about 10 to 20 g of carbohydrate/cup) and electrolytes (around 150 milligrams of sodium/cup) are recommended. The carbohydrate is a source of glucose for the muscle and thus delays fatigue. Commercial sports drinks contain rapidly absorbed sources of carbohydrate, such as

Hyponatremia

Sweating helps us stay cool. But if the water and sodium lost in sweat are not replaced in the right proportions, low blood sodium, or hyponatremia, may result (see Chapter 8). For most activities, sweat losses can be replaced with plain water, and lost electrolytes can be replaced during the meals following exercise. However, during endurance events such as triathalons, when sweating continues for many hours, both water and sodium need to be replenished. If an athlete replaces the lost fluid with plain water, the sodium that remains in the blood is diluted, causing hyponatremia. As sodium concentrations in the blood decrease, fluid moves into body tissues by osmosis, causing swelling. Fluid accumulation in the lungs interferes with gas exchange, and fluid accumulation in the brain causes disorientation, seizure, coma, and death.

The risk of hyponatremia can be reduced by consuming a sodium-containing sports drink during long-distance events, increasing sodium intake several days prior to a competition, and avoiding acetaminophen, aspirin, ibuprofen, and other nonsteroidal anti-inflammatory drugs, which may contribute to the development of hyponatremia by interfering with kidney function. The early symptoms of hyponatremia may be similar to those of dehydration: nausea, muscle cramps, disorientation, slurred speech, and confusion. A proper diagnosis is important because drinking water alone will make the problem worse. Mild symptoms of hyponatremia can be treated by eating salty foods or drinking a sodium-containing beverage, such as a sports drink. More severe symptoms require medical attention.
glucose, sucrose, or glucose polymers (chains of glucose molecules). The right proportion of carbohydrate to water is important. If the concentration of carbohydrate is too low, it will not help performance; if it is too high, it will delay stomach emptying. Water and carbohydrate trapped in the stomach do not benefit the athlete and may cause stomach cramps. Because fruit juices and soft drinks contain twice as much sugar as sports drinks, they are not recommended unless they are diluted with an equal volume of water. The sodium in sports drinks helps prevent hypotension and also enhances intestinal absorption of water and glucose and stimulates thirst. Flavored beverages also tempt athletes to drink more, helping to ensure adequate hydration.

**Food and Drink to Optimize Performance**

For most of us, a trip to the gym requires no special nutritional planning, but for competitive athletes, when and what they eat before, during, and after competition are as important as a balanced overall diet. The type and amount of food eaten at these times may give or take away the extra seconds that can mean victory or defeat.

**Maximizing glycogen stores** Glycogen stores are a source of glucose, and larger glycogen stores allow exercise to continue for longer periods. Glycogen stores and hence endurance are increased by increasing carbohydrate intake (Figure 10.22).

Serious endurance athletes who want to substantially increase their muscle glycogen stores before a competition may choose to follow a dietary regimen referred to as **glycogen supercompensation** or **carbohydrate loading**. Such a regimen involves resting for one to three days before competition while consuming a very high-carbohydrate diet. The diet should provide 10 to 12 g of carbohydrate/kg of body weight per day. For a 150-lb person, this is equivalent to about 700 g of carbohydrate per day. Having a stack of pancakes with syrup and a glass of milk or a plate of pasta with garlic bread and a glass of juice provides more than 200 g of carbohydrate. A number of commercial high-carbohydrate beverages (50 to 60 g of carbohydrate in 8 fluid oz) are available to help athletes consume the amount of carbohydrate recommended to maximize glycogen stores. (These should not be confused with sports drinks designed to be consumed during competition, which contain only about 10 to 20 g of carbohydrate in 8 fluid oz.) Trained athletes who follow a carbohydrate-loading regimen can double their muscle glycogen content.

Although glycogen supercompensation is beneficial to endurance athletes, it provides no benefit, and even has some disadvantages, for those exercising for less than 90 minutes. For every gram of glycogen in the muscle, about 3 g of water is also deposited. This water will cause weight gain and may cause some muscle stiffness. As glycogen is used, the water is released. This can be an advantage when exercising in hot weather, but the extra weight is a disadvantage for individuals competing in short-duration events.

**What to eat before exercise** Meals eaten before exercise should maximize glycogen stores and provide adequate hydration while minimizing digestion, hunger, and gastric distress. A pre-exercise meal should provide enough fluid to maintain hydration and should be high in carbohydrate (60 to 70% of calories). The carbohydrate will help maintain blood glucose and maximize glycogen stores. Muscle glycogen is depleted by activity, but liver glycogen is used to supply blood glucose and is depleted even during rest if no food is ingested.

**Dietary carbohydrate and endurance • Figure 10.22**

The amount of carbohydrate consumed in the diet affects the level of muscle glycogen and hence an athlete’s endurance. This graph shows endurance capacity during cycling exercise after three days of a low-carbohydrate diet (less than 5% of energy from carbohydrate), a normal diet (about 55% of energy from carbohydrate), and a high-carbohydrate diet (82% of energy from carbohydrate).
A pre-exercise meal should contain about 300 Calories and be moderate in protein (10 to 20%) and low in fat (10 to 25%) and fiber in order to minimize gastrointestinal distress and bloating during competition (Figure 10.23). Spicy foods, which can cause heartburn, and large amounts of simple sugars, which can cause diarrhea, should also be avoided unless the athlete is accustomed to eating these foods.

What to eat after exercise

When you stop exercising, your body must shift from the task of breaking down glycogen, triglycerides, and muscle proteins for fuel to the job of restoring muscle and liver glycogen, depositing lipids, and synthesizing muscle proteins. Meals eaten after exercise should replenish lost fluid, electrolytes, and glycogen and provide protein for building and repairing muscle tissue.

After exercise, the first priority for all exercisers is to replace fluid losses. For serious athletes competing on consecutive days, glycogen replacement is also a priority. To maximize glycogen replacement, a high-carbohydrate meal or drink should be consumed within 30 minutes after the competition and again every two hours for about six hours.²² Ideally, the meals or drinks should provide about 1.0 to 1.5 g of easily absorbed carbohydrate per kilogram of body weight, which is about 50 to 100 g of carbohydrate for a 70-kg (154-lb) person—the equivalent of 2 cups of pasta or 2 cups of chocolate milk.²³ Consuming foods such as these that contain both carbohydrate and protein enhances glycogen synthesis even more than does consuming carbohydrate alone.²⁴ To include protein with carbohydrate in postexercise meals also stimulates muscle protein

The precompetition meal • Figure 10.23

When we don’t eat overnight, liver glycogen stores are reduced, so replenishing glycogen by eating is particularly important first thing on the morning of a competition. A high-carbohydrate meal—such as cereal, milk, and juice—two to four hours before competition can restore liver glycogen. The effects of different foods should be tested during training, not during competition. In addition to providing nutritional clout, a meal that includes “lucky” foods may provide an added psychological advantage.
THINKING IT THROUGH
A Case Study on Snacks for Exercise

Mark enjoys long-distance cycling. On weekends, he often goes on a 40- or 50-mile ride, which takes him three to four hours. Despite the sports drink in his bike bottle, after about two hours, he gets hungry and fatigued, so he is looking for a snack that's easy to carry.

What type of snack will give Mark the energy he needs to continue his ride? Why?

Carbohydrate is the fuel that is depleted during prolonged exercise. So if Mark wants to have the energy to keep pedaling, he should choose something high in carbohydrate.

The bike shop sells a variety of energy or endurance bars that claim to prevent hunger and maintain blood glucose during extended activity. Mark should use the Nutrition Facts panel to select a bar that provides about 45 g of carbohydrate and no more than about 8 g of fat and 16 g of protein. Sports bars that are higher in fat or protein or lower in carbohydrate will not give him the blood glucose boost he needs to continue riding.

What are the advantages and disadvantages of energy bars?

Your answer:

With flavors such as chocolate coconut, tropical crisp, and sesame raisin crunch, many energy bars don't sound too different from candy bars. For about half the cost, Mark can buy a candy bar to put in his bike bag.

Based on the labels shown here, how do energy bars differ from candy bars?

Your answer:

Suggest a snack for Mark that provides about the same amounts of carbohydrate and calories as an energy bar but is less expensive.

Your answer:

(Check your answers in Appendix J.)

### Nutrition Facts

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| *Percent Daily Values (DV) are based on a 2,000 calorie diet.

### Nutrition Facts

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</table>

*Based on a 2,000 calorie diet
CHAPTER 10 Nutrition, Fitness, and Physical Activity

WHAT SHOULD I EAT?

Before, During, and After Exercise

Before you exercise

- Fill a water bottle four hours before exercise and finish it before you start.
- Plan to have pasta but pass on the cream sauce.
- Have a pancake breakfast.
- Fix a bowl of cereal with low-fat milk.

During your short workouts (≤ 60 min)

- Fill your water bottle with water.
- Take a swallow of water every 15 min.

During your long workouts (> 60 min)

- Fill your water bottle with a sports drink.
- Take a sip of fluid at every sign or intersection to make sure you consume at least 6 oz every 15 min.
- Carry an apple and a bagel to snack on.
- Bring a bar that’s high in carbohydrates.

The glycogen-restoring regimen just described can replenish muscle and liver glycogen within 24 hours of an athletic event and is critical for optimizing performance on the following day. Athletes who aren’t competing again the next day can replenish their glycogen stores more slowly by consuming high-carbohydrate foods for the next day or so. A diet providing about 65% of calories from carbohydrate, or about 400 g of carbohydrate in a 2500 Calorie diet, should provide sufficient carbohydrate during the recovery period. More than one-third of this amount could be provided by a 6-inch sub, 12 oz of low-fat chocolate milk, a banana, and some pretzels.

Most of us are not competitive athletes, so we don’t need a special glycogen replacement strategy to ensure that our glycogen stores are replenished before our next visit to the gym. If your routine includes 30 to 60 minutes at the gym, a typical diet that provides about 55% of calories from carbohydrate will replace the glycogen used so that you will be ready for a workout again the next day.

Concept Check

1. Why might a low-carbohydrate diet be a poor choice for an endurance athlete?
2. Why is dehydration more likely when it is hot and humid?
3. How much of what fluid should you drink during a two-hour bike ride?
4. What should an athlete eat as a precompetition meal and why?

Ergogenic Aids

LEARNING OBJECTIVES

1. Assess the health risks associated with using anabolic steroids.
2. Explain why creatine supplements affect sprint performance.
3. Describe one way in which a supplement might improve endurance.

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functions. As discussed earlier, exercise increases oxidative processes and therefore increases the production of free radicals, which cause cellular damage and have been associated with fatigue. However, antioxidant supplements have not been found to improve performance.  

Supplements of chromium (chromium picolinate) and vanadium (vanadyl sulfate) are marketed to increase lean body mass and decrease body fat. Chromium is needed for insulin action, and insulin promotes protein synthesis. However, studies have not consistently demonstrated that supplemental chromium has any effect on muscle strength, body composition, or other aspects of health (see Chapter 8). Vanadium is also believed to assist the action of insulin, but there is no evidence that supplemental vanadium increases lean body mass.

Supplements to Build Muscle
Protein supplements are often marketed to athletes with the promise of enhancing muscle growth or improving performance. Adequate protein is necessary for muscle growth, but consuming extra protein, either as food or as supplements, does not increase muscle growth or strength. Muscles enlarge in response to exercise stress. The protein provided by expensive supplements will not meet an athlete’s needs any better than the protein found in a balanced diet. If an athlete’s diet provides enough energy, it usually provides enough protein, without a supplement.
Supplements of the amino acids ornithine, arginine, and lysine are marketed with the promise that they will stimulate the release of growth hormone and, in turn, enhance the growth of muscles. Large doses of these amino acids have been shown to stimulate the release of growth hormone. However, growth hormone levels in the blood of athletes taking these amino acids are no greater than levels typically resulting from exercise alone. Also, supplements of these amino acids have not been found to cause greater increases in muscle mass and strength than those achieved through strength-training exercise alone.\(^3\)
Anabolic steroids accelerate protein synthesis. When taken in conjunction with exercise and an adequate diet, they cause increases in muscle size and strength. However, they have extremely dangerous side effects (see What a Scientist Sees). Anabolic steroids are regulated as controlled substances. Steroid precursors, which are compounds that can be converted into steroid hormones in the body, are also classified as controlled substances. The best known of these is androstenedione, often referred to as “andro.” It was launched to public prominence when professional baseball player Mark McGwire announced his use of it during the 1998 major league baseball season, when he hit 70 home runs, breaking the league’s single-season home-run record. Contrary to marketing claims, the use of andro or other steroid precursors has not been found to increase testosterone levels or produce any ergogenic effects, and they may cause some of the same side effects as anabolic steroids.

Supplements to Enhance Performance in Short, Intense Activities

A number of supplements are marketed to athletes who seek to improve performance in sports that depend on quick bursts of intense activity. Supplements of β-hydroxy-β-methylbutyrate, known as HMB, claim to increase strength and muscle growth and improve muscle recovery; however, the outcome of research studies has been variable. Overall, studies have found a small increase in strength in previously untrained men, but the effects in trained weight lifters are trivial, as is the effect of HMB on body composition.

Bicarbonate is a supplement that may enhance performance in high-intensity activities. Because bicarbonate acts as a buffer in the body, supplementing it is thought to neutralize acid and thus delay fatigue and allow improved performance. Taking sodium bicarbonate, which is just baking soda from the kitchen cupboard, before exercise has been found to improve performance and delay exhaustion in sports, such as sprint cycling and sprint swimming, which entail intense exercise lasting only one to seven minutes. It has also been found to enhance endurance in longer continuous and intermittent exercise, such as running and cycling. However, just because baking soda is an ingredient in your cookies does not mean that it is risk free. Many people experience abdominal cramps and diarrhea after taking sodium bicarbonate, and other possible side effects have not been carefully researched.

One of the most popular ergogenic supplements is creatine. This nitrogen-containing compound is found primarily in muscle, where it is used to make creatine phosphate (Figure 10.25). Higher levels of creatine and creatine phosphate provide more quick energy for short-term muscular activity. Creatine supplementation has been shown to improve performance in high-intensity exercise lasting 30 seconds or less. It is therefore beneficial for exercise that requires explosive bursts of energy, such as sprinting and weight lifting, but not for long-term endurance activities, such as marathons.

Athletes also take creatine supplements to increase muscle mass and strength. Some of the increase in lean body mass is believed to be due to water retention related
The Issue: Energy drinks are sold alongside sports drinks, and manufacturers of these beverages often sponsor athletes and athletic events. Should they be used as ergogenic aids? Is drinking them a safe way to improve your game?

The popularity of energy drinks with names like Red Bull, Monster, and Full Throttle has soared over the past decade. They promise to keep you alert to study, work, drive, party all night, and perhaps excel at your next athletic competition. The main ingredients in these drinks are sugar and caffeine. Glucose is an important fuel for exercise, and caffeine is known to enhance endurance, so these drinks may seem like an ideal ergogenic aid.

A traditional sports drink, like Gatorade, contains about 28 g of sugar in 16 ounces; a typical energy drink provides twice this much (55 to 60 g, or about 14 teaspoons). Since carbohydrate fuels activity, it may seem that the additional sugar would provide energy for prolonged exercise. But more is not always better during activity. The double load of sugar cannot be absorbed quickly, and unabsorbed sugar in the stomach can cause GI distress and also slow fluid absorption.

The caffeine content of energy drinks ranges from 50 to about 500 mg per can or bottle. Caffeine is an effective ergogenic aid that enhances endurance when consumed before or during exercise. But too much caffeine, referred to as caffeine intoxication, causes nervousness, anxiety, restlessness, insomnia, gastrointestinal upset, tremors, increased blood pressure, and rapid heartbeat. A number of cases of caffeine-associated death, seizure, and cardiac arrest have occurred after consumption of energy drinks. Even if the caffeine in an energy drink increases endurance, depending on when it is consumed, it can affect timing and coordination and hurt overall performance. Caffeine is also a diuretic; at the levels contained in these drinks, it may contribute to dehydration, particularly in first-time users. The FDA limits the amount of caffeine in soft drinks to 0.02% (about 71 mg in 12 oz), but energy drinks are considered dietary supplements, so the caffeine content is not regulated.

Energy drinks often also contain other ingredients that promise to improve performance, such as B vitamins, taurine, guarana, and ginseng. B vitamins are needed to produce ATP, so they are marketed to enhance energy production from sugar. But unless you are deficient in these vitamins, drinking them in an energy drink will not enhance your ATP production. Taurine is an amino acid that may reduce the amount of muscle damage and improve exercise performance and capacity, but not all research supports these claims. Guarana is an herbal ingredient that contains caffeine as well as small amounts of the stimulants theobromine and theophylline. The extra caffeine from guarana (not included in the caffeine listed for these beverages) may contribute to caffeine toxicity. Ginseng is also claimed to have performance-enhancing effects, but these effects have not been demonstrated scientifically. In general, the amounts of these ingredients are too small to have much effect, and the safety of consuming them in combination with caffeine prior to or during exercise has yet to be established.

So should you down an energy drink before your next competition? They do provide a caffeine boost, but is it so much caffeine that you risk dehydration, high blood pressure, and heart problems? Energy drinks provide sugar to fuel activity, but will they upset your stomach? What about the herbal ingredients—do they offer a benefit you are looking for?

Think critically: Use the table below to assess the advantages and disadvantages of consuming an 8-oz can of Red Bull versus a 12-oz can of Coca-Cola Classic before your 30-minute run.

<table>
<thead>
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<th>Caffeine content</th>
<th>Serving (fluid ounces)</th>
<th>Caffeine (mg)</th>
<th>Sugar (g)</th>
<th>Energy (calories)</th>
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<td>100-200</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Espresso with sugar</td>
<td>1.5</td>
<td>100</td>
<td>15-30</td>
<td>60-120</td>
</tr>
<tr>
<td>Coca-Cola Classic</td>
<td>12</td>
<td>35</td>
<td>39</td>
<td>140</td>
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<tr>
<td>Mountain Dew</td>
<td>12</td>
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<tr>
<td>Monster</td>
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<td>Jolt Cola</td>
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<td>Full Throttle</td>
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to creatine uptake in the muscle. In addition, an increase in muscle mass and strength may occur when supplementation is combined with muscle-strengthening exercises because the increase in muscle creatine permits a higher level of training intensity, which leads to greater muscle hypertrophy.\textsuperscript{39}

Creatine supplementation at intakes of up to 5 g per day appears to be safe for up to a year, but the safety of higher doses over the long term has not been established.\textsuperscript{40} Ingestion of creatine immediately before or during exercise is not recommended, and the FDA has advised consumers to consult a physician before using creatine.

**Supplements to Enhance Endurance**

Sprinters and weight lifters can benefit from increases in creatine phosphate levels, but endurance athletes are more concerned about running out of glycogen. Glycogen is spared when fat is used as an energy source, allowing exercise to continue for a longer time before glycogen is depleted and fatigue sets in. Supplements that increase the amount of fat or oxygen available to the muscle cell are used to increase endurance.

Carnitine supplements are marketed as fat burners—substances that increase the utilization of fat during exercise. Carnitine is needed to transport fatty acids into the mitochondria, where they are used to produce ATP by aerobic metabolism. However, enough carnitine is made in the body to ensure efficient use of fatty acids. Carnitine supplements have not been shown to increase endurance.\textsuperscript{41}

Medium-chain triglycerides (MCT) are composed of fatty acids with medium-length carbon chains (8 to 10 carbons). These fatty acids can be absorbed directly into the blood without first being incorporated into chylomicrons. They are therefore absorbed quickly, causing blood fatty acids levels to rise and thereby increasing the availability of fat as a fuel for exercise. Nevertheless, research has not found that supplementation with MCT increases endurance, spares glycogen, or enhances performance.\textsuperscript{42}

Caffeine is a stimulant found in coffee, tea, soft drinks, and energy drinks (see Debate: Energy Drinks for Athletic Performance\textsuperscript{43}). Consuming 3 to 6 mg of caffeine per kilogram of body weight, an amount equivalent to about 2.5 cups of percolated coffee, up to an hour before exercising as well as consuming smaller doses of caffeine during exercise (1 to 2 mg/kg) have been shown to improve endurance.\textsuperscript{38} Caffeine enhances the release of fatty acids. When fatty acids are used as a fuel source, less glycogen is used, and the onset of fatigue is delayed. Athletes who are unaccustomed to caffeine respond better to it than do those who consume caffeine routinely. Caffeine also improves concentration and enhances alertness, but in some athletes, it may impair performance by causing gastrointestinal upset.

Athletes also use the hormone erythropoietin, known as EPO, to enhance endurance. Natural erythropoietin is produced by the kidneys and stimulates cells in the bone marrow to differentiate into red blood cells. EPO can enhance endurance by increasing the ability to transport oxygen to the muscles. It therefore increases aerobic capacity and spares glycogen. However, too much EPO can cause production of too many red blood cells, which can lead to excessive blood clotting, heart attacks, and strokes. EPO was banned in 1990, after it was linked to the deaths of more than a dozen cyclists.\textsuperscript{30}

**Other Supplements**

In addition to the supplements discussed thus far, hundreds of other products are marketed to athletes. Most have no effect on performance. For example, brewer’s yeast is a source of B vitamins and some minerals but has not been found to have any ergogenic properties. Likewise, there is no evidence to support claims that bee pollen or wheat germ oil enhance performance. Royal jelly is a substance that worker bees produce to help the queen bee grow larger and live longer, but it does not appear to enhance athletic capacity in humans. Supplements of DNA and RNA are marketed to aid in tissue regeneration. DNA and RNA are needed to synthesize proteins, but they are not required in the diet, and supplements do not help replace damaged cells.

Herbal products are also marketed to athletes. Most have not been studied extensively for their ergogenic effects, so the only evidence of their benefits is anecdotal. Many can harm health as well as performance, so athletes should consider the risks before using these products.

### CONCEPT CHECK

1. **How** do anabolic steroids affect the production of testosterone?

2. **Why** are creatine supplements beneficial for sprint and strength athletes?

3. **How** does caffeine increase endurance?
Summary

1 Physical Activity, Fitness, and Health 354

- Regular exercise improves fitness. How fit an individual is depends on his or her cardiorespiratory endurance, muscle strength, muscle endurance, flexibility, and body composition. Regular aerobic exercise improves aerobic capacity. Muscle-strengthening exercise increases muscle strength and endurance.

- Regular exercise can reduce the risk of chronic diseases such as obesity, heart disease, diabetes, and osteoporosis. It can reduce overall mortality even in obese individuals.

- Exercise helps manage body weight by increasing energy expenditure, as shown in the graph, and by increasing the proportion of body weight that is lean tissue.

Exercise increases energy expenditure • Figure 10.3

2 Exercise Recommendations 357

- To reduce the risk of chronic disease, a minimum of 30 minutes of moderate-intensity aerobic exercise on most days is recommended, as indicated by the calendar. A well-designed fitness program involves aerobic exercise, stretching, and muscle-strengthening exercises.

Exercise recommendations • Figure 10.4

- An exercise program should include activities that are enjoyable, convenient, and safe. Rest is important to allow the body to recover and rebuild. In serious athletes, inadequate rest can lead to overtraining syndrome.
The combination of excessive exercise and energy restriction puts female athletes at risk for the female athlete triad, shown here.

### Female athlete triad • Figure 10.15

- **Disordered Eating**
- **Low energy intake** reduces the intake of calcium and other nutrients important for bone health.
- **Osteoporosis**
  - Estrogen is needed for calcium homeostasis in the bone and for calcium absorption in the intestines. Low levels lead to low peak bone mass, premature bone loss, and increased risk of stress fractures.
- **Amenorrhea**
  - Low estrogen causes amenorrhea.

- The extreme energy restriction of an eating disorder combined with exercise creates a physiological condition that is similar to starvation, which contributes to a drop in estrogen levels. Low estrogen causes amenorrhea.

### Changes in the source of ATP over time • Figure 10.9

![Graph showing changes in the source of ATP over time](image)

- For short-term, high-intensity activity, ATP is generated primarily from the anaerobic metabolism of glucose from glycogen stores. Anaerobic metabolism uses glucose more rapidly and produces lactic acid. Both of these factors are associated with the onset of fatigue. For lower-intensity exercise of longer duration, aerobic metabolism predominates, and both glucose and fatty acids are important fuel sources.

- Fitness training causes changes in the cardiovascular system and muscles that improve oxygen delivery and utilization, allowing aerobic exercise to be sustained for longer periods at higher intensity.

### Energy and Nutrient Needs for Physical Activity • 367

- The diet of an active individual should provide sufficient energy to fuel activity. The pressure to compete and maintain a body weight that is optimal for their sport puts some athletes at risk for eating disorders. A combination of excessive exercise and energy restriction puts female athletes at risk for the female athlete triad, shown here.

- To maximize glycogen stores, optimize performance, and maintain and repair lean tissue, a diet providing about 60% of energy from carbohydrate, 20 to 25% of energy from fat, and about 15 to 20% of energy from protein is recommended.

- Sufficient vitamins and minerals are needed to generate ATP from macronutrients, to maintain and repair tissues, and to transport oxygen and wastes to and from the cells. Most athletes who consume a varied diet that meets their energy needs also meet their vitamin and mineral needs from their diet alone. Those who restrict their food intake may be at risk for deficiencies. Increased iron needs and greater iron losses due to fitness training put athletes, particularly female athletes, at risk for iron deficiency.

- Water is needed to ensure that the body can be cooled and that nutrients and oxygen can be delivered to body tissues. If water intake is inadequate, dehydration can lead to a decline in exercise performance and increase the risk of heat-related illness. Adequate fluid intake before exercise ensures that athletes begin exercise well hydrated. Fluid intake during and after exercise must replace water lost in sweat and from evaporation through the lungs. Plain water is an appropriate fluid to consume for most exercise. Beverages containing carbohydrate and sodium are recommended for exercise lasting more than an hour. Drinking plain water during extended exercise increases the risk of hyponatremia.

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Competitive endurance athletes may benefit from glycogen supercompensation (carbohydrate loading), which maximizes glycogen stores before an event. Meals eaten before competition should help ensure adequate hydration, provide moderate amounts of protein, be high enough in carbohydrate to maximize glycogen stores, be low in fat and fiber to speed gastric emptying, and satisfy the psychological needs of the athlete. During exercise, athletes need beverages and food to replace lost fluid and provide carbohydrate and sodium. Postcompetition meals should replace lost fluids and electrolytes, provide carbohydrate to restore muscle and liver glycogen, and provide protein for muscle protein synthesis and repair.

Anabolic steroids combined with muscle-strengthening exercise increase muscle size and strength, but these supplements are illegal and have dangerous side effects.

Creatine supplementation increases muscle creatine phosphate levels, as illustrated here, and has been shown to increase muscle mass and improve performance in short-duration, high-intensity exercise. Caffeine use can improve performance in endurance activities, but high doses can cause caffeine toxicity and contribute to dehydration in some athletes.

Creatine boosts creatine phosphate • Figure 10.25

Competitive endurance athletes may benefit from glycogen supercompensation or carbohydrate loading, which maximizes glycogen stores before an event. Meals eaten before competition should help ensure adequate hydration, provide moderate amounts of protein, be high enough in carbohydrate to maximize glycogen stores, be low in fat and fiber to speed gastric emptying, and satisfy the psychological needs of the athlete. During exercise, athletes need beverages and food to replace lost fluid and provide carbohydrate and sodium. Postcompetition meals should replace lost fluids and electrolytes, provide carbohydrate to restore muscle and liver glycogen, and provide protein for muscle protein synthesis and repair.

Key Terms

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Online Resources

- For more information on exercise recommendations, go to www.cdc.gov/physicalactivity/everyone/guidelines/index.html.
- Visit your WileyPLUS site for videos, animations, podcasts, self-study, and other media that will aid you in studying and understanding this chapter.
Critical and Creative Thinking Questions

1. On the way to an out-of-town soccer match, Max’s team stops at a fast-food restaurant. It is only about an hour before game time. Most of the boys have burgers, fries, and a soft drink. How might this affect their performance in the game? What would you recommend they do differently for the next match?

2. Evaluate your weekly physical activity. Does it meet the current exercise recommendations? Do you include activities to enhance your strength, endurance, and flexibility? Can each of these activities be performed year-round? If not, suggest alternative activities and locations for inclement weather. How could you improve on what you are currently doing?

3. As part of an exercise study, John is asked to ride a stationary bicycle while breathing into a mouthpiece to measure the gases in inhaled and exhaled air. During his ride, the intensity of the exercise is steadily increased. The graph below shows the results of this test. Based on the data in the graph, what is John’s aerobic capacity? Explain why?

4. Using your knowledge of energy production and body energy stores, explain why during exercise cells rely more on glucose and fat for energy than on protein.

5. Two friends are running a marathon together. One has participated in an intensive training program. The other was too busy and trained only a few hours a week. After about 5 minutes of running the marathon, they have settled into a slow, steady pace and are able to carry on a conversation. After an hour, the well-trained individual is feeling good and so increases her pace. The untrained person tries to keep up but is no longer able to talk, and after about 15 minutes is fatigued and needs to stop. Why does the untrained person tire faster?

6. David is beginning an exercise program. He plans to run before lunch and then play racquetball every night after dinner. When he begins his exercise program, he finds that he feels lethargic and hungry before his late-morning run. After running, he doesn’t have much of an appetite, so he saves his lunch until midafternoon. He is still hungry enough to eat dinner at home with his family but finds that he is getting stomach cramps and is too full when he goes to play racquetball. His typical diet is

   - Breakfast: Orange juice, coffee
   - Lunch: Ham and cheese sandwich, potato chips, soft drink, cookies
   - Dinner: Steak, baked potato with sour cream and butter, green beans in butter sauce, salad with Italian dressing, whole milk

How might David change his diet to make it better suited to his exercise program? Do you think David will be able to stick with this exercise program? Why or why not? Suggest some changes that would make David’s exercise program more convenient and more balanced.

7. Do a risk–benefit analysis of an ergogenic aid. (A quick way to do this is to use the Internet to collect information.) List the risks and benefits and then write a conclusion, stating why you would or would not take this substance.

What is happening in this picture?

During competitive events, cyclists often spend six or more hours a day riding their bikes. This rider is collecting water bottles from his team’s car. He will carry these ahead and deliver them to the other cyclists on his team.

Think Critically

1. How much might someone need to drink during six hours of cycling?
2. What type of fluid do you think is in the water bottles? Why?
3. What type of food might the riders want to pick up from their team car?
1. Which bar on this graph indicates the proportion of energy obtained from glucose, fatty acids, and amino acids that would be used as fuel while studying for an exam?
   a. A
   b. B
   c. C

2. Which of the following occurs as a result of aerobic exercise training?
   a. decrease in resting heart rate
   b. increase in the number of red blood cells
   c. more muscle mitochondria
   d. greater glycogen storage
   e. all of the above

3. If an athlete loses a lot of water and salt in sweat but drinks only water, he is at risk for ________.
   a. hypertension
   b. hypodermic
   c. hyperactivity
   d. hyponatremia
   e. dehydration

4. Which statement is true of the energy system indicated by the arrow?
   a. It provides energy for the first 10 to 15 seconds of activity.
   b. It can use glucose, amino acids, and fatty acids to produce ATP.
   c. It produces ATP rapidly but inefficiently.
   d. It can use only glucose to generate ATP.

5. Andreas is 30 years old. He would like to exercise at an intensity that ensures he is in his aerobic zone. Use this graph to determine the heart rate range that is appropriate for Andreas.
   a. 114 to 162
   b. 114 to 190
   c. 120 to 170
   d. 87 to 120
   e. 123 to 170

6. The source of fuel in the first few seconds of exercise is ________.
   a. ATP and creatine phosphate
   b. stored glycogen
   c. glucose made by the liver
   d. fatty acids
   e. protein

7. Which nutrient can be used to produce energy in the absence of oxygen?
   a. protein
   b. fatty acids
   c. glucose
   d. B vitamins
   e. lactic acid
14. Amy lives in Connecticut, where the summer temperature and humidity can vary dramatically from day to day. On Monday, it is 88°F, with a relative humidity of 90%. On Tuesday, the temperature goes up to 96°F, but the humidity drops to 60%. By Wednesday, the temperature has dropped slightly to 92°F, but the humidity has increased to 65%. On Thursday, the temperature drops to 90°F, and the humidity climbs to 85%. Use the table shown here to determine which day has the lowest heat index.

a. Monday  c. Wednesday  
b. Tuesday  d. Thursday

15. Which of the following best describes how creatine supplements enhance performance?

a. They increase the amount of creatine phosphate in the muscle.
b. They increase the transport of fatty acids into the mitochondria.
c. They increase delivery of oxygen to the muscle.
d. They eliminate free radicals.