Human Energy

CHAPTER THREE

LEARNING OBJECTIVES

After studying this chapter, you should be able to:

1. Understand the interrelationships among the various forms of chemical, thermal, and mechanical energy, and be able to perform mathematical conversions from one form of energy to another.
2. Identify the three major human energy systems, their major energy sources as stored in the body, and various nutrients needed to sustain them.
3. List the components of total daily energy expenditure (TDEE) and how each contributes to the total amount of caloric energy expended over a 24-hour period.
4. Describe the various factors that may influence resting energy expenditure (REE).
5. List and explain the various means whereby energy expenditure during exercise, or the thermic effect of exercise (TEE), may be measured, and be able to calculate conversions among the various methods.
6. Explain the relationship between exercise intensity, particularly walking and running, and energy expenditure, and relate walking and running intensity to other types of physical activities.
7. Understand the concept of the physical activity level (PAL) and how it relates to estimated energy expenditure (EER). Calculate your EER based on an estimate of your PAL and the physical activity coefficient (PA).
8. Describe the role of the three energy systems during exercise.
9. Explain the various causes of fatigue during exercise and discuss nutritional interventions that may help delay the onset of fatigue.

KEY TERMS

adenosine triphosphate 88
aerobic glycolysis 91
aerobic lipolysis 92
anaerobic glycolysis 91
ATP-PCr system 90
basal energy expenditure (BEE) 94
basal metabolic rate 94
Calorie (kilocalorie) 87
calorimeter 86
chronic fatigue syndrome 107
crossover concept 106
dietary-induced thermogenesis (DIT) 94
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work 84

Introduction

As noted in chapter 1, the body uses the food we eat to provide energy, to build and repair tissues, and to regulate metabolism. Of these three functions, the human body ranks energy production first and will use food for this purpose at the expense of the other two functions in time of need. Energy is the essence of life.

Through technological processes, humans have harnessed a variety of energy sources such as wind, waterfalls, the sun, wood, and oil to operate the machines invented to make life easier. However, humans cannot use any of these energy sources for their own metabolism but must rely on food sources found in nature. The food we eat must be converted into energy forms that the body can use. Thus, the human body is equipped with a number of metabolic systems to produce and regulate energy for its diverse needs, such as synthesis of tissues, movement of substances between tissues, and muscular contraction.

Sport energy! The underlying basis for the control of movement in all sports is human energy, and successful performance depends upon the ability of the athlete to produce the right amount of energy and to control its application to the specific demands of the sport. Sports differ in their energy demands. In some events, such as the 100-meter dash, success is dependent primarily upon the ability to produce energy very rapidly. In others, such as the 26.2-mile marathon, energy need not be produced so rapidly but must be sustained for a much longer period. In still other sports, such as golf, the athlete need not only produce energy at varying rates (compare the drive with the putt) but must carefully control the application of that energy. Thus, each sport imposes specific energy demands upon the athlete.

A discussion of the role of nutrition as a means to help provide and control human energy is important from several standpoints. First, inadequate supplies of necessary energy nutrients, such as muscle glycogen or blood glucose, may cause fatigue. Fatigue also may be caused by the inability of the energy systems to function optimally because of a deficiency of other nutrients, such as selected vitamins and minerals. In addition, the human body is capable of storing energy reserves in a variety of body forms, including body fat and muscle tissue. Excess body weight in the form of fat or decreased body weight due to losses of muscle tissue may adversely affect some types of athletic performance.

One purpose of this chapter is to review briefly the major human energy systems and how they are used in the body under conditions of exercise and rest. Following this, chapters 4 through 9 discuss the role of each of the major classes of nutrients as they relate to energy production in the human body, with the primary focus on prevention of fatigue caused by impaired energy production. Another purpose of this chapter is to discuss the means by which humans store and expend energy. Chapters 10 through 12 focus on weight control methods and expand on some of the concepts presented in this chapter.

Measures of Energy

What is energy?

For our purposes, **energy** represents the capacity to do work. **Work** is one form of energy, often called mechanical energy. When we throw a ball or run a mile, we have done work; we have produced mechanical energy.

Energy exists in a variety of other forms in nature, such as the light energy of the sun, nuclear energy in uranium, electrical energy in lightning storms, heat energy in fires, and chemical energy in oil. The six forms of energy—mechanical, chemical, heat, electrical, light, and nuclear—are interchangeable according to various laws of thermodynamics. We take advantage of these laws every day. One such example is the use of the chemical energy in gasoline to produce mechanical energy—the movement of our cars.

In the human body, four of these types of energy are important. Our bodies possess stores of chemical energy that can be used to produce electrical energy for creation of electrical nerve impulses, to produce heat to help keep our body temperature at 37°C (98.6°F) even on cold days, and to produce mechanical work through muscle shortening so that we may move about.

The sun is the ultimate source of energy. Solar energy is harnessed by plants, through photosynthesis, to produce either plant carbohydrates, fats, or proteins, all forms of stored chemical energy. When humans consume plant and animal products, the carbohydrates, fats, and proteins undergo a series of metabolic changes and are utilized to develop body structure, to regulate body processes, or to provide a storage form of chemical energy (figure 3.1).

The optimal intake and output of energy is important to all individuals, but especially for the active person. To perform to capacity, body energy stores must be used in the most efficient manner possible.

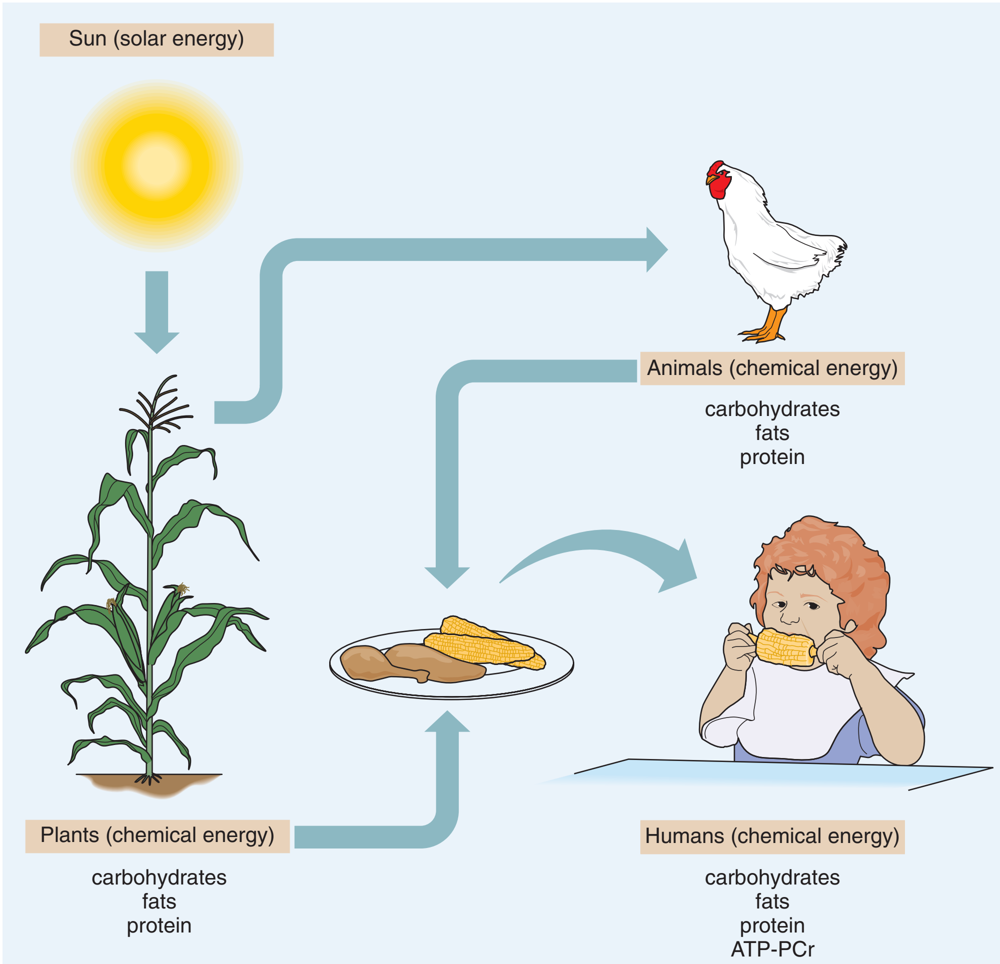


FIGURE 3.1 Through photosynthesis, plants utilize solar energy and convert it to chemical energy in the form of carbohydrates, fats, or proteins. Animals eat plants and convert the chemical energy into their own stores of chemical energy—primarily fat and protein. Humans ingest food from both plant and animal sources and convert the chemical energy for their own stores and use.

How do we measure work and energy?

Energy has been defined as the ability to do work. According to the physicist's definition, work is simply the product of force times vertical distance, or in formula format, Work = Force × Distance. When we speak of how fast work is done, the term **power** is used. Power is simply work divided by time, or Power = Work/Time.

Two major measurement systems have been used in the past to express energy in terms of either work or power. The metric system has been in use by most of the world, while England, its colonies, and the United States have used the English system. In an attempt to provide some uniformity in measurement systems around the world, the International Unit System (*Systeme International d'Unites,* or SI) has been developed. Most of the world has adopted the SI. Although legislation has been passed by Congress to convert the United States to the SI, and terms such as *gram, kilogram, milliliter, liter,* and *kilometer* are becoming more prevalent, it appears that it will take some time before this system becomes part of our everyday language.

The SI is used in most scientific journals today, but the other two systems appear in older journals. Terms that are used in each system are presented in table 3.1. For our purposes in this text, we shall use several English terms that are still in common usage in the United States, but if you read scientific literature, you should be able to convert values among the various systems if necessary. For example, work may be expressed as either foot-pounds, kilogram-meters (kgm), joules, or watts. If you weigh 150 pounds and climb a 20-foot flight of stairs in one minute, you have done 3,000 foot-pounds of work. One kgm is equal to 7.23 foot-pounds, so you would do about 415 kgm. One **joule** is equal to about 0.102 kgm, so you have done about 4,062 joules of work. One watt is equal to one joule per second, so you have generated about 68 watts of power. Some basic interrelationships among the measurement systems are noted in table 3.2. Other equivalents may be found in appendix A.

In general, exercise scientists and nutritionists are interested in measuring work output under two conditions. One condition involves specific exercise tasks. Various laboratory techniques have been developed to accurately record work output during exercise, such as measurement of kgm or watts on a cycle ergometer. The other condition involves measurement of work output during normal daily activities over prolonged periods of time, such as a

TABLE 3.1 Terms in the English, metric, and international systems

Unit	English system	Metric system	International system
Mass	slug	kilogram (kg)	kilogram (kg)
Distance	foot (ft)	meter (m)	meter (m)
Time	second (s)	second (s)	second (s)
Force	pound (lb)	newton (N)	newton (N)
Work	foot-pound (ft-lb)	kilogram-meter (kgm)	joule (J)
Power	horsepower (hp)	watt (W)	watt (W)

TABLE 3.2 Some interrelationships between work measurement systems

Weight	Distance	Work	Power
1 kilogram = 2.2 pounds	1 meter = 3.28 feet	1 kgm = 7.23 foot-pounds	1 watt = 1 joule per second
1 kilogram = 1,000 grams	1 meter = 1.09 yards	1 kgm = 9.8 joules	1 watt = 6.12 kgm per minute 1 watt = 0.0013 horsepower
454 grams = 1 pound	1 foot = 0.30 meter	1 foot-pound = 0.138 kgm	1 horsepower = 550 foot-pounds per second
1 pound = 16 ounces	1,000 meters = 1 kilometer	1 foot-pound = 1.35 joules	1 horsepower = 33,000 foot-pounds per minute
1 ounce = 28.4 grams	1 kilometer = 0.6215 mile	1 newton = 0.102 kg	1 horsepower = 745.8 watts
3.5 ounces = 100 grams	1 mile = 1.61 kilometers 1 inch = 2.54 centimeters 1 centimeter = 0.39 inch	1 joule = 1 newton meter 1 kilojoule = 1,000 joules 1 megajoule = 1,000,000 joules 1 joule = 0.102 kgm 1 joule = 0.736 foot-pound 1 kilojoule = 102 kgm	

24-hour period. Various devices, such as small pedometers or accelerometers attached to the body, detect motion throughout the day and provide an approximation of daily work output.

To measure work we need to know the weight of an object and the vertical distance through which it is moved. This is fine according to the formal definition of work, but are you doing work while holding a stationary weight out in front of your body? According to the formal definition, the answer is no, because the distance the weight moved is zero. How about when you come down stairs as compared to going up? It is much easier to descend the stairs, and yet according to the formula you have done the same amount of work. Also, how about when you run a mile? You know you have worked, but most of the distance you covered was horizontal, not vertical. Accelerometers may provide accurate measurement of the amount of movement you do, but may not account for the energy you expend. For example, comparing an accelerometer with indirect calorimetry, Campbell and others noted that the accelerometer would overestimate the energy expenditure for some activities and underestimate it for others, but suggested that refinements may increase its accuracy. Therefore, we need to have means to express the energy expenditure of the human body other than simply the amount of work done.

The other means of measuring energy in the body deal with chemical and heat energy. Without going into much detail, look briefly at several different methods for measuring energy production in humans. First, a device known as a **calorimeter** may be used to measure the energy content of a given substance. Figure 3.2 shows how a bomb calorimeter works. For example, a gram of fat contains a certain amount of chemical energy. When placed in the calorimeter and oxidized completely, the heat it gives off can be recorded. We then know the heat energy of one gram of fat and can equate it to chemical or work units of energy if needed. Large, expensive whole-room calorimeters (metabolic chambers) are available that can accommodate human beings and measure their heat production under normal home activities and some conditions of exercise. This technique is known as *direct calorimetry.*

A second, more commonly used method of measuring energy is to determine the amount of oxygen an individual consumes, an *indirect calorimetry* technique. This procedure is normally done

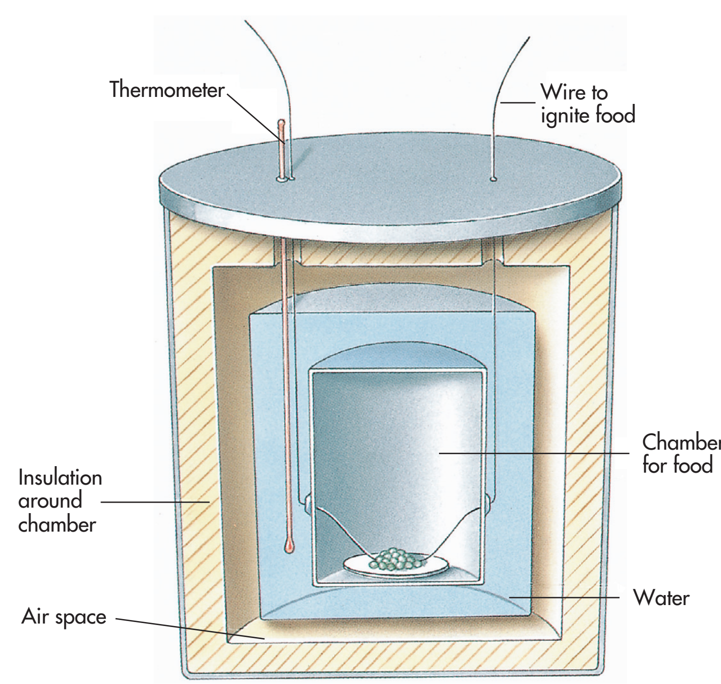


FIGURE 3.2 A bomb calorimeter. The food in the calorimeter is combusted via electrical ignition. The heat (Calories) given off by the food raises the temperature of the water, thereby providing data about the caloric content of specific foodstuffs.

under laboratory conditions (see figure 3.3), but lightweight portable oxygen analyzers are also available. The volume of oxygen one uses is usually expressed in liters (L) or milliliters (ml); one L is equal to 1,000 ml. One liter is slightly larger than a quart. In general, humans need oxygen, which helps metabolize the various nutrients in the body to produce energy. It is known that when oxygen combines with a gram of carbohydrate, fat, or protein, a certain amount of energy is released. If we can accurately measure the oxygen consumption (and carbon dioxide production) of an individual, we can get a pretty good measure of energy expenditure. The amount of oxygen used can be equated to other forms of energy, such as work done in foot-pounds or heat produced in Calories.

A third method is the doubly labeled water (DLW) technique in which stable isotopes of hydrogen and oxygen in water ($^{2}H_2{}^{18}O$) are ingested. This is a safe procedure as the isotopes are stable and emit no radiation. Analysis of urine and blood samples provide data on ^{2}H and ^{18}O excretion. The labeled oxygen is eliminated from the body as water and carbon dioxide, whereas the hydrogen is eliminated only as water. Subtracting the hydrogen losses from the oxygen losses provides a measure of carbon dioxide fluctuation, which may be converted to energy expenditure. Although expensive, the advantage of this technique is that it may be used with individuals while they perform their normal daily activities, and they need not be confined to a metabolic chamber or be attached to equipment to measure oxygen consumption.

Newer techniques have been developed to measure daily energy expenditure. Fully portable devices can be worn throughout the day and may monitor physiological functions such as muscle contraction, heart rate, oxygen consumption, and joint movements. Although all of these techniques to measure energy expenditure have limitations, they do provide useful data relative to the energy cost of exercise and normal daily activities. Schutz and others provide an excellent review of several means to measure daily physical activity energy expenditure.

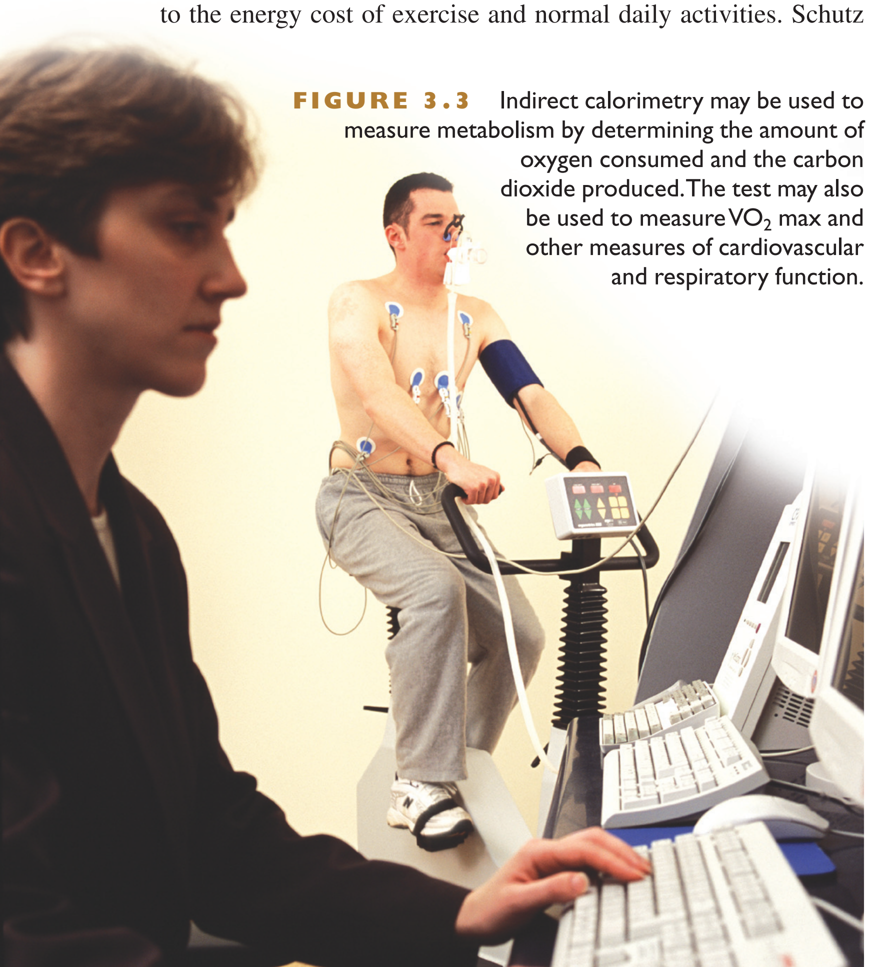


FIGURE 3.3 Indirect calorimetry may be used to measure metabolism by determining the amount of oxygen consumed and the carbon dioxide produced. The test may also be used to measure VO_2 max and other measures of cardiovascular and respiratory function.

What is the most commonly used measure of energy?

Although there are a number of different ways to express energy, the most common term used in the past and still most prevalent and understood in the United States by most people is **Calorie.**

A calorie is a measure of heat. One gram calorie represents the amount of heat needed to raise the temperature of one gram of water one degree Celsius; it is sometimes called the gram calorie. A kilocalorie is equal to 1,000 small calories. It is the amount of heat needed to raise 1 kg of water (1 L) one degree Celsius. In human nutrition, because the gram calorie is so small, the kilocalorie is the main expression of energy. It is usually abbreviated as kcal, kc, or C, or capitalized as Calorie. Throughout this book, *Calorie* or *C* will refer to the kilocalorie.

According to the principles underlying the first law of thermodynamics, energy may be equated from one form to another. Thus, the Calorie, which represents thermal or heat energy, may be equated to other forms of energy. Relative to our discussion concerning physical work such as exercise and its interrelationships with nutrition, it is important to equate the Calorie with mechanical work and the chemical energy stored in the body. As will be explained later, most stored chemical energy must undergo some form of oxidation in order to release its energy content as work.

The following represents some equivalent energy values for the Calorie in terms of mechanical work and oxygen utilization. Some examples illustrating several of the interrelationships will be used in later chapters.

1 C = 3,086 foot-pounds

1 C = 427 kgm

1 C = 4.2 kilojoules (kJ) or 4,200 joules

1 C = 200 ml oxygen (approximately)

Although the Calorie is the most commonly used expression in the United States for energy, work, and heat, **kilojoule** is the proper term in the SI. It is important for you to be able to convert from Calories to kilojoules, and vice versa. To convert Calories to kilojoules, multiply the number of Calories by 4.2 (4.186 to be exact); to convert kilojoules to Calories, divide the number of kilojoules by 4.2. Simply multiplying or dividing by 4 for each respective conversion will provide a ballpark estimate. In some cases megajoules (MJ), a million joules, are used to express energy. One MJ equals about 240 Calories, or 4.2 MJ is the equivalent of about 1,000 Calories.

Through the use of a calorimeter, the energy contents of the basic nutrients have been determined. Energy may be derived from the three major foodstuffs—carbohydrate, fat, and protein—plus alcohol. The caloric value of each of these three nutrients may vary somewhat, depending on the particular structure of the different forms. For example, carbohydrate may exist in several forms—as glucose, sucrose, or starch—and the caloric value of each will differ slightly. In general, one gram of each of the three nutrients, measured in a calorimeter, yields the following Calories:

1 gram carbohydrate = 4.30 C

1 gram fat = 9.45 C

1 gram protein = 5.65 C

1 gram alcohol = 7.00 C

Unfortunately, or fortunately if one is trying to lose weight, humans do not extract all of this energy from the food they eat. The human body is not as efficient as the calorimeter. For one, the body cannot completely absorb all the food eaten. Only about 97 percent of ingested carbohydrate, 95 percent of fat, and 92 percent of protein are absorbed. In addition, a good percentage of the protein is not completely oxidized in the body, with some of the nitrogen waste products being excreted in the urine. In summary, then, the caloric value of food is reduced somewhat in relation to the values given above. Although the following values are not exactly precise, they are approximate enough to be used effectively in determining the caloric values of the foods we eat. Thus, the following caloric values are used throughout this text as a practical guide:

1 gram carbohydrate = 4 C

1 gram fat = 9 C

1 gram protein = 4 C

1 gram alcohol = 7 C

For our purposes, the Calories in food represent a form of potential energy to be used by our bodies to produce heat and work (figure 3.4). However, the fact that fat has about twice the amount of energy per gram as carbohydrate does not mean that it is a better energy

FIGURE 3.4 Eight ounces of orange juice will provide enough chemical energy to enable an average man to produce enough mechanical energy to run about one mile.

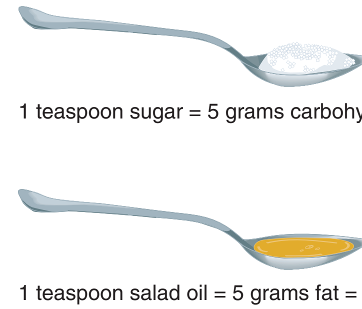


FIGURE 3.5 The Calorie as a measure of energy.

source for the active individual (figure 3.5), as we shall see in later chapters when we talk of the efficient utilization of body fuels.

Key Concept Recap

- Energy represents the capacity to do work, and food is the source of energy for humans.
- The Calorie, or kilocalorie, is a measure of chemical energy stored in foods; this chemical energy can be transformed into heat and mechanical work energy in the body. A related measure is the kilojoule. One Calorie is equal to 4.2 kilojoules.

Check for Yourself

Measure the height of a step on a flight of stairs or bleachers and convert it to feet (9 inches = 0.75 foot). Stepping in place, count the total number of steps you do in one minute. Multiply your count by the step height to determine the number of feet you have climbed. Next, multiply this value by your body weight in pounds to determine the number of foot-pounds of work you have done. Then, convert this number of foot-pounds to the equivalent amount of kilogram-meters (kgm), kilojoules (kJ), and Calories.

Human Energy Systems

How is energy stored in the body?

The ultimate source of all energy on earth is the sun. Solar energy is harnessed by plants, which take carbon, hydrogen, oxygen, and nitrogen from their environment and manufacture either carbohydrate, fat, or protein. These foods possess stored energy. When we consume these foods, our digestive processes break them down into simple compounds that are absorbed into the body and transported to various cells. One of the basic purposes of body cells is to transform the chemical energy of these simple compounds into forms that may be available for immediate use or other forms that may be available for future use.

Energy in the body is available for immediate use in the form of **adenosine triphosphate (ATP).** It is a complex molecule constructed with high-energy bonds, which, when split by enzyme action, can release energy rapidly for a number of body processes, including muscle contraction. ATP is classified as a high-energy compound and is stored in the tissues in small amounts. It is important to note that ATP is the immediate source of energy for all body functions, and the other energy stores are used to replenish ATP at varying rates.

Another related high-energy phosphate compound, **phosphocreatine (PCr),** is also found in the tissues in small amounts. Although it cannot be used as an immediate source of energy, it can rapidly replenish ATP.

ATP may be formed from either carbohydrate, fat, or protein after those nutrients have undergone some complex biochemical changes in the body. Figure 3.6 represents a basic schematic of how ATP is formed from each of these three nutrients. PCr is actually derived from excess ATP.

Because ATP and PCr are found in very small amounts in the body and can be used up in a matter of seconds, it is important to have adequate energy stores as a backup system. Your body stores of carbohydrate, fat, and protein can provide you with ample amounts of ATP, enough to last for many weeks even on a starvation diet. The digestion and metabolism of carbohydrate, fat, and protein are discussed in their respective chapters, so it is unnecessary to present that full discussion here. However, you may wish to preview figure 3.12 in order to visualize the metabolic interrelationships between the three nutrients in the body. For those who desire more detailed schematics of energy pathways, appendix G provides some of the major metabolic pathways for carbohydrate, fat, and protein.

It is important to note that parts of each energy nutrient may be converted to the other two nutrients in the body under certain circumstances. For example, protein may be converted into carbohydrate during prolonged exercise, whereas excess dietary carbohydrate may be converted to fat in the body during rest.

Table 3.3 summarizes how much energy is stored in the human body as ATP, PCr, and various forms of carbohydrate, fat, and protein. The total amount of energy, represented by Calories, is approximate and may vary considerably between individuals.

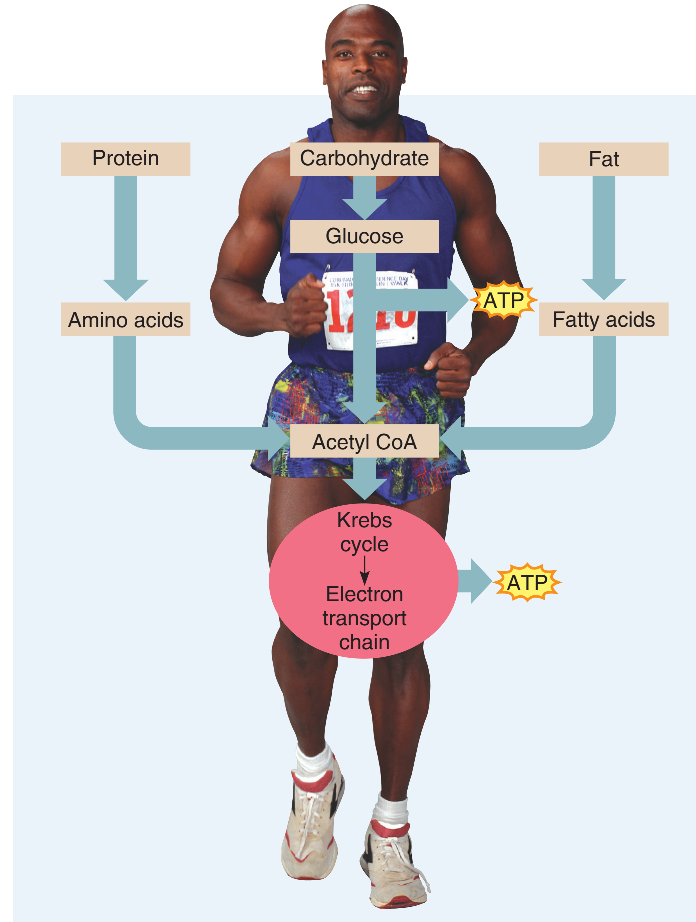


FIGURE 3.6 Simplified schematic of ATP formation from carbohydrate, fat, and protein. All three nutrients may be used to form ATP, but carbohydrate and fat are the major sources via the aerobic metabolism of the Krebs cycle. Carbohydrate may be used to produce small amounts of ATP under anaerobic conditions, thus providing humans with the ability to produce energy rapidly without oxygen for relatively short periods. For more details, see appendix G.

TABLE 3.3 Major energy stores in the human body with approximate total caloric value*

Energy source	Major storage form	Total body Calories	Total body kilojoules	Distance covered**
ATP	Tissues	1	4.2	17.5 yards
PCr	Tissues	4	16.8	70 yards
Carbohydrate	Serum glucose	20	88	350 yards
	Liver glycogen	400	1,680	4 miles
	Muscle glycogen	1,500	6,300	15 miles
Fat	Serum-free fatty acids	7	29.2	123 yards
	Serum triglycerides	75	315	0.75 mile
	Muscle triglycerides	2,500	10,500	25 miles
	Adipose tissue triglycerides	80,000	336,000	800 miles
Protein	Muscle protein	30,000	126,000	300 miles

*These values may have extreme variations depending on the size of the individual, amount of body fat, physical fitness level, and diet.
**Running at an energy cost of 100 Calories per mile (1.6 kilometers).

Carbohydrate is stored in limited amounts as blood glucose, liver glycogen, and muscle glycogen. The largest amount of energy is stored in the body as fats. Fats are stored as triglycerides in both muscle tissue and adipose (fat) tissue; triglycerides and free fatty acids (FFA) in the blood are a limited supply. The protein of the body tissues, particularly muscle tissue, is a large reservoir of energy but is not used under normal circumstances. Table 3.3 also depicts how far an individual could run using the total of each of these energy sources as the sole supply. The role of each of these macronutrient energy stores during exercise is an important consideration that is discussed briefly in this chapter and more extensively in their respective chapters.

What are the human energy systems?

Why does the human body store chemical energy in a variety of different forms? If we look at human energy needs from an historical perspective, the answer becomes obvious. Sometimes humans needed to produce energy at a rapid rate, such as when sprinting to safety to avoid dangerous animals. Thus, a fast rate of energy production was an important human energy feature that helped ensure survival. At other times, our ancient ancestors may have been deprived of adequate food for long periods, and thus needed a storage capacity for chemical energy that would sustain life throughout these times of deprivation. Hence, the ability to store large amounts of energy was also important for survival. These two factors—rate of energy production and energy capacity—appear to be determining factors in the development of human energy systems.

One need only watch weekend television programming for several weeks to realize the diversity of sports popular throughout the world. Each of these sports imposes certain requirements on humans who want to be successful competitors. For some sports, such as weight lifting, the main requirement is brute strength, while for others such as tennis, quick reactions and hand/eye coordination are important. A major consideration in most sports is the rate of energy production, which can range from the explosive power needed by a shot-putter to the tremendous endurance capacity of an ultramarathoner. The physical performance demands of different sports require specific sources of energy.

As noted above, the body stores energy in a variety of ways—in ATP, PCr, muscle glycogen, and so on. In order for this energy to be used to produce muscular contractions and movement, it must undergo certain biochemical reactions in the muscle. These biochemical reactions serve as a basis for classifying human energy expenditure by three energy, or power, systems: the ATP-PCr system, the lactic acid system, and the oxygen system.

The **ATP-PCr system** is also known as the phosphagen system because both adenosine triphosphate (ATP) and phosphocreatine (PCr) contain phosphates. ATP is the immediate source of energy for almost all body processes, including muscle contraction. This high-energy compound, stored in the muscles, rapidly releases energy when an electrical impulse arrives in the muscle. No matter what you do, scratch your nose or lift 100 pounds, ATP breakdown makes the movement possible. ATP must be present for the muscles to contract. The body has a limited supply of ATP and must replace it rapidly if muscular work is to continue. See figure 3.7 for a graphical representation of ATP breakdown.

PCr, which is also a high-energy compound found in the muscle, can help form ATP rapidly as ATP is used. Energy released when PCr splits is used to form ATP from ADP and P. PCr is also in short supply and needs to be replenished if used. PCr breakdown to help resynthesize ATP is illustrated in figure 3.8.

The ATP-PCr system is critical to energy production. Because these phosphagens are in short supply, any all-out exercise for 5 to 10 seconds could deplete the supply in a given muscle. Hence, the phosphagens must be replaced, and this is the function of the other energy sources. Although some supplements, such as creatine, discussed in later chapters are theorized to facilitate ATP or PCr replenishment, we do not eat ATP-PCr per se, but we can produce it from

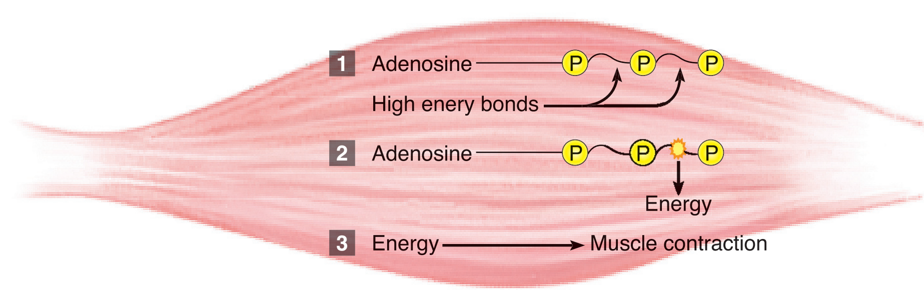


FIGURE 3.7 ATP, adenosine triphosphate. *(1)* ATP is stored in the muscle in limited amounts. *(2)* Splitting of a high-energy bond releases adenosine diphosphate (ADP), inorganic phosphate (P), and energy, which *(3)* can be used for many body processes, including muscular contraction. The ATP stores may be used maximally for fast, all-out bursts of power that last about one second. ATP must be replenished from other sources for muscle contraction to continue.

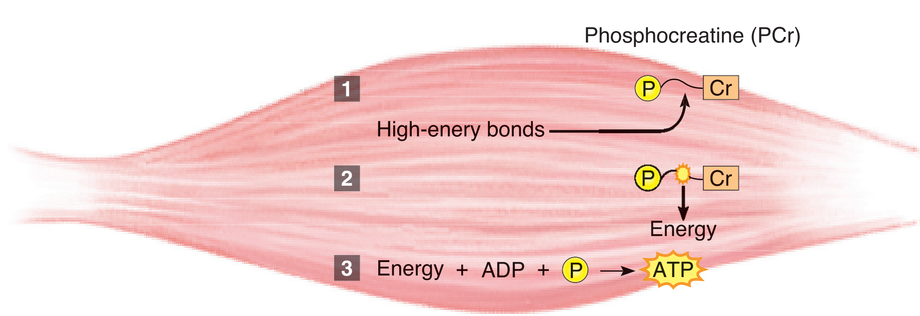


FIGURE 3.8 Phosphocreatine (PCr). *(1)* PCr is stored in the muscle in limited amounts. *(2)* Splitting of the high-energy bond releases energy, which *(3)* can be used to rapidly synthesize ATP from ADP and P. ATP and PCr are called phosphagens and together represent the ATP-PCr energy system. This system is utilized primarily for quick, maximal exercises lasting about 1 to 6 seconds, such as sprinting.

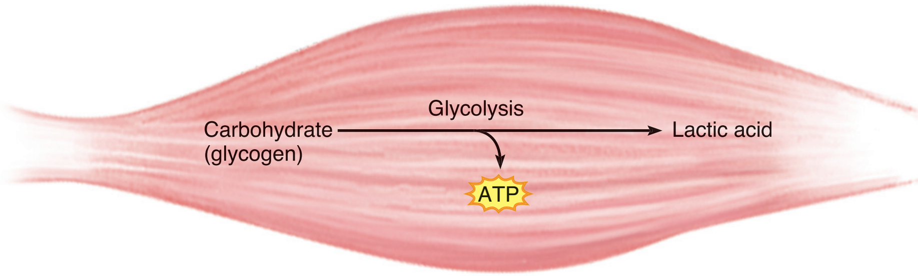


FIGURE 3.9 The lactic acid energy system. Muscle glycogen can break down without the utilization of oxygen. This process is called anaerobic glycolysis. (See appendix G, figure G.1, for more details.) ATP is produced rapidly, but lactic acid is the end product. Lactic acid may be a major cause of fatigue in the muscle. The lactic acid energy system is utilized primarily during exercise bouts of very high intensity, those conducted at maximal rates for about 30 to 120 seconds.

the other nutrients stored in our body. PCr replenishment will not be discussed, but keep in mind that when ATP is being regenerated, so is some PCr. In summary, the value of the ATP-PCr system is its ability to provide energy rapidly, for example, in sport events such as competitive weight lifting or sprinting 100 meters. *Anaerobic power* is a term often associated with the ATP-PCr energy system.

The **lactic acid system** cannot be used directly as a source of energy for muscular contraction, but it can help replace ATP rapidly when necessary. If you are exercising at a high intensity level and need to replenish ATP rapidly, the next best source of energy besides PCr is muscle glycogen. To be used for energy, muscle glycogen must be broken down to glucose, which undergoes a series of reactions to eventually form ATP, a process called **glycolysis.** One of the major factors controlling the metabolic fate of muscle glycogen is the availability of oxygen in the muscle cell. In simple terms, if oxygen is available, a large amount of ATP is formed. This is known as **aerobic glycolysis.** If inadequate oxygen is available to meet the energy demands of the exercise task or to maintain a high level of aerobic glycolysis, then insufficient ATP is formed and lactic acid is a by-product of the process to generate more ATP. This is known as anaerobic (inadequate oxygen) glycolysis; **anaerobic glycolysis** is the scientific term for the lactic acid energy system. The lactic acid system is diagrammed in figure 3.9. It is used in sport events in which energy production is near maximal for 30–120 seconds, such as a 200- or 800-meter run. *Anaerobic capacity* is a term often associated with the lactic acid energy system.

The lactic acid system has the advantage of producing ATP rapidly. Its capacity is limited in comparison to aerobic glycolysis, for only about 5 percent of the total ATP production from muscle glycogen can be released. Moreover, the lactic acid produced as a by-product may be involved in the onset of fatigue. Lactic acid releases a hydrogen ion that increases the acidity within the muscle cell and disturbs the normal cell environment. The processes of energy release and muscle contraction in the muscle cell are controlled by enzymes whose functions may be impaired by the increased acidity in the cell. The lactate present after loss of the hydrogen ion still has considerable energy content, which may be used by other tissues for energy or converted back into glucose in the liver.

The third system is the **oxygen system.** It is also known as the aerobic system. *Aerobics* is a term used by Dr. Kenneth Cooper in 1968 to describe a system of exercising that created an exercise revolution in this country. In essence, aerobic exercises are designed to stress the oxygen system and provide benefits for the heart and lungs. Figure 3.10 represents the major physiological processes involved in the oxygen system. The oxygen system, like the lactic acid system, cannot be used directly as a source of energy for muscle contraction, but it does produce ATP in rather large quantities from other energy sources in the body. Muscle glycogen, liver glycogen, blood glucose, muscle triglycerides, blood FFA and triglycerides, adipose cell triglycerides, and body protein all may be ultimate sources of energy for ATP production and subsequent muscle contraction. To do this, glycogen and fats must be present within the muscle cell or must enter the muscle cell as glucose, FFA, or amino acids. Through a complex series of reactions metabolic by-products of carbohydrate, fat, or protein combine with oxygen to produce energy, carbon dioxide, and water. These reactions occur in the energy powerhouse of the cell, the **mitochondrion.** The whole series of events of oxidative

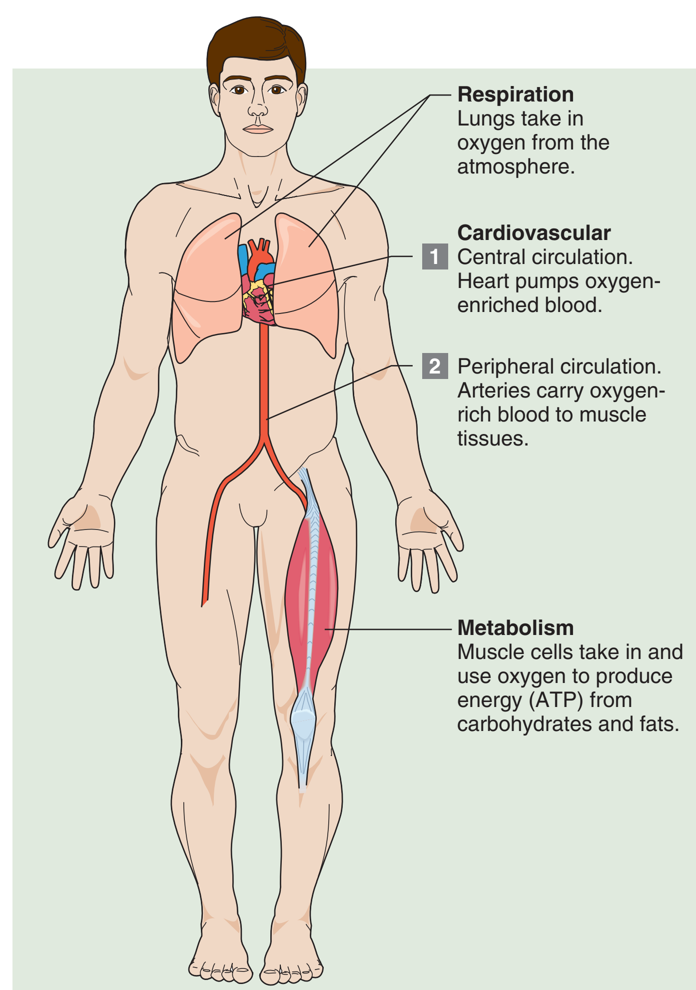


FIGURE 3.10 Physiological processes involved in oxygen uptake.

energy production primarily involves aerobic processing of carbohydrates and fats (and small amounts of protein) through the **Krebs cycle** and the **electron transfer system.** The oxygen system is depicted in figure 3.11. The Krebs cycle and the electron transfer system represent a highly structured array of enzymes designed to remove hydrogen, carbon dioxide, and electrons from substrates such as glucose. At different steps in this process energy is released and ATP is formed, with most of the ATP produced during the electron transfer process. The hydrogen and electrons eventually combine with oxygen to form water (see appendix G).

Although the rate of ATP production is lower, the major advantage of the oxygen system over the other two energy systems is the production of large amounts of energy in the form of ATP. However, oxygen from the air we breathe must be delivered to the muscle cells deep in the body and enter the mitochondria to be used.

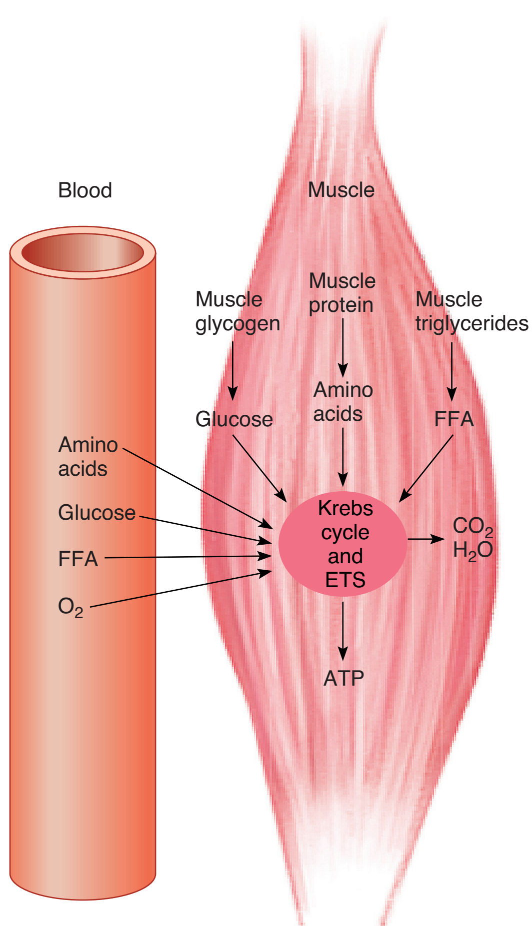


FIGURE 3.11 The oxygen energy system. The muscle stores of glycogen and triglycerides, along with blood supplies of glucose and free fatty acids (FFA), as well as small amounts of muscle protein and amino acids, undergo complex biochemical changes for entrance into the Krebs cycle and the associated electron transfer system (ETS). In this process, in which oxygen is the final acceptor to the electron, large amounts of ATP may be produced. The oxygen energy system is utilized primarily during endurance-type exercises, those lasting longer than 4 or 5 minutes. (See appendix G for more details.)

This process may be adequate to handle mild and moderate levels of exercise but may not be able to meet the demand of very strenuous exercise. The oxygen system is used primarily in sports emphasizing endurance, such as distance runs ranging from 5 kilometers (3.1 miles) to the 26.2-mile marathon and beyond.

Hawley and Hopkins subdivided the oxygen energy system into two systems. The scientific terms for these two subdivisions are aerobic glycolysis, which uses carbohydrates (muscle glycogen and blood glucose) for energy production, and **aerobic lipolysis,** which uses fats (muscle triglycerides, blood FFA). As discussed in the next two chapters, carbohydrate is the more efficient fuel during high-intensity exercise, whereas fat becomes the predominant fuel used at lower levels of exercise intensity. Thus, aerobic glycolysis provides most of the energy in high-intensity aerobic running events such as 5 kilometers (3.1 miles), 10 kilometers (6.2 miles), and even races up to two hours, while aerobic lipolysis may contribute significant amounts of energy in more prolonged aerobic events, such as ultramarathons of 50 to 100 kilometers (31 to 62 miles). Aerobic glycolysis and aerobic lipolysis may respectively be referred to as *aerobic power* and *aerobic capacity.* Details relative to the role of these energy systems during exercise are presented in chapters 4 and 5.

Figure 3.12 presents a simplified schematic reviewing the three human energy systems.

What nutrients are necessary for the operation of the human energy systems?

Although the energy for the formation of ATP is derived from the energy stores in carbohydrate, fat, and sometimes protein, this energy transformation and utilization would not occur without the participation of the other major nutrients—water, vitamins, and minerals. These three classes of nutrients function very closely with protein in the structure and function of numerous enzymes, many of which are active in the muscle-cell energy processes.

Water is used to help break up and transform some energy compounds by a process known as hydrolysis.

Several vitamins are needed for energy to be released from the cell sources. For example, niacin serves an important function in glycolysis, thiamin is needed to convert glycolytic end products to acetyl CoA for entrance into the Krebs cycle, and riboflavin is essential to forming ATP through the Krebs cycle and electron transfer system. A number of other B vitamins are also involved in facets of energy transformation within the cell.

Minerals, too, are essential for cellular energy processes. Iron is one of the more critical compounds. Aside from helping hemoglobin deliver oxygen to the muscle cell, it is also a component of myoglobin and the cytochrome part of the electron transfer system. It is needed for proper utilization of oxygen within the cell itself. Other minerals such as zinc, magnesium, potassium, sodium, and calcium are involved in a variety of ways, either as parts of active enzymes, in energy storage, or in the muscle-contraction process.

Proper utilization of body energy sources requires attention not only to the major energy nutrients but also to the regulatory nutrients—water, vitamins, and minerals. In addition, other nutrients and non-nutrients (such as creatine and caffeine) found in food may affect energy metabolism.

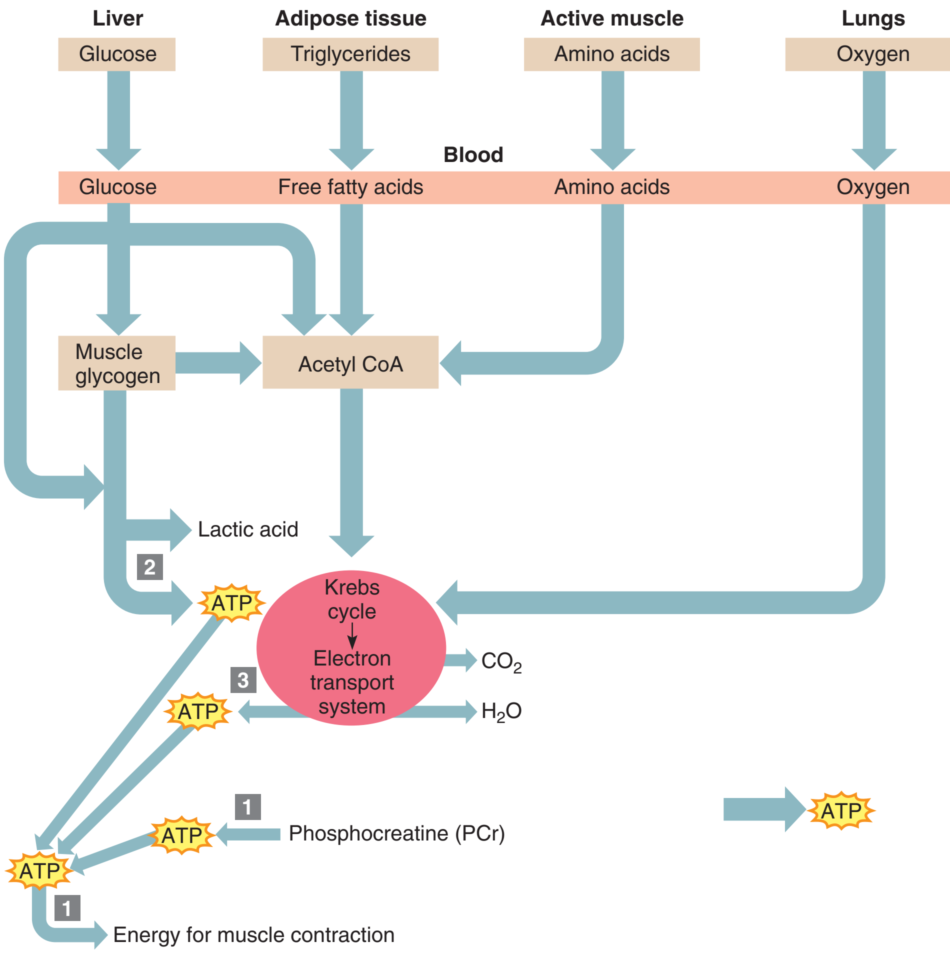


FIGURE 3.12 Simplified flow diagram of the three energy systems. The major nutrients and oxygen are transported to the cells for energy production. In the muscles, ATP is the immediate source of energy for muscle contraction. *(1)* The ATP-PCr system is represented by muscle stores of ATP and phosphocreatine (PCr); PCr can replenish ATP rapidly. *(2)* Glucose or muscle glycogen can produce ATP rapidly via the lactic acid system. *(3)* The oxygen system can produce large amounts of ATP via the aerobic processes in the Krebs cycle. Numerous other energy pathways exist, and some are described in chapter 4 (carbohydrates), chapter 5 (fats), and chapter 6 (protein).

Human Energy Metabolism during Rest

What is metabolism?

Human **metabolism** represents the sum total of all physical and chemical changes that take place within the body. The transformation of food to energy, the formation of new compounds such as hormones and enzymes, the growth of bone and muscle tissue, the destruction of body tissues, and a host of other physiological processes are parts of the metabolic process.

Metabolism involves two fundamental processes, anabolism and catabolism. Anabolism is a building-up process, or constructive metabolism. Complex body components are synthesized from the basic nutrients. For the active individual, this may mean an increased muscle mass through weight training or an increased amount of cellular enzymes to better use oxygen following endurance-type training. Energy is needed for anabolism to occur. Catabolism is the tearing-down process. This involves the disintegration of body compounds into their simpler components. The breakdown of muscle glycogen to glucose and eventually CO_2, H_2O, and energy is an example of a catabolic process. The energy released from some catabolic processes is used to support the energy needs of anabolism.

Metabolism is life. It represents human energy. The metabolic rate reflects how rapidly the body is using its energy stores, and this rate can vary tremendously depending upon a number of factors. For all practical purposes, the **total daily energy expenditure (TDEE)** may be accounted for by three factors: basal energy expenditure, increases due to eating a meal, and physical activity. Basal energy expenditure accounts for the largest component of TDEE, whereas physical activity is the most variable. We shall examine basal energy expenditure and the effect of eating in this section, while the role of physical activity, or exercise, will be covered in the section "Human Energy Metabolism during Exercise."

What factors account for the amount of energy expended during rest?

The body is constantly using energy to build up and tear down substances within the cells. Certain automatic body functions such as contraction of the heart, breathing, secretion of hormones, and

Key Concept Recap

- Carbohydrates and fats are the primary energy nutrients, but protein may also be an energy source. In the human body one gram of carbohydrate = 4 Calories, one gram of fat = 9 Calories, and one gram of protein = 4 Calories. Alcohol is also a source of energy; one gram = 7 Calories.
- The potential energy sources in the body include ATP and PCr; serum glucose, glycogen in the liver and muscle; serum free fatty acids (FFA); triglycerides in the muscle and in adipose tissue; and muscle protein.
- Three human energy systems have been classified on the basis of their ability to release energy at different rates of speed; they are the ATP-PCr, lactic acid, and oxygen energy systems.

the constant activity of the nervous system also are consuming energy.

Basal metabolism, or the **basal metabolic rate (BMR),** represents the energy requirements of the many different cellular and tissue processes that are necessary to continuing physiological activities in a resting, postabsorptive state throughout most of the day. Other than sleeping, it is the lowest rate of energy expenditure. The determination of the BMR is a clinical procedure conducted in a laboratory or hospital setting. The individual fasts for 12 hours. Then, with the subject in a reclining position, the individual's oxygen consumption and carbon dioxide production are measured. Through proper calculations, the BMR is determined. **Basal energy expenditure (BEE)** represents the BMR extrapolated over a 24-hour period.

The **resting metabolic rate (RMR)** is slightly higher than the BMR. It represents the BMR plus small amounts of additional energy expenditure associated with eating and previous muscular activity. According to the National Research Council, the BMR and RMR differ by less than 10 percent. Consequently, although there are some fine differences in the two terms, they are often used interchangeably. Additionally, the National Research Council uses the term **resting energy expenditure (REE)** to account for the energy processes at rest when extrapolated over 24 hours. In general, we shall use REE to also represent RMR.

Although some of the energy released during oxidative processes at rest supports physiological functions, such as pumping activity of the heart muscle, the majority of energy is released as heat, a thermal effect that keeps our body temperature at about 98.6° Fahrenheit (37° Celsius). Eating a meal and exercise are two other factors that induce a thermal effect.

What effect does eating a meal have on the metabolic rate?

The significant elevation of the metabolic rate that occurs after ingestion of a meal was previously known as the specific dynamic action of food but is now often referred to as **dietary-induced thermogenesis (DIT)** or **thermic effect of food (TEF).** This elevation is usually highest about 1 hour after a meal and lasts for about 4 hours, and it is due to the energy necessary to absorb, transport, store, and metabolize the food consumed. The greater the caloric content of the meal, the greater this TEF effect. Also, the type of food ingested may affect the magnitude of the TEF. The TEF for protein approximates 20–30 percent, carbohydrate approximates 5–10 percent, while the effect of fat is minimal (0–5 percent). Crovetti and others noted that a very high protein meal (68% of Calories) elicited a greater TEF for seven hours post-eating than did corresponding diets high in carbohydrate and fat. However, the increased TEF averaged only about six Calories more per hour, not an appreciable amount. Alcohol intake also causes about a 15 percent rise in the REE.

The TEF is expressed as a percent of the energy content of the ingested meal. The normal increase in the BMR due to TEF from a mixed meal of carbohydrate, fat, and protein is about 5–10 percent. A TEF of 10 percent will account for 50 Calories of a 500 Calorie meal. The remaining 450 Calories are available for energy use by other body processes. The TEF effect accounts for approximately 5–10 percent of the total daily energy expenditure.

de Jonge and Bray, in a review of 49 studies, reported that obesity is associated with a decreased TEF, suggesting that the obese are more efficient in storing fat. The composition of some diets for weight-loss purposes has been based upon this TEF effect; this topic is discussed in chapters 10 and 11 concerning diets for weight control.

How can I estimate my daily resting energy expenditure (REE)?

There are several ways to estimate your REE, but whichever method is used, the value obtained is an estimate and will have some error associated with it. To get a truly accurate value you would need a clinical evaluation, such as a standard BMR test. Accurate determination of REE is important for clinicians dealing with obesity patients, for such testing is needed to rule out hypometabolism. However, a number of formula estimates may give you an approximation of your daily REE.

Table 3.4 provides a simple method for calculating the REE of males and females of varying ages. Examples are provided in the table along with calculation of a 10-percent variability. Keep in mind that this is only an estimate of the daily REE, and additional energy would be expended during the day through the TEF effect and the effect of physical activity, as noted later.

A very simple, rough estimate of your REE is one Calorie per kilogram body weight per hour. Using this procedure, the estimated value for the male in table 3.4 is 1,680 Calories per day (1 × 70 kg × 24 hours) and for the female is 1,320 Calories (1 × 55 kg × 24 hours), values which are not substantially different than those calculated by the table procedure.

What genetic factors affect my REE?

Your REE is directly related to the amount of metabolically active tissue that you possess. At rest, tissues such as the heart, liver, kidneys, and other internal organs are more metabolically active than muscle tissue, but muscle tissue is more metabolically active than fat. Changes in the proportion of these tissues in your body will therefore cause changes in your REE.

Many factors influencing the REE, such as age, sex, natural hormonal activity, body size and surface area, and to a degree, body composition, are genetically determined. The effect of some of these factors on the REE is generally well known. Because infants have a large proportion of metabolically active tissue and are growing rapidly, their REE is extremely high. The REE declines through childhood, adolescence, and adulthood as full growth and maturation are achieved. Individuals with naturally greater muscle mass in comparison to body fat have a higher REE; the REE of women is about 10–15 percent lower than that of men, mainly because women have a higher proportion of fat to muscle tissue. Genetically lean individuals have a higher REE than do stocky individuals because their body surface area ratio is larger in

TABLE 3.4 Estimation of the daily resting energy expenditure (REE)

Age (years)	Equation
Males	
3–9	(22.7 × body weight*) + 495
10–17	(17.5 × body weight) + 651
18–29	(15.3 × body weight) + 679
30–60	(11.6 × body weight) + 879
> 60	(13.5 × body weight) + 487
Example	
154-lb male, age 20 154 lbs/2.2 = 70 kg (15.3 × 70) + 679 = 1,750	
Females	
3–9	(22.5 × body weight*) + 499
10–17	(12.2 × body weight) + 746
18–29	(14.7 × body weight) + 496
30–60	(8.7 × body weight) + 829
> 60	(10.5 × body weight) + 596
Example	
121-lb female, age 20 121 lbs/2.2 = 55 kg (14.7 × 55) + 496 = 1,304	
To get a range of values, simply add or subtract a normal 10-percent variation to the RMR estimate.	
Male example: 10 percent of 1,750 = 175 Calories Normal range = 1,575–1,925 Calories/day Female example: 10 percent of 1,304 = 130 Calories Normal range = 1,174–1,434 Calories/day	

*Body weight is expressed in kilograms (kg).

proportion to their weight (body volume) and they lose more body heat through radiation.

How does body composition affect my REE?

Body composition may be changed so as to alter REE. Losing body weight, including both body fat and muscle tissue, generally lowers the total daily REE. The REE may be decreased significantly in obese individuals who go on a very low-Calorie diet of less than 800 Calories per day. The decrease in the REE, which is greater than would be due to weight loss alone, may be caused by lowered levels of thyroid hormones. In one study, the REE of obese subjects dropped 9.4 percent on a diet containing only 472 Calories per day. This topic is covered in more detail in chapters 10 and 11. The possibility of decreased REE in some athletes who maintain low body weight through exercise, such as female distance runners and male wrestlers, has been the subject of recent debate and will be covered in chapter 10 when we discuss body composition.

On the other hand, maintaining normal body weight while reducing body fat and increasing muscle mass may raise the REE slightly because muscle tissue has a somewhat higher metabolic level than fat tissue or because the ratio of body surface area to body weight is increased. The decline in the REE that occurs with aging may be attributed partially to physical inactivity with a consequent loss of the more metabolically active muscle tissue and an accumulation of body fat. Methods to lose body fat and increase muscle mass are covered in chapters 11 and 12.

What environmental factors may also influence the REE?

Several lifestyle and environmental factors may influence our metabolism. For example, although caffeine is not a food, it is a common ingredient in some of the foods we may eat or drink. Caffeine is a stimulant and may elicit a significant rise in the REE. One study reported that the caffeine in 2–3 cups of regular coffee increased the REE 10–12 percent.

Smoking cigarettes also raises the REE. Apparently the nicotine in tobacco stimulates the metabolism similarly to caffeine. This may be one of the reasons why some individuals gain weight when they stop smoking.

Climatic conditions, especially temperature changes, may also raise the REE. Exposure to the cold may stimulate the secretion of several hormones and muscular shivering, which may stimulate heat production up to 400 percent. Exposure to warm or hot environments will increase energy expenditure through greater cardiovascular demands and the sweating response. Altitude exposure will also increase REE due to increased ventilation.

Many of these factors influencing the REE are important in themselves but may also be important considerations relative to weight control programs and body temperature regulation. Thus, they are discussed further in later chapters.

The most important factor that can increase the metabolic rate in general is exercise. As we shall see in the next section, exercise also may exert some effects upon the REE.

What energy sources are used during rest?

The vast majority of the energy consumed during a resting situation is used to drive the automatic physiological processes in the body. Because the muscles expend little energy during rest, there is no need to produce ATP rapidly. Hence, the oxygen system is able to provide the necessary ATP for resting physiological processes.

The oxygen system can use carbohydrates, fats, and protein as energy sources. However, as noted in chapter 6, protein is not used as a major energy source under normal dietary conditions. Carbohydrates and fats, when combined with oxygen in the cells, are the major energy substrates during rest. Several factors may influence which of the two nutrients is predominantly used. In general, though, on a mixed diet of carbohydrate, protein, and fat, about 40 percent of the REE is derived from carbohydrate and about 60 percent comes from fat. However, eating a diet rich in carbohydrate or fat will increase the percent of the REE derived, respectively, from carbohydrate and fat. Also, when carbohydrate levels are low, such as after an overnight fast, the percentage of the REE derived from fat increases.

Key Concept Recap

- Human metabolism represents the sum total of all physiological processes in the body, and the metabolic rate reflects the speed at which the body utilizes energy.
- The basal metabolic rate (BMR) represents the energy requirements necessary to maintain physiological processes in a resting, postabsorptive state, while the resting metabolic rate (RMR) is a little higher due to eating and prior muscular activity. The terms BEE and REE represent total basal energy expenditure and resting energy expenditure, respectively, over a 24-hour period.
- A number of different factors may affect the REE, including body composition, drugs, climatic conditions, and prior exercise.
- Eating a meal increases the metabolic rate as the digestive system absorbs, metabolizes, and stores the energy nutrients, a process termed the thermic effect of food (TEF).

Check for Yourself

Using the formula in table 3.4, estimate your daily resting energy expenditure (REE) in Calories. Keep this record for later comparisons.

Human Energy Metabolism during Exercise

What effect does muscular exercise have on the metabolic rate?

As noted above, the REE is measured with the subject at rest in a reclining position. Any physical activity will raise metabolic activity above the REE and thus increase energy expenditure. Accounting for changes in physical activity over the day may provide a reasonable, although imprecise, estimate of the total daily energy expenditure. Very light activities such as sitting, standing, playing cards, cooking, and typing all increase energy output above the REE, but we normally do not think of them as exercise. For purposes of this discussion, the **exercise metabolic rate (EMR),** represents the increase in metabolism brought about by moderate or strenuous physical activity such as brisk walking, climbing stairs, cycling, dancing, running, and other such activities. The EMR is known more appropriately as the **thermic effect of exercise (TEE).**

Exercise is a stressor to the body, and almost all body systems respond. If the exercise is continued daily, the body systems begin to adapt to the stress of exercise. As noted previously and as we shall see in later chapters, these adaptations may have significant health benefits. The two body systems most involved in exercise are the nervous system and the muscular system. The nervous system is needed to activate muscle contraction, but it is in the muscle cell itself that the energetics of exercise occur. Most other body systems are simply designed to serve the needs of the muscle cell during exercise.

The muscle cell, or muscle fiber, is a rather simple machine in design but extremely complex in function. It is a tube-like structure containing filaments that can slide by one another to shorten the total muscle. The shortening of the muscle moves bones, and hence work is accomplished, be it simply the raising of a barbell as in weight training or moving the whole body as in running. Like most other machines, the muscle cell has the capability of producing work at different rates, ranging from very low levels of energy expenditure during sleep to nearly a ninety-fold increase during maximal, short-term anaerobic exercise.

The human body possesses several different types of muscle fibers, and their primary differences are in the ability to produce energy. Type I is called a slow-twitch red fiber, and it can produce energy primarily by aerobic processes, the oxygen system. It is also referred to as the slow-oxidative fiber (SO). Type IIa is known as a fast-twitch red fiber; it also can produce energy by aerobic processes but in addition can produce energy anaerobically via the lactic acid system. It is also known as the fast-oxidative glycolytic fiber (FOG). The third fiber type, IIb, is a fast-twitch white fiber that produces energy primarily by anaerobic processes and is also known as the fast glycolytic fiber (FG). Type II fibers may use the ATP-PCr system at a faster rate than Type I fibers.

The most important factor affecting the metabolic rate is the intensity or speed of the exercise. To move faster, your muscles must contract more rapidly, consuming proportionately more energy. Use of type I muscle fibers predominates during low-intensity exercise, and type II fibers are increasingly recruited with more intense exercise. The following represents approximate energy expenditure in Calories per minute for increasing levels of exercise intensity for an average-sized adult male. However, for most of us it would be impossible to sustain the higher levels of energy expenditure for a minute, and the highest level could be sustained for only a second or so.

Level of intensity	Caloric expenditure per minute
Resting metabolic rate	1.0
Sitting and writing	2.0
Walking at 2 mph	3.3
Walking at 3 mph	4.2
Running at 5 mph	9.4
Running at 10 mph	18.8
Running at 15 mph	29.3
Running at 20 mph	38.7
Maximal power weightlift	>90.0

Although the intensity of the exercise is the most important factor affecting the magnitude of the metabolic rate, there are some other important considerations. In some activities the increase in energy expenditure is not directly proportional to speed, for the efficiency of movement will affect caloric expenditure. Very fast walking becomes more inefficient, so the individual burns more

Calories per mile walking briskly compared to more leisurely walking. A beginning swimmer wastes a lot of energy, whereas one who is more accomplished may swim with less effort, saving Calories when swimming a given distance. Swimming and cycling at very high speeds exponentially increase water or air resistance, so caloric expenditure also increases exponentially. Moreover, the individual with a greater body weight will burn more Calories for any given amount of work in which the body has to be moved, as in walking, jogging, or running. It simply costs more total energy to move a heavier load.

How is exercise intensity measured?

The intensity of a given exercise may be measured in two general ways. One way is to measure the actual work output or power of the activity, such as foot-pounds per second, kilojoules per second, or watts. In some cases this is rather easy to do because some machines, such as bicycle ergometers, are designed to provide an accurate measure of work output. However, the actual work output of a basketball player during a game is more difficult to measure, although use of accelerometers and other motion-detection devices help. Data, such as watt production, derived from these techniques may be used to infer the predominant energy system being used.

A second way is to measure the physiological cost of the activity by monitoring the activity of the three human energy systems. Ward-Smith noted that due to accurate measurements of oxygen uptake and carbon dioxide output, the energy contributions from aerobic metabolism are readily quantifiable, while the energy contribution from anaerobic metabolism is far more difficult to determine.

Energy production from the ATP-PCr energy system has been measured by several procedures. One procedure involves a muscle biopsy with subsequent analysis for ATP and PCr levels to determine use following exercise, but the small muscle biopsy may not represent ATP-PCr use in other muscles. ATP and PCr levels may also be determined by computerized imaging procedures, a noninvasive procedure, but the exercise task needs to be confined to specific movements due to the nature of the imaging equipment. Thus, Lange and Bury indicate that it is difficult to obtain precise physiological or biochemical data during common explosive-type exercise tests, such as short sprints.

Laboratory techniques are also available to measure the role of the lactic acid system in exercise, primarily by measuring the concentration of lactic acid in the blood or in muscle tissues. One measure of exercise intensity is the so-called anaerobic threshold, or that point where the metabolism is believed to shift to a greater use of the lactic acid system. This point is often termed the **onset of blood lactic acid (OBLA),** or lactate threshold. The anaerobic threshold may also be referred to as the **steady-state threshold,** indicating that endurance exercise may continue for prolonged periods if you exercise below this threshold value. Exercise physiologists disagree about which is the better term, but all terms may be found in scientific literature. Some sport scientists also use specific measurements to define these terms, such as a certain level of blood lactic acid.

Laboratory tests also are necessary to measure the contribution of the oxygen system during exercise, and this is the most commonly used technique for measuring exercise intensity (see figure 3.3). The most commonly used measurement is the **maximal oxygen uptake,** which represents the highest amount of oxygen that an individual may consume under exercise situations. In essence, the technique consists of monitoring the oxygen uptake of the individual while the exercise intensity is increased in stages. When oxygen uptake does not increase with an increase in workload, the maximal oxygen uptake has been reached. Maximal oxygen uptake is usually expressed as **VO_2 max,** which may be stated as liters per minute or milliliters per kilogram body weight per minute. An example is provided in figure 3.13. A commonly used technique to indicate exercise intensity is to report it as a certain percentage of an individual's VO_2 max, such as 50 or 75 percent. If blood samples are taken periodically, the percent of VO_2 max at which the steady-state threshold occurs may be determined. Additionally, measurement of oxygen during recovery from exercise may be used to calculate the maximal accumulated oxygen deficit (MAOD), an indirect marker for anaerobic contributions to energy expenditure during exercise.

In summary, measurement of the three energy systems during exercise provides us with a measure of the energy cost of the physical activity.

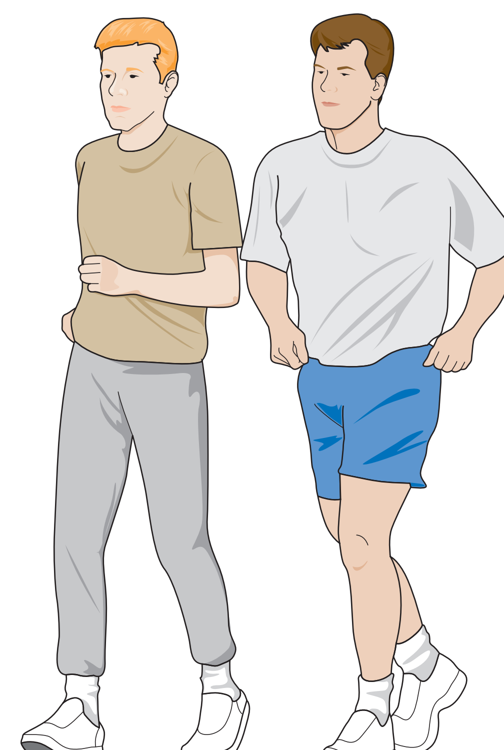


FIGURE 3.13
Maximal oxygen uptake (VO_2 max). The best way to express VO_2 max is in milliliters of oxygen per kilogram (kg) of body weight per minute (ml O_2/kg/min). As noted in the figure, the smaller individual has a lower VO_2 max in liters but a higher VO_2 max when expressed relative to weight. In this case, the smaller individual has a higher degree of aerobic fitness, at least as measured by VO_2 max per unit body weight.

VO_2 max: liters/minute	3.6 L (3600 ml)	4.0 L (4000 ml)
kg body weight	60	80
VO_2 max: ml O_2/kg/minute	60	50

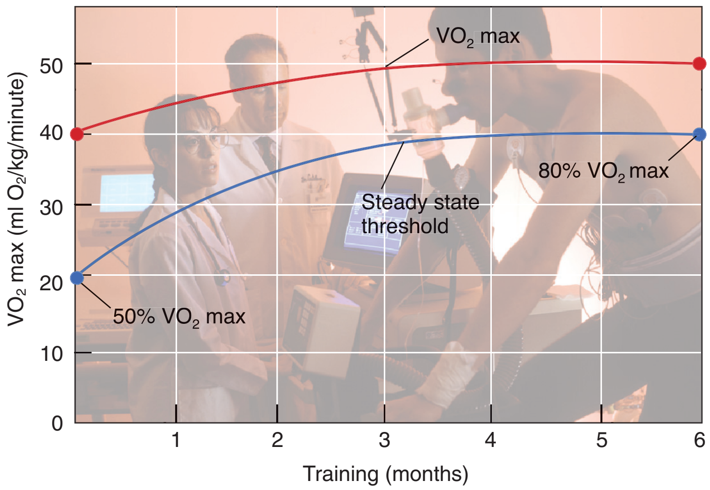


FIGURE 3.14 The effect of training upon VO_2 max and the steady-state threshold. Training increases both your VO_2 max and your steady-state threshold, which is the ability to work at a greater percentage of your VO_2 max without producing excessive lactic acid—a causative factor in fatigue. For example, before training the VO_2 max may be 40 ml while the steady-state threshold is only 20 ml (50% of VO_2 max). After training, VO_2 max may rise to 50 ml, but the steady-state threshold may rise to 40 ml (80% of the VO_2 max).

Proper training may increase both VO_2 max and the steady-state threshold, as illustrated in figure 3.14.

How is the energy expenditure of exercise metabolism expressed?

A number of research studies have been conducted to determine the energy expenditure of a wide variety of sports and other physical activities.

The energy costs have been reported in a variety of ways, including Calories per minute based upon body weight, kilojoules (kJ), oxygen uptake, and **METS.** The MET is a unit that represents multiples of the resting metabolic rate (see figure 3.15). These concepts are, of course, all interrelated, so an exercise can be expressed in any one of the four terms and converted into the others. For our purposes, we will express energy cost in Calories per minute based upon body weight, as that appears to be the most practical method for this book. However, just in case you see the other values in another book or magazine, here is how you may simplify the conversion. We know the following approximate values:

1 C = 4 kJ

1 L O_2 = 5 C

1 MET = 3.5 ml O_2/kg body weight/min

(amount of oxygen consumed during rest)

These values are needed for the following calculations:
Example: Exercise cost = 20 kJ/minute
To get Calorie cost, divide kJ by the equivalent value for Calories.

20 kJ/min/4 = 5 C/min

Example: Exercise cost = 3 L of O_2/min
To get Calorie cost, multiply liters of O_2 × Calories per liter.

Caloric cost = 3 × 5 = 15 C/min

Example: Exercise cost = 25 ml O_2/kg body weight/min
You need body weight in kg, which is weight in pounds divided by 2.2. For this example 154 lbs = 70 kg. Determine total O_2 cost/min by multiplying body weight times O_2 cost/kg/min.

70 × 25 = 1,750 ml O_2

Convert ml to L: 1,750 ml = 1.75 L

Multiply liters O_2 × Calories per liter

Caloric cost = 1.75 × 5 = 8.75 C/min

Example: Exercise cost = 12 METS
You need body weight in kg—for this example, 70 kg.
Multiply total METS times O_2 equivalent of 1 MET.

12 × 3.5 ml O_2/kg/min = 42.0 ml O_2/kg/min

Multiply body weight times this result.

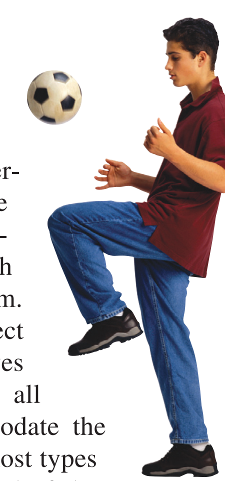
70 × 42 ml O_2/kg/min = 2,940 ml O_2/min

Convert ml to L: 2,940 ml O_2/min = 2.94 L O_2/min

Multiply liters O_2 × Calories per liter

Caloric cost = 2.94 × 5 = 14.70 C/min

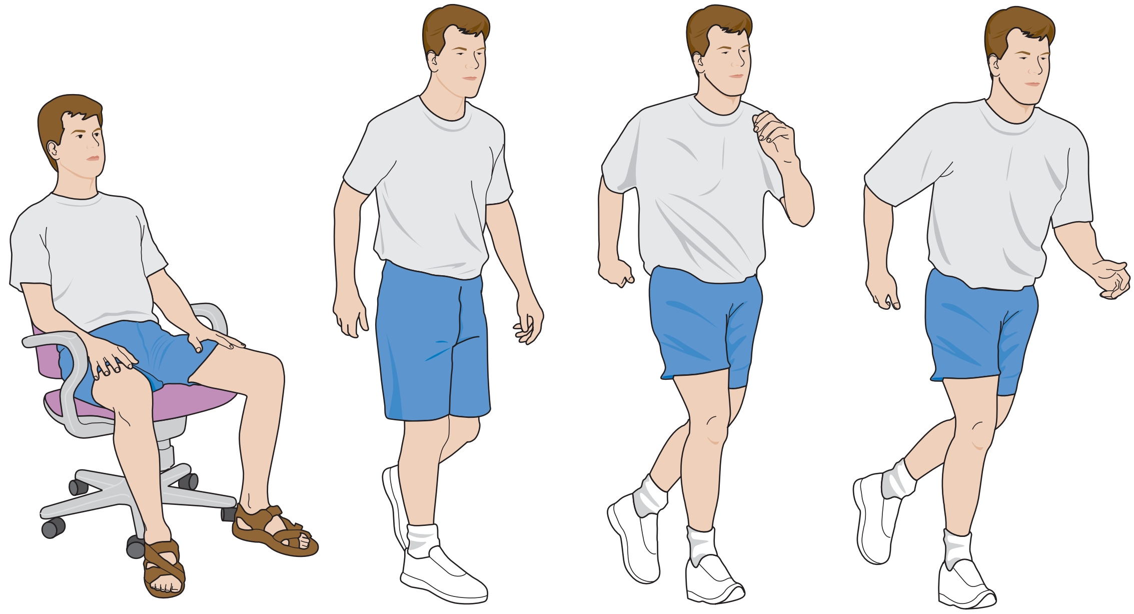
How can I tell what my metabolic rate is during exercise?



The human body is basically a muscle machine designed for movement. Almost all of the other body systems serve the muscular system. The nervous system causes the muscles to contract. The digestive system supplies nutrients. The cardiovascular system delivers these nutrients along with oxygen in cooperation with the respiratory system. The endocrine system secretes hormones that affect muscle nutrition. The excretory system removes waste products. When humans exercise, almost all body systems increase their activity to accommodate the increased energy demands of the muscle cell. In most types of sustained exercises, however, the major demand of the muscle cells is for oxygen.

As noted previously, the major technique for evaluating metabolic rate is to measure the oxygen consumption of an individual during exercise. Athletes may benefit from such physiological testing. Measurements of VO_2 max, maximal heart rate, and the anaerobic threshold may help in planning an optimal training program, and subsequent testing may illustrate training effects. Such testing is becoming increasingly available at various universities and comprehensive fitness/wellness centers.

Unfortunately, this may not be practical for most of us. However, because of some interesting relationships among exercise intensity, oxygen consumption, and heart rate, the average individ-



	Rest	Slow walk (2 mph)	Fast walk (5 mph)	Run (8 mph)
Liters of oxygen/minute	.25	.5–.75	1.5–1.75	2.5–3.0
Calories/minute	1.25	2.5–3.75	7.5–8.75	12.5–15.0
Kilojoules/minute	5	10–15	30–35	50–60
METS	1	2–3	6–7	10–12

FIGURE 3.15 Energy equivalents in oxygen consumption, Calories, Kilojoules, and METS. This figure depicts four means of expressing energy expenditure during four levels of activity. These approximate values are for an average male of 154 pounds (70 kg). If you weigh more or less, the values will increase or decrease accordingly.

ual may be able to get a relative approximation of the metabolic rate during exercise. A more or less linear relationship exists between exercise intensity and oxygen uptake. As the intensity level of work increases, so does the amount of oxygen consumed. The two systems primarily responsible for delivering the oxygen to the muscles are the cardiovascular and respiratory systems. There is also a fairly linear relationship between their responses and oxygen consumption. In general, maximal heart rate (HRmax) and VO_2 max coincide at the same exercise intensity level. A simplified schematic is presented in figure 3.16.

Because the heart rate (HR) generally is linearly related to oxygen consumption (the main expression of metabolic rate), and because it is easy to measure this physiological response during exercise either at the wrist or neck pulse, it may prove to be a practical guide to your metabolic rate. The higher your heart rate, the greater your metabolic rate. However, a number of factors may influence your specific heart rate response to exercise, such as the type of exercise (running vs. swimming), your level of physical fitness, sex, age, skill efficiency, percentage of body fat, and a number of environmental conditions. Thus, it is difficult to predict your exact metabolic rate from your exercise HR. As we shall see in chapter 11, however, the HR data during exercise may be used as a basis for establishing a personal fitness program for health and weight control.

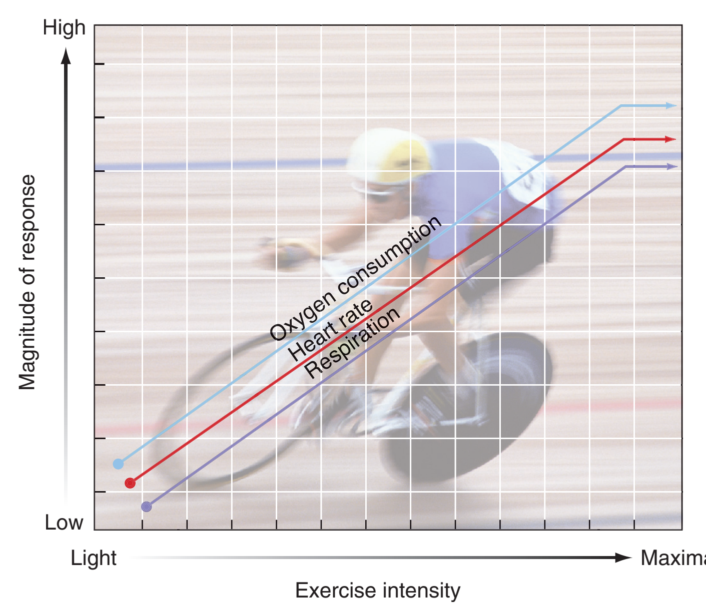


FIGURE 3.16 Relationships between oxygen consumption, heart rate, and respiration responses to increasing exercise rates. In general, as the intensity of exercise continues, there is a rise in oxygen consumption, which is accompanied by proportional increases in heart rate and respiration. VO_2 max and HRmax usually occur at the same exercise intensity.

How can I determine the energy cost of exercise?

To facilitate the determination of the energy cost of a wide variety of physical activities, appendix B has been developed. This is a composite table of a wide variety of individual reports in the literature. When using this appendix, keep the following points in mind.

1. The figures include the REE. Thus, the total cost of the exercise includes not only the energy expended by the exercise itself, but also the amount you would have used anyway during that same period. Suppose you ran for 1 hour and the calculated energy cost was 800 Calories. During that same time at rest you may have expended 75 Calories as your REE. The net cost of the exercise is only 725 Calories.
2. The figures in the table are only for the time you are doing the activity. For example, in an hour of basketball you may exercise strenuously for only 35–40 minutes, as you may take time-outs and rest during foul shots. In general, record only the amount of time that you are actually moving during the activity.
3. The figures may give you some guidelines to total energy expenditure, but actual caloric cost might vary somewhat because of such factors as your skill level, running against the wind or uphill, and so forth.
4. Not all body weights could be listed, but you may approximate by going to the closest weight listed.
5. There may be small differences between men and women, but not enough to make a marked difference in the total caloric value for most exercises.

As one example, suppose we calculate the energy expenditure of a 154-pound individual who ran 5 miles in 30 minutes. You must calculate either the minutes per mile or miles per hour (mph).

1. 30 minutes / 5 miles = 6 min/mile
2. 60 minutes / 6 minutes/mile = 10 mph

Consult appendix B and find the caloric value per minute for a body weight of 155 lbs and a running speed of 10 mph, a value of 18.8 Calories/minute. Multiply this value times the number of minutes of running, and you get the total caloric cost of that exercise. In this example, 30 × 18.8 = 564 total C expended.

If the activity you do does not appear in appendix B, try to find one you think closely matches the movements found in your activity. Then check the caloric expenditure for the related activity.

What are the best types of activities to increase energy expenditure?

Activities that use the large muscle groups of the body and are performed continuously usually will expend the greatest amount of Calories. Intensity and duration are the two key determinants of total energy expenditure. Activities in which you may be able to exercise continuously at a fairly high intensity for a prolonged period will maximize your total caloric loss. Although this may encompass a wide variety of different physical activities, those that have become increasingly popular include walking, running, swimming, bicycling, and aerobic dance. A few general comments about these common modes of exercising would appear to be in order.

Walking and Running Walking and running are popular exercises because they are so practical to do. All you need is a good pair of shoes. As a general rule, the caloric cost of running a given distance does not depend on the speed. It will take you a longer time to cover the distance at a slower speed, but the total caloric cost will be similar to that expended at a faster speed. However, walking is more economical than running, and hence you generally expend fewer Calories for a given distance walking than you do running. A good rule of thumb is that you expend about 1 Calorie per kilogram/body weight per mile walking at a speed for 2–4 miles per hour. Walking uses fewer Calories per mile as compared to running. This does not hold true, however, if you walk vigorously at a high speed. A study by Thomas and Londeree has shown that the caloric cost of jogging at 4.7 mph is only about 5 percent higher than walking at the same speed. At high walking speeds (above 5 mph), you may possibly expend more energy than if you jogged at the same speed. Fast, vigorous walking, known as aerobic walking, can be an effective means to expend Calories. However, as with other exercise activities, it takes practice to become a fast walker.

For a simplified procedure, you may calculate the approximate caloric expenditure for running a given distance by either one of the following formulas:

Caloric cost = 1 C/kg body weight/kilometer

Caloric cost = 0.73 C/pound body weight/mile

If you are an average-sized male of about 154 lbs (70 kg), or an average-sized female of about 121 lbs (55 kg), you would burn approximately the following amounts of Calories for a kilometer or a mile.

	Male (154 lbs, 70 kg)	Female (121 lbs, 55 kg)
Kilometer	70	55
Mile	112	88

Slow, leisurely walking would burn a little more than half this amount of Calories per mile.

Climbing stairs, at home, at work, in an athletic stadium, or on step machines, is one means to make walking more vigorous. Skipping is also more vigorous but may lead to injuries.

Many individuals use small weights in conjunction with their walking or running programs either by carrying them or strapping them to the ankles or wrists. The most popular technique is to carry small weights of 1–3 pounds. A number of research studies have reported that this technique, particularly if the arms are swung vigorously through a wide range of motion during walking, may increase the energy expenditure about 5–10 percent or higher above unweighted walking at the same speed. Use of walking poles, similar to ski poles, may increase caloric expenditure by 15 percent. Increases in energy expenditure greater than 30 percent have been reported with vigorous pumping of 1-pound hand weights as compared with just running at the same speed. The heart rate response also increases, and using hand weights with fast walking is an adequate stimulus to promote a training effect on the cardiovascular system. However, use of hand weights exaggerates the blood pressure response, and thus should be used with caution by individuals with blood pressure problems. Since some researchers have noted that simply walking a little faster without weights will have the same effect on energy cost and heart rate response, this may be a good alternative. Nevertheless, at any given walking speed, hand weights will increase energy expenditure. Addition of weights to the ankle also will increase energy expenditure, but it may also change the normal running style and may predispose one to injury.

Swimming Because of water resistance, swimming takes more energy to cover a given distance than does either walking or running. Although the amount of energy expended depends somewhat on the type of swimming stroke used and the ability of the swimmer, swimming a given distance takes about four times as much energy as running. For example, swimming a quarter-mile is the energy equivalent of running a mile. Water aerobics and water running (doing aerobics or running in waist-deep, chest-deep, or deep water) may be effective exercise regimens that help prevent injuries due to impact.

Cycling Bicycling takes less energy to cover a given distance in comparison to running on a level surface. The energy cost of bicycling depends on a number of factors such as body weight, the type of bicycle, hills, and body position on the bike (assuming a streamlined position to reduce air resistance). Owing to rapidly increasing air resistance at higher speeds such as 20 mph, the energy cost of bicycling increases at a much faster rate at such speeds. A detailed method for calculating energy expenditure during bicycling is presented in the article by Hagberg and Pena. In general, cycling 1 mile is approximately the energy equivalent of running one-third the distance.

Aerobic Dance Aerobic dance, as now known, has been a popular form of exercise for over 20 years. There is a variety of styles of aerobic dance varying in intensity and the degree of impact with the floor. Several studies have shown that high-intensity, high-impact aerobic dancing approximates 10 Calories per minute in women, which is indicative of strenuous exercise. Unfortunately, other research has shown that high-impact dancing is more traumatic and may lead to a higher incidence of leg injuries. Thus, the low-impact, or soft-impact, technique in which one foot usually remains in contact with the floor was introduced. Several studies have also shown that if done at a high intensity, low-impact aerobic dance may also use approximately 9–10 Calories per minute and be less likely to induce injuries to the legs. The use of step benches may also increase exercise intensity.

Home Exercise Equipment Home exercise equipment may also provide a strenuous aerobic workout. Recent research suggests that for any given level of perceived effort, treadmill running burned the most Calories. Exercising on elliptical trainers, cross-country ski machines, rowing ergometers, and stair-climbing apparatus also expended significant amounts of Calories, more so than bicycling apparatus. Many modern pieces of exercise equipment are electronically equipped with small computers to calculate energy cost as Calories per minute and total caloric cost of the exercise.

Table 3.5 provides a classification of some common physical activities based upon rate of energy expenditure. The implications

TABLE 3.5 Classification of physical activities based upon rate of energy expenditure*

Light, mild aerobic exercise (< 5 Calories/min)		
Archery	Bowling	Horseback riding (walk)
Badminton, social	Dancing, waltz	Swimming (20–25 yards/min)
Baseball	Golf (Cart)	Walking (2–3 mph)
Bicycling (5 mph)		
Moderate aerobic exercise (5–10 Calories/min)		
Badminton, competitive	Golf (carrying clubs)	Swimming (30–40 yards/min)
Basketball, recreational	Rope skipping (60 rpm)	Tennis, recreational
Bicycling (10 mph)	Running (5 mph)	Walking (3–4.5 mph)
Dancing, aerobic	Skiing, cross-country (2.5 mph)	Weight training
Moderately heavy to heavy aerobic exercise (> 10 Calories/min)		
Bicycling (15–20 mph)	Rope skipping (120–140 rpm)	Swimming (50–70 yards/min)
Calisthenics, vigorous	Running (6–9 mph)	Tennis, competitive
In-line skating (10–15 mph)	Skiing, cross-country (5–6 mph)	Walking (5.0–6.0 mph)

*Calories per minute based upon a body weight of 70 kg, or 154 pounds. Those weighing more or less will expend more or fewer Calories, respectively, but the intensity level of the exercise will be the same. The actual amount of Calories expended may also depend on a number of other factors, depending on the activity. For example, bicycling into or with the wind will increase or decrease, respectively, the energy cost. See appendix B for more details.

Source: Modified from M.H. Williams, *Nutritional Aspects of Human Physical and Athletic Performance,* 1985, Charles C Thomas Publishers, Springfield, IL.

of these types of exercises in weight control programs are discussed in later chapters.

Does exercise affect my resting energy expenditure (REE)?

Exercise not only raises the metabolic rate during exercise but, depending upon the intensity and duration of the activity, will also keep the REE elevated during the recovery period. The increase in body temperature and in the amounts of circulating hormones such as adrenaline (epinephrine) will continue to influence some cellular activity, and some other metabolic processes, such as circulation and respiration, will remain elevated for a limited time. This effect, which has been labeled the **metabolic aftereffects of exercise,** is calculated by monitoring the oxygen consumption for several hours during the recovery period after the exercise task. The amount of oxygen in excess of the preexercise REE, often called excess postexercise oxygen consumption (EPOC), reflects the additional caloric cost of the exercise above and beyond that expended during the exercise task itself.

Some older research noted that the average number of additional Calories expended after each exercise session would be about 45–50. However, in a series of more recent studies with more appropriate controls, although most investigators did report an increased REE following exercise of varying durations and intensities, the magnitude of the response was generally lower. Depending on the intensity and duration of the exercise bout in these studies, the REE during the recovery period ranged from 4–16 percent higher than the preexercise REE, and it remained elevated for only 15–20 minutes in some studies but up to 4–5 hours in others. Both aerobic and resistance-type exercises increase EPOC, with greater increases associated with high-intensity, long duration exercise. Burleson and others reported that when matched for oxygen consumption during exercise, weight training exhibited a greater post-exercise oxygen consumption, but the amount was rather small. Using the oxygen consumption values presented in these studies, the additional energy expenditure ranged from 3–30 Calories.

Although the metabolic aftereffects of exercise would not appear to make a significant contribution to weight loss, exercise may help mitigate the decrease in the REE often seen in individuals on very low-Calorie diets. This point is explored further in chapter 11.

Does exercise affect the thermic effect of food (TEF)?

Many studies have been conducted to investigate the effect of exercise on the thermic effect of food (TEF). Unfortunately, no clear answer has been found. Some studies have reported an increase in TEF when subjects exercise either before or after the meal, while others revealed little or no effects. Some research even suggests that exercise training decreases the TEF. Other studies have investigated differences between exercise-trained and untrained individuals relative to TEF, and although some preliminary research noted a decreased TEF in endurance-trained athletes, Tremblay and others also noted that it is still unclear if training causes any significant alterations in TEF. In any case, the increases or decreases noted in the TEF due to either exercise or exercise training were minor, averaging about 5–9 Calories for several hours.

How much energy do I need to consume daily?

The National Academy of Sciences, through the Institute of Medicine, recently released its DRI for energy in conjunction with DRI for carbohydrate, fat, and protein, as noted in chapter 2. Because of possible problems in developing obesity, no RDA or UL were developed for energy. Instead, the Institute of Medicine uses the term **Estimated Energy Requirement (EER),** which it defines as the dietary intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health. In essence, the EER estimates your REE based on age, gender, weight and height, and then modifies this value depending on your daily level of physical activity, which we refer to in this book as TEE.

Your total daily energy expenditure (TDEE) is the sum of your BEE, your TEF, and your TEE. Figure 3.17 provides some approximate values for the typical active individual, indicating that BEE accounts for 60–75 percent of the total daily energy expenditure, TEF represents 5–10 percent, and TEE explains 15–30 percent. These values are approximate and may vary tremendously, particularly TEE, which may range from near 0 percent in the totally sedentary individual to 50 percent or more in ultraendurance athletes.

In order to illustrate the effect that physical activity, or TEE, may have on your TDEE, the Institute of Medicine developed four **physical activity level (PAL)** categories, which are presented in Table 3.6. The PAL describes the ratio of the TDEE divided by the BEE over a 24-hour period. The higher the ratio, the greater the amount of daily physical activity.

The energy expenditure in individuals in the Sedentary category represents their REE, including the TEF, plus various physi-

TABLE 3.6 The Physical Activity Level Categories

Category	Physical Activity Level (PAL)	Physical Activity Coefficient (PA) Males/Females
Sedentary	≥ 1.0 – < 1.4	1.00/1.00
Low Active	≥ 1.4 – < 1.6	1.11/1.12
Active	≥1.6 – < 1.9	1.25/1.27
Very Active	≥1.9 – < 2.5	1.48/1.45

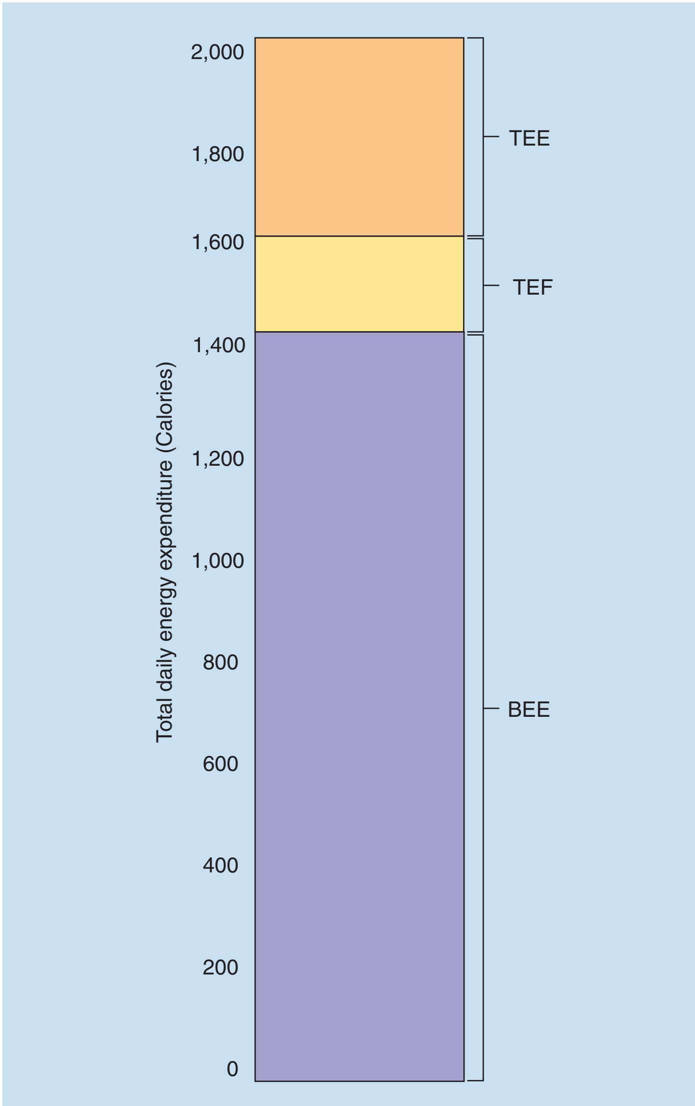


FIGURE 3.17 Total daily energy expenditure. Three major factors account for the total daily energy expenditure. Basal energy expenditure (BEE) accounts for 60–75 percent, the thermic effect of food (TEF) accounts for 5–10 percent, and 15–30 percent is accounted for by the thermic effect of exercise (TEE). However, all of these percentages are variable in different individuals, with exercise being the most modifiable component. In the figure, the BEE is 70 percent, the TEF is 10 percent, and the TEE is 20 percent.

cal activities associated with independent living, such as walking from the house or work to the car, typing, and other forms of very light activity.

For the other categories, the Institute of Medicine bases the PAL on the amount of daily physical activity that is the equivalent of walking at a rate of 3–4 miles per hour. For example, an adult male who weighs 154 pounds (70 kg) and who, in addition to the normal daily activities of independent living, expended the physical activity equivalent of walking 2.2 miles per day would be in the Low Active category, with a PAL of 1.5. To be in the Active category with a PAL of 1.75, he would need to expend the physical activity energy equivalent of walking 7.0 miles per day, and to be in the Very Active category an energy equivalent of 17 miles per day. Keep in mind that you do not need to walk this many miles per day, but simply do a multitude of physical activities, such as climbing stairs, golfing, swimming, and jogging that add up to this energy equivalent. Table 3.5 provides examples of physical activities ranging from light to heavy that may be used to total the required energy equivalents of walking. A more detailed table, based on body weight, is presented in appendix B.

Based on a number of doubly labeled water studies, the Institute of Medicine developed equations for the Estimated Energy Requirement (EER). Here are two:

Males, 19 years and older:

$$EER = 662 - 9.53 \times age + [PA \times (15.91 \times Weight + 539.6 \times Height)]$$

Females, 19 years and older:

$$EER = 354 - 6.91 \times age + [PA \times (9.361 \times Weight + 726 \times Height)]$$

Age: In years.

Weight: In kilograms (kg). To convert weight in pounds to kilograms, multiply by 0.454.

Height: In meters (m). To convert height in inches to meters, multiply by 0.0254.

PA: PA is the physical activity coefficient, which is based on the PAL. Based on mathematical consideration to equate energy expenditure between the various PAL categories, the PA coefficient for the Sedentary category was set at 1.0 and the PA for the other categories adjusted accordingly. The PAs for the four PAL categories are presented for adult males and females in Table 3.6.

The Physical Activity Level (PAL) describes the ratio of the TDEE divided by the BEE over a 24-hour period. The higher the ratio, the greater the amount of daily physical activity. The Physical Activity Coefficient (PA) is based on the PAL and is used to equate energy expenditure between the various PAL categories, setting the Sedentary category as 1.0.

Although there may be variances in this estimate of your EER, the estimate may provide you with a ballpark figure of your daily energy needs. Let's look at an example, as depicted in figure 3.18, of the difference that physical activity may have on the daily energy needs of a sedentary and very active adult female. Both are 20 years old, weigh 132 pounds (60 kg), and are 55 inches (1.4 m) tall.

Sedentary:

$$EER = 354 - 6.91 \times 20 + [1.0 \times (9.361 \times 60 + 726 \times 1.4)]$$

$$EER = 354 - 138.2 + [1.0 \times (561.66 + 1016.4)]$$

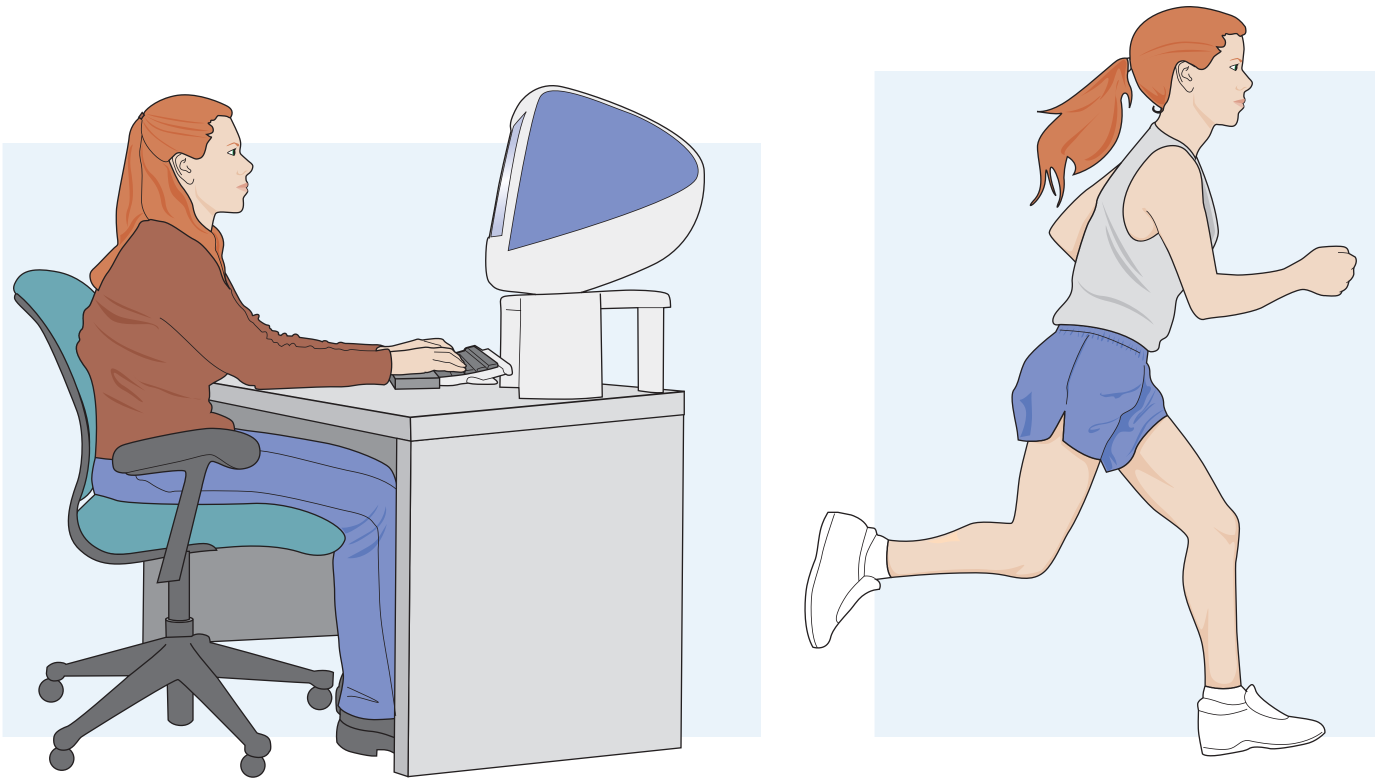
$$EER = 215.8 + [1578.06] = 1794 \text{ Calories}$$

Very active:

$$EER = 354 - 6.91 \times 20 + [1.45 \times (9.361 \times 60 + 726 \times 1.4)]$$

$$EER = 354 - 138.2 + [1.45 \times (561.66 + 1016.4)]$$

$$EER = 215.8 + [2288.19] = 2504 \text{ Calories}$$



Sedentary lifestyle
PA = 1.0
EER = 1,794 Calories

Very active lifestyle
PA = 1.45
EER = 2,504 Calories

FIGURE 3.18 Estimated Energy Requirement (EER) for two 20-year-old females. Both weigh 132 pounds (60 kg) and are 55 inches (1.4 m) tall. The sedentary female has a Physical Activity Coefficient (PA) of 1.0, whereas the very active female has a PA of 1.45. Compared to her sedentary counterpart, the very active female needs 700 additional Calories to sustain her physically active lifestyle.

The total caloric difference between the sedentary and very active women approximates 700 Calories per day, which may be important in several ways for the very active female. First, as noted in chapter 1, increased physical activity is an important aspect of a healthy lifestyle to prevent a variety of chronic diseases. Second, this additional 700 Calories of energy expenditure daily could have a significant impact on her body weight over time, approximating a loss of over a pound per week if not compensated for by increased food intake. Third, if she is at an optimal body weight, she may consume an additional 700 Calories per day without gaining weight.

If you are interested in increasing your PAL, then your best bet is to incorporate more light, moderate, and moderately heavy to heavy physical activities into your daily lifestyle. Some additional guidelines for estimating your daily TDEE and EER, particularly in the design of a proper weight control program, are presented in chapter 11. If you are interested in obtaining the full details concerning the EER and PAL, you may do so at the National Academies Press Website, www.nap.edu. Simply type in Dietary Reference Intake for Energy in the search box, and review chapters 5 and 12 which focus on energy and physical activity.

Key Concept Recap

- The thermic effect of exercise (TEE), or exercise metabolic rate (EMR), provides us with the most practical means to increase energy expenditure.
- The metabolic rate during exercise is directly proportional to the intensity of the exercise, and the exercise heart rate may serve as a general indicator of the metabolic rate.
- Activities that use the large muscle groups of the body, such as running, swimming, bicycling, and aerobic dance, facilitate energy expenditure.
- The total daily energy expenditure (TDEE) is accounted for by BEE (60–75%), TEF (5–10%), and TEE (15–30%), although these percentages may vary.
- The Estimated Energy Requirement (EER) is defined as the dietary intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, height, weight, and level of physical activity consistent with good health. Changing from a sedentary Physical Activity Level (PAL) to a very active PAL is a very effective means to increase TDEE and EER.

Check for Yourself

Record the types and amounts (in minutes) of your daily physical activity (or use the record from chapter 1) and consult appendix B to determine your total amount of daily energy expenditure through physical activity and exercise. The application exercise on page 109 may be useful.

Human Energy Systems and Fatigue during Exercise

What energy systems are used during exercise?

In sport, energy expenditure can vary tremendously. For example, Asker Jeukendrup and his associates recently noted that in one sport, World Class Cycling, events may range in duration from 10 seconds to 3 weeks, involving race distances between 200 meters to 4,000 kilometers. Exercise intensity in a 200-meter event would be extremely high, and much lower during the prolonged event.

The most important factor determining which energy system will be used is the intensity of the exercise, which is the rate, speed, or tempo at which you pursue a given activity. In general, the faster you do something, the higher your rate of energy expenditure and the more rapidly you must produce ATP for muscular contraction. Very rapid muscular movements are characterized by high rates of power production. If you were asked to run 100 meters as fast as you could, you would exert maximal speed for a short time. On the other hand, if you were asked to run 5 miles, you certainly would not run at the same speed as you would for the 100 meters. In the 100-meter run your energy expenditure would be very rapid, characterized by a high-power production. The 5-mile run would be characterized by low-power production, or endurance.

The requirement of energy for exercise is related to a power-endurance continuum. On the power end, we have extremely high rates of energy expenditure that a sprinter might use; on the endurance end, we see lower rates that might be characteristic of a marathon runner. The closer we are to the power end of the continuum, the more rapidly we must produce ATP. As we move toward the endurance end, our rate of ATP production does not need to be as great, but we need the capacity to produce ATP for a longer time.

It should be noted from the outset that all three energy systems—ATP-PCr, lactic acid, and oxygen—are used in one way or another during most athletic activities. (Gastin provides an excellent overview.) However, one system may predominate, depending primarily upon the intensity level of the activity. In this regard, the three human energy systems may be ranked according to several characteristics, which are displayed in table 3.7

Both the ATP-PCr and the lactic acid systems are able to produce ATP rapidly and are used in events characterized by high intensity levels that occur for short periods, because their capacity for total ATP production is limited. Because both of these systems may function without oxygen, they are called anaerobic. Relative to running performance, the ATP-PCr system predominates in short, powerful bursts of muscular activity such as the short dashes like 100 meters, whereas the lactic acid system begins to predominate during the longer sprints and middle distances such as 200, 400 and 800 meters. In any athletic event where maximal power production lasts about 1–10 seconds, the ATP-PCr system is the major energy source. The lactic acid system begins to predominate in events lasting 30–120 seconds, but studies have noted significant elevations in muscle lactic acid in maximal exercise even as brief as 10 seconds.

The oxygen system possesses a lower rate of ATP production than the other two systems, but its capacity for total ATP production is much greater. Although the intensity level of exercise while using the oxygen system is by necessity lower, this does not necessarily mean that an individual cannot perform at a relatively high speed for a long time. The oxygen system can be improved through a physical conditioning program so that ATP production may be able to meet the demands of relatively high-intensity exercise, as discussed previously and highlighted in figure 3.14. Endurance-type activities, such as those that last 5 minutes or more, are dependent primarily upon the oxygen system, but the oxygen system makes a very significant contribution even in events as short as 30–90 seconds, as recently documented by Spencer and Gastin.

TABLE 3.7 Major characteristics of the human energy systems*

	ATP-PCr	Lactic acid	Oxygen	Oxygen
Main energy source	ATP; phosphocreatine	Carbohydrate	Carbohydrate	Fat
Intensity level	Highest	High	Lower	Lowest
Rate of ATP production	Highest	High	Lower	Lowest
Power production	Highest	High	Lower	Lowest
Capacity for total ATP production	Lowest	Low	High	Highest
Endurance capacity	Lowest	Low	High	Highest
Oxygen needed	No	No	Yes	Yes
Anaerobic/aerobic	Anaerobic	Anaerobic	Aerobic	Aerobic
Characteristic track event	100-meter dash	200–800 meters	5,000-meter (5 km) run	Ultradistance
Time factor	1–10 seconds	30–120 seconds	5 minutes or more	Hours

*Keep in mind that during most exercises, all three energy systems will be operating to one degree or another. However, one system may predominate, depending primarily on the intensity of the activity. See text for further explanation.

In summary, we may simplify this discussion by categorizing the energy sources as either aerobic or anaerobic. Anaerobic sources include both the ATP-PCr and lactic acid systems while the oxygen system is aerobic. Table 3.8 illustrates the approximate percentage contribution of anaerobic and aerobic energy sources, dependent upon the level of maximal intensity that can be sustained for a given time period. Thus, for a 100-meter dash covered in 10 seconds, 85 percent of the energy is derived from anaerobic sources. For a marathoner (26.2 miles) with times of approximately 125–130 minutes in international-level competition, the aerobic energy processes contribute 99 percent. Although Ward-Smith, using a mathematical approach to predict aerobic and anaerobic contributions during running, noted that these percentage values may be modified slightly for elite athletes, the concept is correct. For example, using track athletes as subjects, Spencer and Gastin found that the relative contribution of the aerobic energy system was 29 percent in the 200-meter run and increased progressively to 84 percent in the 1500-meter run, noting that the contribution of the aerobic energy system during track running events is greater than traditionally thought. These values are somewhat higher than the aerobic percentage values presented in table 3.8, but support the concept. The key point is that the longer you exercise, the less your intensity has to be, and the more you rely on your oxygen system for energy production.

What energy sources are used during exercise?

The ATP-PCr system can use only adenosine triphosphate and phosphocreatine, but as noted previously, these energy sources are in short supply and need to be replaced by the other two energy systems.

The lactic acid system uses only carbohydrate, primarily the muscle glycogen stores. At high-intensity exercise levels that may be sustained for 1–2 minutes or less, such as exercising well above your VO_2 max, carbohydrate will supply over 95 percent of the energy. However, the accumulation of lactic acid may cause the early onset of fatigue.

On the other hand, the oxygen system can use a variety of different energy sources, including protein, although carbohydrate and fat are the primary ones. The carbohydrate is found as muscle glycogen, liver glycogen, and blood glucose. The fats are stored primarily as triglycerides in the muscle and adipose cells. As we shall see in this section and in chapters 4, 5, and 6, a number of different factors can influence which energy source is used by the oxygen system during exercise, but exercise intensity and duration are the two most important factors.

Under normal conditions, exercise intensity is the key factor determining whether carbohydrate or fat is used. Holloszy and others note that both absolute and relative (i. e., percent of VO_2 max) exercise intensities play important roles in the regulation of substrate metabolism. The absolute work rate determines the total quantity of fuel required, while relative exercise intensity plays a major role in determining the proportions of carbohydrate and fat oxidized by the working muscles. Hoppeler and Weibel noted that as one does mild to moderate exercise, say up to 50 percent of one's VO_2 max, blood glucose and fat may provide much of the needed energy. However, the transfer of glucose and fat from the vascular system to the muscles becomes limited at about 50 percent of VO_2 max. Thus, as you start to exceed 50 percent of your VO_2 max, you begin to rely more on your intramuscular stores of glycogen and triglycerides. As you continue to increase your speed or intensity, you begin to rely more and more on carbohydrate as an energy source. Apparently the biochemical processes for fat metabolism are too slow to meet the increased need for faster production of ATP, and carbohydrate utilization increases. The major source of this carbohydrate is muscle glycogen. The transition from use of fat to carbohydrate as the primary fuel source during increasing intensity of exercise has been referred to as the **crossover concept,** and although the technicalities of specific fuel contributions are the subject of debate, exercise scientists agree that at some specific point in the increase of exercise intensity an individual will begin to derive more energy from carbohydrate than fat. At high levels of energy expenditure, 70–80 percent of VO_2 max, carbohydrates may contribute more than 80 percent of the energy sources. This speaks for the need of adequate muscle glycogen stores when this level of exercise is to be sustained for long periods, say in events lasting over 60–90 minutes.

In events of long duration, when body stores of carbohydrate are nearly depleted, the primary energy source is fat. In the later stages of ultramarathoning events, fat may become the only fuel available. However, protein may become an important energy source in these circumstances; its role is detailed in chapter 6.

Other than exercise intensity and duration, a number of different factors are known to influence the availability and use of human energy sources during exercise. Gender, hormones, state of training, composition of the diet, time of eating prior to competition, nutritional status, nutrient intake during exercise, environmental temperature, and drugs are some of the more important considerations. For example, warm environmental temperatures may increase the use of carbohydrates, whereas caffeine may facilitate the use of fats. These considerations will be incorporated

TABLE 3.8 Percentage contribution of anaerobic and aerobic energy sources during different time periods of maximal work

Time	10 sec	1 min	2 min	4 min	10 min	30 min	60 min	120 min
Anaerobic	85	70	50	30	15	5	2	1
Aerobic	15	30	50	70	85	95	98	99

*Percentages are approximate and may vary between sedentary individuals and elite athletes.

in the following chapters where appropriate. For the interested reader, Hargreaves provides an excellent detailed review.

What is fatigue?

Fatigue is a very complex phenomenon. It may be chronic, or it may be acute. Both types may affect the athlete.

Chronic fatigue in the athlete may develop over time, usually in endurance athletes involved in prolonged, intense training. A key contributing factor may be inadequate energy. Louise Burke notes that each athlete has unique energy requirements. Wim Saris indicates that if these energy requirements are not satisfied, athletes may become overtrained. According to Roy Shephard, overtraining and/or a negative energy balance may be related to the development of the **chronic fatigue syndrome.** The chronic fatigue syndrome is characterized by mental depression and prolonged fatigue (over 6 months) in which fatigue is disproportionate to the exercise effort. In such cases, training would be adversely affected and performance would certainly suffer. Sports scientists are attempting to identify the causes, prevention, and treatment of the chronic fatigue syndrome.

Acute fatigue is experienced by most athletes at one time or another during maximal efforts. As acute fatigue can adversely affect sports performance, it has been the subject of considerable research. Tim Noakes, an international scholar in sports medicine, noted that the actual cause of fatigue during maximal exercise has not been identified but that several models may be viable, including energy supply and depletion, inadequate muscle recruitment, and models involving biomechanics and psychological factors. Walsh adds that each body organ, such as the heart, lungs, and muscles, has an established critical power for maximal exercise, which if exceeded will lead to fatigue. The site and cause of fatigue in the human body is related to the type of fatiguing exercise. For example, the site and cause of fatigue are different between maximal performances in powerlifting and marathon running.

In general, sports scientists classify the site of fatigue in the body as either central or peripheral. Central fatigue involves the brain or spinal cord of the central nervous system (CNS). The theory of CNS fatigue will be discussed in both chapters 4 and 6 in relation to the effects of dietary carbohydrates and amino acids on brain neurotransmitters. Fatigue may also be peripheral, located in the muscle tissue itself or at the junction of the muscle and nerve fibers (see figure 3.19). The actual psychological or physiological causes of fatigue are also very complex, but they appear to be related closely to the intensity and duration of the mental or physical tasks to be accomplished. However, most instances of fatigue during exercise are believed to be related to adverse changes in the muscle itself.

For purposes of the present discussion, **fatigue** will be defined as the inability to continue exercising at a desired level of intensity. Relative to this definition, fatigue may be due to a failure of the rate of energy production in the human body to meet the demands of the exercise task. In simple terms, ATP production rates are unable to match ATP utilization rates. This failure may be due to an inability of the central nervous system to fully stimulate the appropriate muscles, an insufficient supply of the optimal energy source, a reduced ability to metabolize the energy source in the muscle, or inadequate support from body systems, such as blood flow, serving the muscle. In essence, for one or more of these reasons the muscle cannot produce or use ATP rapidly enough to sustain the desired level of exercise intensity. Some possible causes of fatigue during exercise are listed in table 3.9.

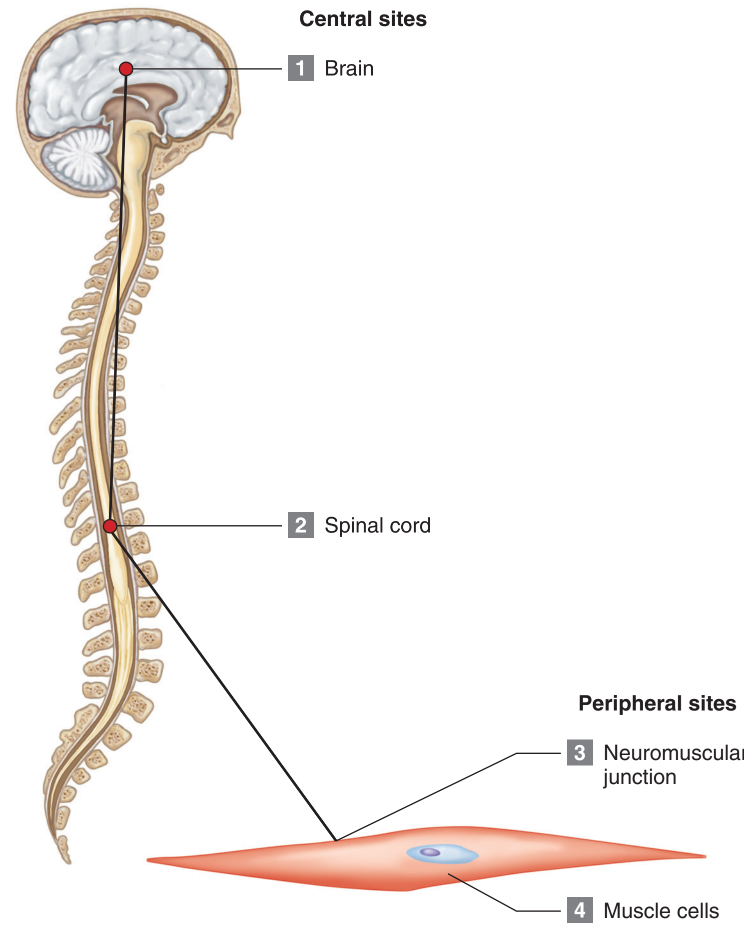


FIGURE 3.19 Fatigue sites. The causes of fatigue are complex and may involve central sites such as the brain and spinal cord or peripheral sites in the muscles. Hypoglycemia, or low blood sugar, could adversely affect the functioning of the brain, while the acidity associated with the production of lactic acid could possibly interfere with optimal energy production in the muscle cells.

How can I delay the onset of fatigue?

The most important factor in the prevention of premature fatigue is proper training, including physiological, psychological, and biomechanical training.

Physiologically, athletes must train specifically the energy system or systems that are inherent to their event. Under the guidance of sport physiologists and coaches, appropriate physiological training for each specific energy system may increase its energy stores, enzymatic activity, and metabolic efficiency, thus enhancing energy production. Physiological training enhances physical power.

Psychologically, athletes must train the mind to tolerate the stresses associated with their specific event. Sport psychologists

TABLE 3.9 Some possible causes of fatigue during exercise

Increased formation of depressant neurotransmitters
Increased serotonin levels
Decreased levels of energy substrates
Decrease in phosphocreatine levels Depletion of muscle glycogen Decrease in blood-sugar levels Decrease in plasma branched-chain amino acids
Disturbed intracellular environment
Impaired calcium recycling
Disturbed acid-base balance
Increase in hydrogen ions due to excess lactic acid production
Decreased oxygen transport
Decreased blood volume due to dehydration
Increased core body temperature resulting in hyperthermia
Decreased cooling effect due to dehydration
Disturbed electrolyte balance
Increased or decreased concentration due to sweat losses and water replacement

may help provide the athlete with various mental strategies, such as inducing either a state of relaxation or arousal, whichever may be appropriate for their sport. Physiological training may also confer some psychological advantages, such as tolerating higher levels of pain associated with intense exercise. Psychological training enhances mental strength.

Biomechanically, athletes must maximize the mechanical skills associated with their sport. For any sport, sport biomechanists can analyze the athlete's skill level and recommend modifications in movement patterns or equipment to improve energy production or efficiency. In many cases, modification of the amount of body fat and muscle mass may provide the athlete with a biomechanical advantage. Biomechanical training helps provide a mechanical edge.

Proper physiological, psychological, and biomechanical training represents the best means to help deter premature fatigue. However, what you eat may affect physiological, psychological, and biomechanical aspects of sport performance. Thus, nutrition is an important consideration in delaying the onset of fatigue during sport training and competition.

How is nutrition related to fatigue processes?

As noted in our discussion of the power-endurance continuum, we can exercise at different intensities but the duration of our exercise is inversely related to the intensity. We can exercise at a high intensity for a short time or at a low intensity for a long time. The importance of nutrition to fatigue is determined by this intensity-duration interrelationship.

In very mild aerobic activities, such as distance walking or low-speed running in a trained ultramarathoner, the body can sustain energy production by using fat as the primary fuel when carbohy-

TABLE 3.10 Examples of some nutritional ergogenic aids and, theoretically, how they may influence physiological, psychological, or biomechanical processes to delay fatigue

Provide energy substrate	**Attenuate fatigue-related metabolic by-products**
Carbohydrate: Energy substrate for aerobic glycolysis Creatine: Substrate for formation of phosphocreatine (PCr)	Aspartate salts: Amino acids that mitigate ammonia production Sodium bicarbonate: Buffer to reduce effects of lactic acid
Enhance energy-generating metabolic pathways	**Prevent catabolism of energy-generating cells**
B vitamins: Coenzymes in aerobic and anaerobic glycolysis Carnitine: Enzyme substrate to facilitate fat metabolism	Antioxidants: Vitamins to prevent unwanted oxidation of cell membranes HMB: By-product of amino acid metabolism to prevent protein degradation
Increase cardiovascular-respiratory function	**Ameliorate psychological function**
Iron: Substrate for hemoglobin formation and oxygen transport Glycerol: Substance to increase blood volume	BCAA: Amino acids that favorably modify neurotransmitter production Choline: Substrate for formation of acetylcholine, a neurotransmitter
Increase size or number of energy-generating cells	**Improve mechanical efficiency**
Arginine and ornithine: Amino acids that stimulate production of human growth hormone, an anabolic hormone Chromium: Mineral to potentiate activity of insulin, an anabolic hormone	Ma huang: Stimulant to increase metabolism for fat loss Hydroxycitrate (HCA): Supplement to increase fat oxidation for fat loss

Note: These examples as to how nutritional aids may delay fatigue are based on theoretical considerations. As shall be shown in respective chapters, supplementation with most of these nutritional ergogenic aids has not been shown to enhance exercise or sport performance.

drate levels diminish. Because the body has large stores of fat, energy supply is not a problem. However, low blood-sugar levels, dehydration, and excessive loss of minerals may lead to the development of both mental and physical fatigue in very prolonged activities.

In moderate to heavy aerobic exercise, the body needs to use more carbohydrate as an energy source and thus will run out of muscle glycogen faster. As we shall see later, carbohydrate is a more efficient fuel than fat, so the athlete will have to reduce the pace of the activity when liver and muscle carbohydrate stores are depleted, such as during endurance-type activities lasting over 90 minutes. Thus, energy supply may be critical. Low blood sugar, changes in blood constituents such as certain amino acids, and dehydration also may be important factors contributing to the development of mental or physical fatigue in this type of endeavor.

In very high-intensity exercise lasting only 1 or 2 minutes, the probable cause of fatigue is the disruption of cellular metabolism caused by the accumulation of hydrogen ions resulting from excess lactic acid production. There is some evidence to suggest that sodium bicarbonate (discussed in chapter 9) may help reduce this disruptive effect of lactic acid to some extent. Furthermore, a very low supply of muscle glycogen in fast-twitch muscle fibers may impair this type of performance.

In extremely intense exercise lasting only 5–10 seconds, a depletion of phosphocreatine (PCr) may be related to the inability to maintain a high force production. Although some nutritional practices, such as phosphate loading or gelatin supplements, have been used in attempts to increase PCr, they have not been regarded to be effective. However, recent research involving creatine supplements has shown some beneficial effects, which are discussed in chapter 6.

In summary, a deficiency of almost every nutrient may be a causative factor in the development of fatigue. A poor diet can hasten the onset of fatigue. Proper nutrition is essential to assure the athlete that an adequate supply of nutrients is available in the diet not only to provide the necessary energy, such as through carbohydrate and fat, but also to ensure optimal metabolism of the energy substrate via protein, vitamins, minerals, and water. The role of specific nutrients relative to fatigue processes will be discussed in later sections of the book where appropriate. Table 3.10 provides some examples of how some nutrients or dietary supplements are thought to delay fatigue.

Key Concept Recap

- The ATP-PCr and lactic acid energy systems are used primarily during fast, anaerobic, power-type events, while the oxygen system is used primarily during aerobic, endurance-type events.
- Fats serve as the primary source of fuel during mild levels of exercise intensity, but carbohydrates begin to be the preferential fuel as the exercise intensity increases.
- A sound training program and proper nutrition are important factors in the prevention of fatigue during exercise.

Check for Yourself

Check the world records in running for 100 meters, 400 meters, 1,500 meters, and the marathon (42,200 meters). Calculate the average speed for each distance. Can you relate your findings to the human energy systems and their relationship to fatigue?

APPLICATION EXERCISE

Borrow, rent, or buy a pedometer or an accelerometer and keep a record of your daily movement (recording the amount every 2 hours). This will provide you with an estimate of your daily physical activity involving movement and will be useful in determining your estimated energy requirement (EER) and maintaining an optimal body weight as discussed in chapter 11.

	Distance logged Sunday	Distance logged Monday	Distance logged Tuesday	Distance logged Wednesday	Distance logged Thursday	Distance logged Friday	Distance logged Saturday
12:00–2:00 A.M.							
2:00–4:00 A.M.							
4:00–6:00 A.M.							
6:00–8:00 A.M.							
8:00–10:00 A.M.							
10:00–12:00 A.M.							
12:00–2:00 P.M.							
2:00–4:00 P.M.							
4:00–6:00 P.M.							
6:00–8:00 P.M.							
8:00–10:00 P.M.							
10:00–12:00 P.M.							

Review Questions—Multiple Choice

1. Which energy system would predominate in an all-out, high-intensity, 400-meter dash in track?
   (a) ATP-PC
   (b) lactic acid
   (c) oxygen–carbohydrate
   (d) oxygen–fat
   (e) oxygen–protein
2. If a 50 kilogram body-weight athlete was exercising at an oxygen consumption level of 2.45 liters (2,450 ml) per minute, approximately how many METS would she be attaining?
   (a) 8
   (b) 10
   (c) 11
   (d) 12
   (e) 14
   (f) insufficient data to calculate the answer
3. Which of the following classifications of physical activity is rated as light, mild aerobic exercise—because it is likely to burn less than 7 Calories per minute?
   (a) competitive racquetball
   (b) running at a speed of 7 miles per hour
   (c) walking at a speed of 2.0 miles per hour
   (d) competitive singles tennis
   (e) bicycling at a speed of 12 miles per hour
4. Which of the following statements relative to the basal metabolic rate or resting metabolic rate is false?
   (a) The BMR is high in infancy but declines throughout adolescence and adulthood.
   (b) The BMR is higher in women than in men due to the generally higher levels of body fat in women.
   (c) The resting metabolic rate is the equivalent of one MET.
   (d) The resting metabolic rate is higher than the BMR.
   (e) Dietary-induced thermogenesis raises the resting metabolic rate.
5. Which of the following energy sources found in the human body represents the greatest storage of potential energy in the form of total calories?
   (a) blood glucose
   (b) ATP
   (c) muscle glycogen
   (d) adipose tissue triglycerides
   (e) muscle protein
6. Of the following statements concerning the interrelationships between various forms of energy, which one is false?
   (a) A kilojoule is greater than a kilocalorie.
   (b) A kilogram-meter is equal to 7.23 foot-pounds.
   (c) A gram of fat has more Calories than a gram of carbohydrate.
   (d) A gram of fat has more Calories than a gram of protein.
   (e) A liter of oxygen can release more than one kilocalorie when metabolizing carbohydrate.
7. Approximately how many calories will a 200-pound individual use while jogging a mile?
   (a) 70
   (b) 145
   (c) 200
   (d) 255
   (e) 440
8. Which of the following statements relative to exercise and metabolic rate is false?
   (a) The intensity of the exercise is the most important factor to increase the metabolic rate.
   (b) Increased efficiency for swimming a set distance will decrease the energy cost.
   (c) The heavier person will burn more calories running a mile than a lighter person.
   (d) Oxygen consumption and heart rate are two ways to monitor the metabolic rate.
   (e) Walking a mile slowly or jogging a mile cost the same amount of calories.
9. Which energy system has the greatest capacity for energy production, i.e., endurance?
   (a) ATP-PCr
   (b) lactic acid
   (c) anaerobic glycolysis
   (d) oxygen
   (e) phosphagens
10. Which of the following is *not* needed to calculate the estimated energy requirement (EER)?
    (a) body fat percentage
    (b) age
    (c) height
    (d) weight
    (e) physical activity level (PAL)

Answers to multiple choice questions:
1. b; 2. e; 3. c; 4. b; 5. d; 6. a; 7. b; 8. e; 9. d; 10. a.

Review Questions—Essay

1. If an individual performed 5,000 foot pounds of work in one minute, how many kilojoules of work were accomplished?
2. Name the sources of energy stored in the human body and discuss their role in the three human energy systems.
3. Differentiate between BMR, RMR, BEE, REE, TEF, TEE, EER, and TDEE as defined in this text.
4. Explain the role of the three energy systems during exercise and provide an example using track running events.
5. List the major causes of fatigue during exercise and indicate how various nutritional interventions may help prevent premature fatigue.

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