7 Water and Electrolytes

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Learning Objectives

1. Describe the approximate amount, distribution, and roles of body water.
2. Discuss the processes by which water movements occur between compartments in the body.
3. Define euhydration, hyperhydration, hypohydration, and dehydration.
4. Identify avenues of water and sodium loss and intake.
5. Discuss the effect of exercise on fluid balance and outline strategies for maintaining fluid balance before, during, and after exercise.
6. Identify the role fluid plays in body temperature regulation during exercise and on performance and health.
7. Discuss the effect of caffeine on hydration status.
8. Explain the phenomenon of hyponatremia and outline a strategy for prevention in endurance and ultraendurance athletes.

Pre-Test Assessing Current Knowledge of Water and Electrolytes

Read the following statements about water and electrolytes and decide if each is true or false.

1. The two major aspects of fluid balance are the volume of water and the concentration of the substances in the water.
2. Now that sports beverages are precisely formulated, it is rare that water would be a better choice than a sports beverage for a trained athlete.
3. Athletes should avoid caffeinated drinks because caffeine is a potent diuretic.
4. A rule of thumb for endurance athletes is to drink as much water as possible.
5. Under most circumstances, athletes will not voluntarily drink enough fluid to account for all the water lost during exercise.

Water is often considered the most important nutrient. Failure to consume other nutrients may result in harmful deficiencies over a span of weeks, months, or years, but humans can only live for a few days without water. It is the most abundant substance in the body, comprising approximately 60 percent of an average person's body weight. Water provides the **aqueous** medium for chemical reactions and other processes within cells, transports substances throughout the body, facilitates **thermoregulation** (maintenance of body temperature), and is critical to most other physiological processes. Because of the additional physiological stress generated by physical activity, exercise, and sport, fluid balance is an important consideration for athletes and active people.

Loss of body water can be detrimental to both performance and health, as can excessive water consumption. In extreme cases, these situations can be fatal. The challenge for athletes, especially those exercising in hot and humid environments, is to adequately replenish water that is lost during (if possible) and after exercise. Some simple postexercise assessments, such as scale weight, urine color, and degree of thirst, can help athletes monitor if fluid has been adequately restored. The loss and intake of **electrolytes** (e.g., sodium) must also be balanced.

Each athlete needs an individualized plan for fluid and/or electrolyte intake before, during, and after exercise under normal training conditions. The plan will need to be adjusted to reflect changing environmental conditions (e.g., increasing temperature, stress of competition). The amount and timing of fluid and/or electrolyte intake are critical elements of the plan. For many athletes, carbohydrate intake will also be critical and the amount, type, and concentration of carbohydrate are included as part of the plan because fluid is often used as a vehicle for carbohydrate delivery.

Sports beverages may be part of the athlete's individualized plan for fluid and/or electrolyte intake before, during, and after exercise.

Overview of Water and Electrolytes

There are two major aspects to fluid balance that must be considered and understood: 1) water volume and 2) the concentration of **solutes** in body fluid. First, the body must have an adequate volume of water to meet physiological demands, a condition referred to as **euhydration.** An excess amount of water is generally a temporary condition in healthy people and is called **hyperhydration,** while an insufficient volume of water in the body is termed **hypohydration.** The term **dehydration** refers to the process of losing body water and moving from a state of euhydration to hypohydration. Dehydration is often used interchangeably with hypohydration, but these terms have different meanings.

Second, because of the potential for water to move from one area to another by **osmosis** due to concentration differences, the overall concentration of substances dissolved in body water must be considered as well. This is the concept of **tonicity;** body fluids are considered to be **hypotonic, isotonic,** or **hypertonic** if they have a concentration of solutes that is less than, the same as, or greater than the concentration of solutes in the cells, respectively. Although a number of substances are osmotically active, the tonicity of body fluids is due largely to the concentration of electrolytes, electrically

Table 7.1 Electrolytes Involved in Fluid Balance

Cations	Anions
Sodium (Na^+)	Chloride (Cl^-)
Potassium (K^+)	Bicarbonate ($HC0_3^{-}$)
Calcium (Ca^{2+})	Phosphate (PO_4^{3-})
Magnesium (Mg^{2+})	Protein

Cations are positively charged electrolytes and anions are negatively charged electrolytes.

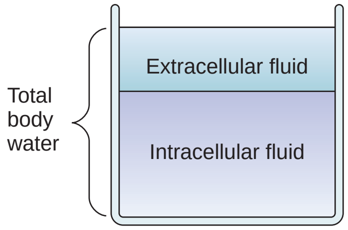

Figure 7.1 Body Water Compartments

Approximately two-thirds of body water is found in the intracellular fluid (ICF) compartment and approximately one-third is found in the extracellular fluid (ECF) compartment.

charged **cations** such as sodium (Na^+) and potassium (K^+), and **anions** such as chloride (Cl^-) and phosphate (PO_4^{3-}). Table 7.1 lists the cations and anions involved in fluid balance.

Body Water and Electrolytes

The amount of water in the body depends on a variety of factors, including body size, gender, age, and body composition. In general, larger people have more body water compared to those of smaller stature and males have more water than females because men typically have more muscle mass and less body fat than women. Body water percentage has an inverse relationship with both age and body fatness; it declines with advancing age and increasing body fatness. On average, an adult's body is approximately 60 percent water by weight, but individuals may range from 40 to 80 percent. An average 70-kg (154-lb) male has approximately 42 liters (L) of total body water, and the average female approximately 30 L. Expressed as a nonmetric measurement, the average female and male have approximately 8 and 11 gallons of body water, respectively. Different body tissues contain varying proportions of water. For example, blood **plasma** is largely fluid and consists of approximately 90 percent water. Muscle and other organ tissue can range from 70 to 80 percent water, while bone contains much less water, about 22 percent. Lipids are **anhydrous,** therefore, fat tissue contains very little water—approximately 10 percent.

DISTRIBUTION OF BODY WATER

Water is distributed throughout the body. This distribution is often separated into two major compartments: intracellular fluid (ICF) and extracellular fluid (ECF). Intracellular fluid consists of all the water contained within the trillions of cells in the body. Some cells have higher concentrations of water than others. All of these cells maintain their integrity because of their cell membranes, which separates the fluid inside the cells from the extracellular fluid. The ECF is further divided into subcompartments. One subcompartment is the plasma, the watery portion of the blood. Another is the **interstitial fluid,** the fluid that is found between the cells. Approximately two-thirds of total body water is in the ICF, leaving approximately one-third in the ECF (Figure 7.1).

Intracellular Fluid. The body contains trillions of cells, many with different structures, composition, and functions. The water content of cells may vary dramatically. For example, myocytes or muscle cells may contain as much as 75 to 80 percent water by weight, while osteocytes or bone cells may consist of as little as 22 percent water. Collectively,

Aqueous: Consisting mostly of water.

Thermoregulation: Maintenance of body temperature in the normal range.

Electrolyte: A substance that will dissociate into ions in solution and is capable of conducting electricity.

Solute: A substance dissolved in a solution.

Euhydration: "Good" hydration (eu = good); a normal or adequate amount of water for proper physiological function.

Hyperhydration: A temporary excess of water; beyond the normal state of hydration.

Hypohydration: An insufficient amount of water; below the normal state of hydration.

Dehydration: The process of going from a state of euhydration to hypohydration.

Osmosis: Fluid movement through a semipermeable membrane from a greater concentration to a lesser concentration so the concentrations will equalize.

Tonicity: The ability of a solution to cause water movement.

Hypotonic: Having a lower osmotic pressure than another fluid.

Isotonic: Having an equal osmotic pressure to another fluid.

Hypertonic: Having a higher osmotic pressure than another fluid.

Cation: A positively charged ion.

Anion: A negatively charged ion.

Plasma: Fluid component of blood or lymph; does not include cells.

Anhydrous: Containing no water.

Interstitial fluid: Found between cells, tissues, or parts of an organ.

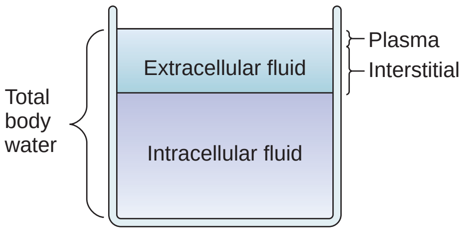

Figure 7.2 Extracellular Water Compartments

The two main components of the Extracellular Fluid (ECF) compartment are the interstitial fluid, composing approximately 80 percent of the ECF, and the plasma, which is approximately 20 percent of the ECF.

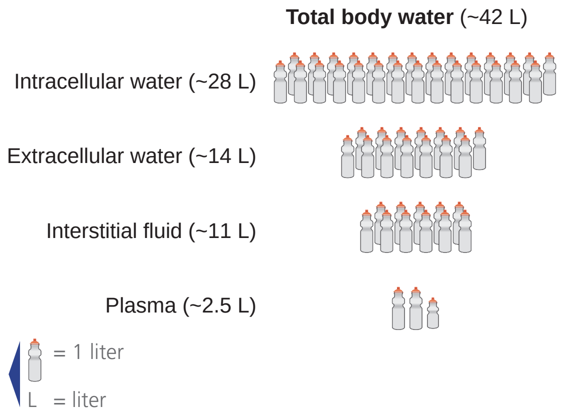

Figure 7.3 Total Body Water Distribution

though, the cells of the body contain approximately two-thirds of the body's total water volume, and all cells together are considered the intracellular fluid compartment. If an average male has 42 L of body water, approximately 28 L (~7.5 gal) is contained in the cells or about 40 percent of total body weight.

Extracellular Fluid. All of the water in the body not contained inside cells is considered a part of the extracellular fluid compartment. This is approximately one-third of the total body water, or about 14 L (~3.5 gal) in the average male. As shown in Figures 7.2 and 7.3, the ECF can be further subdivided into discrete areas such as the plasma (~2.8 L or ~3 qt) and the interstitial fluid (11.2 L or 3 gal).

The plasma serves as the fluid transportation medium to transport red blood cells, gases, nutrients, hormones, and other substances throughout the body. It is a major reservoir of fluid and plays a critical role in thermoregulation, particularly for activity in hot and humid environments. Of the total ECF volume, plasma accounts for approximately one-fifth, or 20 percent. The plasma is contained within the vascular system and is separated from the interstitial fluid by the walls of the blood vessels. The thicker walls of the larger blood vessels (e.g., arteries and veins) provide a substantial barrier to fluid movement, while the smaller and thinner walls of the capillaries are very permeable and can allow considerable movement of water between compartments.

The major component of the ECF compartment (approximately 80 percent) is interstitial fluid. The interstitial fluid surrounds the cells and provides protection and an avenue for exchange with the cells of the body. The remaining ECF compartments are considered negligible compared to plasma and interstitial fluid because they are so small. Lymph is fluid contained in the lymphatic system, which returns fluid from the interstitial space to the blood. Transcellular fluids are found in specialized cells such as the brain and spinal column (cerebrospinal fluid), joints (synovial fluid), areas surrounding the internal organs, heart, and lungs (peritoneal, pericardial, and intrapleural fluids, respectively), eyes (intraocular fluid), and digestive juices. While these fluids play critical functional roles, the total amount of water contained in these fluids is small and generally stable, so these fluid compartments are usually not included in discussions of body fluid balance. Figure 7.3 illustrates total body water distribution.

Water Movement between Compartments. The water that is found in ICF and ECF is not **static.** Water can be added to or removed from these compartments, and although there are barriers separating the various compartments, fluid moves between compartments relatively easily. Because intracellular fluid exists in isolated cells, water must pass through the extracellular fluid compartment in order to reach cells. The ECF therefore acts as a gateway for water entry into the body, initially through the plasma.

All cells are freely permeable to water so water can move through cell membranes easily, but there must be some force that stimulates the movement of water. The two major forces that result in the movement of water are fluid (hydrostatic) pressure and osmotic pressure.

Fluid or hydrostatic pressure is created when there is a difference in fluid pressure between two areas. For example, the cardiovascular system uses hydrostatic pressure to move blood throughout the body. When the heart contracts, it squeezes the blood that fills it, increasing blood pressure. This increase in blood pressure creates the driving force to propel blood through the blood vessels in the pulmonary and **systemic circulation.** This type of pressure can also result in water moving from the area of higher pressure (blood plasma), to areas of lower pressure (interstitial spaces). In another example of the fluid shifts resulting from hydrostatic pressure, feet and ankles may swell if a person stands for long periods of time. When a person stands upright, blood rushes towards the feet due to gravity. This increase in hydrostatic pressure inside the blood vessels in the lower extremities results in more movement of water to the interstitial spaces in the feet and lower legs, resulting in swelling or **edema.**

The second cause of water movement is due to osmosis, the tendency of water to move from areas of high solute concentration to areas of lower solute concentration. This would not be a factor if the fluid in the various

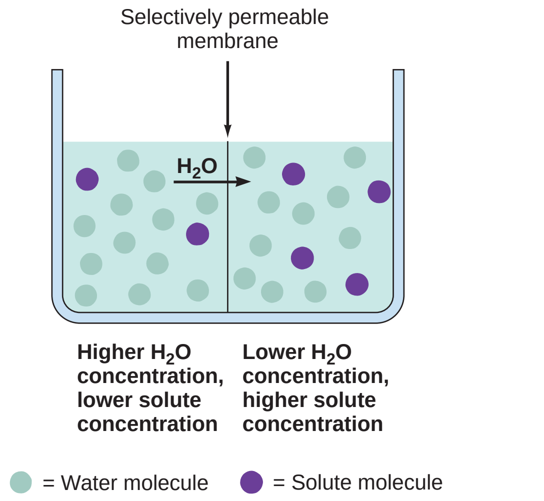

Figure 7.4 Osmosis

Water will move by osmosis across a selectively permeable membrane from an area of lower solute concentration to an area of higher solute concentration.

compartments contained only water. However, fluids in the body contain a wide variety of solutes dissolved in the water. Figure 7.4 illustrates the net movement of water by osmosis from an area of lower to higher solute concentration across a selectively permeable membrane.

The membranes of cells are selectively permeable, allowing free movement of water but often maintaining differences in the distribution of solutes.

Osmotic pressure is measured in milliosmoles (mOsm). When the number of particles (solute) is measured per *kilogram* of **solvent,** the correct term is **osmolality;** when measured per *liter* of solvent, the correct term is **osmolarity.** In nutrition and medicine, *osmolarity* is the standard term, whereas in exercise physiology the term *osmolality* is more commonly used because osmolality is not affected by temperature (Gropper, Smith, and Groff, 2005). In this textbook, the term osmolarity will be used.

The two major subcompartments of the ECF—plasma and interstitial fluid—have a nearly identical composition and distribution of electrolytes (see Figure 7.5). In

Static: Not moving or changing.

Systemic circulation: Circulation of blood to all parts of the body other than the lungs.

Edema: An abnormal buildup of fluid between cells.

Solvent: A substance (usually a liquid) in which other substances are dissolved.

Osmolality: Osmoles of solute per kilogram of solvent.

Osmolarity: Osmoles of solute per liter of solution.

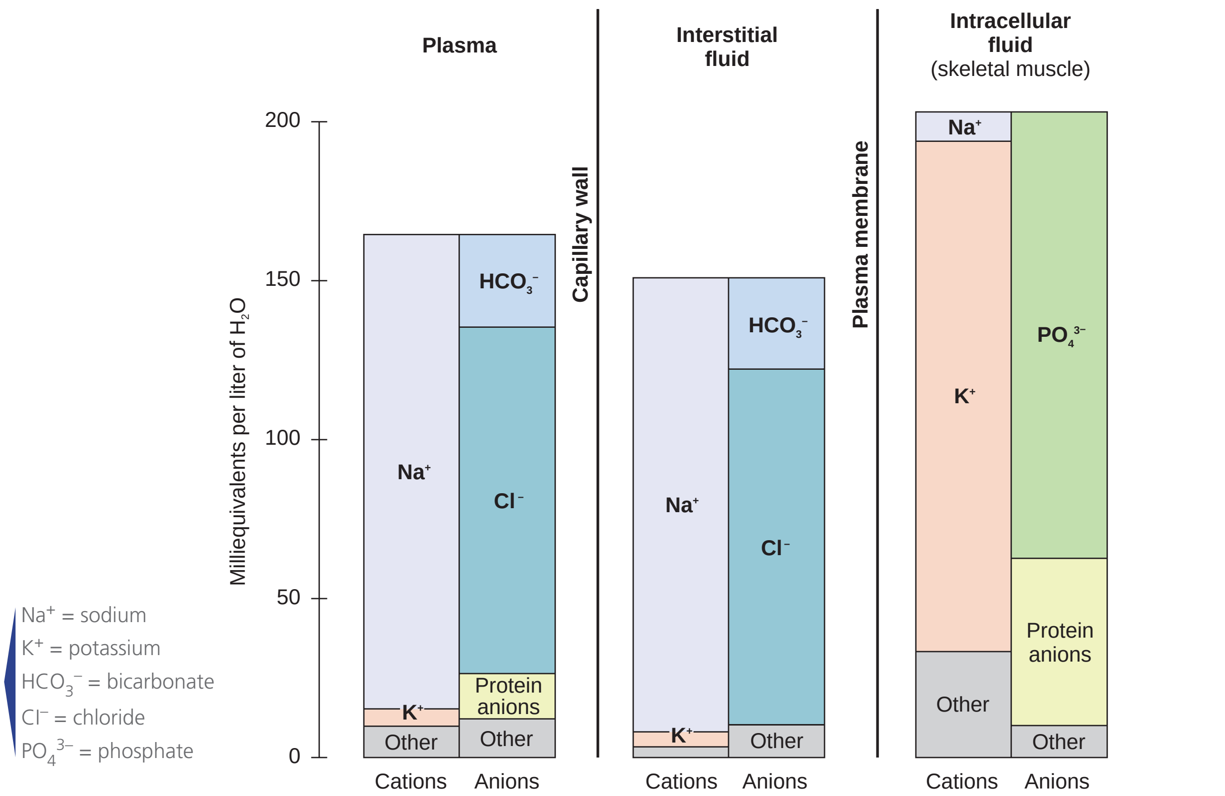

Figure 7.5 Electrolyte Distribution in Body Fluid Compartments

extracellular fluid the major cation (positively charged ion) is sodium. The amount and concentration of potassium and other cations are much smaller. The major anions (negatively charged ions) are chloride and bicarbonate. In addition, there are some negatively charged proteins in plasma (e.g., albumin) that are typically not found in the interstitial fluid, but the amount is small compared to chloride and bicarbonate.

The composition and distribution of electrolytes inside the cells are quite different from those found in the extracellular fluid (see Figure 7.5). Potassium is the primary cation in the ICF, with sodium being present but at a much lower concentration. This distribution is opposite that of the ECF, and represents an important concentration differential for each ion. Because of these concentration differences, there is constant pressure for sodium to leak into cells and for potassium to leak out of cells. Normal intracellular and extracellular concentrations are maintained by the action of the sodium-potassium pumps located in the cell membranes, which constantly pump sodium ions out of the cells, while simultaneously pumping potassium ions back into the cells. The major anions inside the cells are phosphate and the negatively charged intracellular proteins.

It is important to note that while the ionic composition differs between the ICF and the ECF, the osmolarity or total concentration of all solutes in those compartments is generally the same. Shifts in fluid between the ECF and ICF occur solely due to osmosis, the movement of water from an area of lower concentration to an area of higher concentration. Under normal homeostatic conditions, the osmolarities of the ECF and ICF are the same, and there is no net movement of water. However, if the concentration in either compartment changes, a fluid shift may occur. If sodium increases in concentration in the extracellular fluid, water would move by osmosis out of the cells and into the ECF in an attempt to dilute the extracellular fluid and restore balance. For example, heavy sweating can cause a large loss of plasma volume due to water loss, resulting in an increased concentration of sodium in the plasma. This stimulates movement of water out of the cells (i.e., ICF) and into the plasma (i.e., ECF), causing the cells to shrink. Conversely, if the concentration of sodium in the extracellular fluid is decreased, the osmolarity of the ECF would be less than that in the cells, and water would move by osmosis into the cells in an attempt to correct the concentration imbalance. The resulting movement of water into the cells would cause the cells to expand.

The concentration of solutes, or osmolarity, in a particular fluid is not static, and it can sometimes change relatively quickly. The concept of tonicity describes this change in solute concentration. Recall that isotonicity refers to a concentration of solutes that are equal to each other. Water will pass in and out of the cell, but the net movement of water will be zero. When a fluid has a higher concentration of solutes compared to another fluid, it is said to be hypertonic. For example, when a person sweats heavily, there is a loss of water from the extracellular fluid and the ECF becomes hypertonic in relation to the intracellular fluid. The opposite concentration difference is called hypotonic, when a fluid has a lower osmolarity than the reference fluid. If a person consumes a large amount of water very quickly, this water is absorbed into the extracellular fluid, resulting in a dilution of the ECF and making it hypotonic compared to the intracellular fluid (see Figure 7.6).

If one understands how water moves by osmosis, one can easily understand how fluid shifts in the body. The movement of fluid occurs as a result of controlling the amount of water in the ECF and the osmolarity of the ECF. The amount of water and the osmolarity in the ECF is controlled by water intake and loss, sodium intake and loss, and by compensatory regulatory mechanisms in the kidney and gastrointestinal tract.

What's the point? Water will move from an area higher to lower pressure or from an area of lower to higher solute concentration.

WATER LOSS AND WATER INTAKE

Fluid balance in the body is partially a result of the daily balance of water intake and water loss. There are a limited number of avenues for water intake, but a wider variety of ways that water may be lost from the body (see Figure 7.7).

Water Loss. Water loss from the body is generally categorized as either **insensible** or **sensible.** Insensible refers to avenues of loss that are not normally noticed by the individual, including water lost through ventilation and through nonsweat diffusion through the skin. With each breath, the inspired (i.e., inhaled) air is humidified to protect delicate lung tissues from drying. The water vapor that is added is then lost with the subsequent expiration, because the water is not recaptured before the air is exhaled from the body. This water loss is typically not noticed except on cold days when we can "see our breath." When warm, humid air from the lungs is rapidly cooled by the cold air outside, water vapor condenses into water droplets that can be readily seen. Water losses by this route can increase in environments in which the air is colder and drier, as more water vapor needs to be added to the inspired air. Increased levels of ventilation as a result of exercise may also cause an increased insensible loss of water.

Skin must be kept moist to prevent drying and cracking, and some of the water that diffuses into the

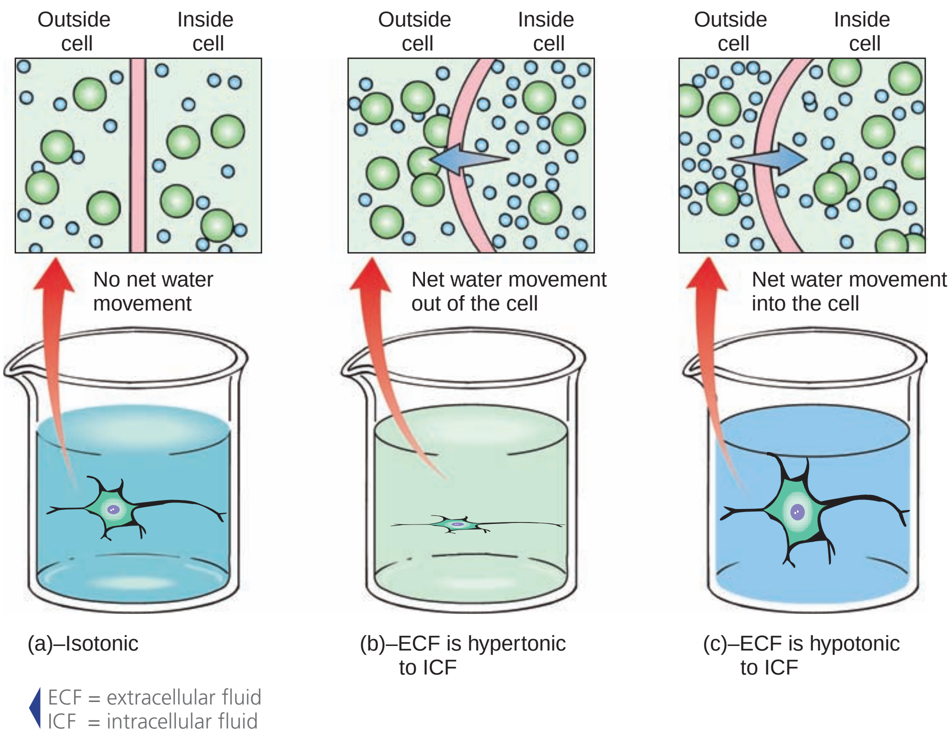

Figure 7.6 Isotonicity, Hypertonicity, and Hypotonicity

One avenue of water loss is through ventilation.

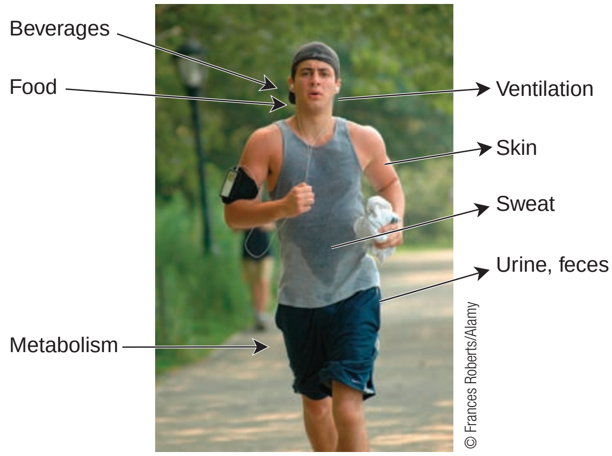

Figure 7.7 Avenues of Water Gain and Loss

Water can be gained by the body through the consumption of food and/or beverages, and as a result of metabolism. Water can be lost via ventilation, insensible loss through the skin, sweating, and urine and fecal losses.

skin is lost from the body. Water loss by this mechanism may also increase in dry environments with low humidity. Total insensible water losses average approximately 1,000 milliliters (ml) or ~36 oz (~4.5 cups) per day for the average person.

The three major areas of sensible water loss are the fluid lost in urine, feces, and sweat (see Figure 7.7). The amount of water in feces is variable, but daily loss by this route averages approximately 100 ml (~3.5 oz) per day. This is not typically a major avenue of water loss by the body, unless an individual has a disease such as dysentery that results in large volumes of watery diarrhea.

The renal system provides the major physiological mechanism for controlling fluid balance in the body via the production and excretion of urine. Urine output can vary dramatically, but for the average person under homeostatic conditions it approximates 1,500 ml per day (~54 oz or 6–7 cups). The amount of renal water loss

Insensible: Imperceptible.

Sensible: Perceptible.

is highly variable, and can be influenced by the amount of fluid and salt intake, renal function, the action of various hormones, and by the consumption of compounds that have a **diuretic** effect.

A diuretic is a substance that increases urine output. All fluids can have a diuretic effect. Water is a diuretic if a person is in fluid balance and ingests a large volume of water. However, the focus is generally on substances that exert a diuretic effect by a mechanism in addition to an increased volume of fluid. For example, alcohol has a mild diuretic effect because it inhibits the production of antidiuretic hormone (ADH). Nearly 200 herbs are known to have a diuretic effect. Some diuretics are prescription medications (e.g., Lasix™) and can block the reabsorption of fluid and/or electrolytes from the renal tubules. These substances may have a substantial effect on hydration status, and athletes are cautioned about their use especially if they are already hypohydrated.

Caffeine (found in caffeinated coffee and some soft drinks) and theophylline (found in tea) increase urine output by increasing the blood flow in the kidneys and increasing sodium and chloride excretion. In the past, athletes were cautioned about consuming these beverages because they are mild diuretics, but avoidance is no longer recommended. Armstrong (2002) reviewed studies of caffeine ingestion and the effect on fluid and electrolyte imbalance. Based on the current body of scientific literature, a daily caffeine intake of 300 mg or less does not have a negative effect on fluid or electrolyte balance. The caffeine content of brewed coffee can vary, but a rule of thumb measurement is that an 8-oz cup of caffeinated coffee contains approximately 100 mg of caffeine. Thus, 1 to 3 cups of caffeinated coffee daily (or the equivalent from other beverages) as part of a normal diet is not considered detrimental to euhydration, and it is no longer recommended that caffeine be completely avoided by athletes. This level of caffeine intake would also be unlikely to result in a positive urinary caffeine test when caffeine is listed by a sports-governing body as a banned substance. More information about caffeine and alcohol can be found in Chapter 10.

Another highly variable avenue of water loss is sweating, one of the body's major thermoregulatory mechanisms. Sweat is water that is secreted from sweat glands onto the surface of the skin. When this water evaporates (i.e., changes from water to water vapor), it results not only in a loss of water, but in a transfer of heat away from the body. If an individual is not in a hot environment, sweating is minimal and water loss by this mechanism averages approximately 100 ml (~3.5 oz) daily. As environmental temperatures rise and/or activity increases, thermoregulatory demands increase, and water loss via sweating increases. It would not be uncommon for active adults in hot and/or humid environments to lose several liters of water each day through sweating. The effect of exercise and activity on water loss will be discussed in greater detail later in this chapter.

In many athletes the loss of water through sweating is very visible, but in others it may not be as noticeable. Athletes that compete and train in the water, such as swimmers and water polo players, may sweat as part of their thermoregulatory response, but this avenue of water loss is not readily apparent. One study of elite male water polo players showed an average sweat rate of 287 ml per hour during training and 786 ml per hour during competitive matches. The same study showed elite male and female swimmers having an average sweat rate during training of 138 ml and 107 ml per kilometer swum, respectively (Cox et al., 2002). The hydration needs of these athletes should not be overlooked.

Water Intake. The addition of water to the body is primarily accomplished through the fluid content of beverages and foods consumed each day, and secondarily through metabolism (see Figure 7.7). On average, an adult will take in approximately 2,350 ml (~84 oz or 10.5 cups) of water each day from beverage and food sources, but there can be considerable variation depending on how much an individual eats and drinks. The water content of foods can vary dramatically, as can be illustrated by comparing watermelon (~90 percent water) and bran cereal (~2 percent water). Beverages also vary in their water content. Water, coffee (black), and tea (plain) are 99 percent water with a small amount of minerals and other compounds accounting for the remaining 1 percent. A sports beverage such as Gatorade Thirst Quencher® contains 93 percent water and fruit juice is approximately 88 percent water (the remainder is mostly sugar). Milk, depending on the fat content, ranges from 88 to 91 percent water, with the remainder being substances such as proteins and minerals. All beverages are predominately water, but each can have a different effect on fluid balance and osmolarity because of the other substances contained.

Another source of water is a result of aerobic metabolism. As explained in Chapter 3, in the metabolic pathway of oxidative phosphorylation, oxygen is required in the mitochondria to be the final electron acceptor at the end of the electron transport chain. Oxygen (O) molecules pick up the electrons in the form of hydrogen (H) molecules, and are thus converted to water (H_20). Aerobic metabolism contributes approximately 350 ml (~12.5 oz) of water each day. For the average adult in homeostasis, approximately 2,700 ml (~96 oz or 12 cups) of water are consumed or produced by the body each day via food and beverage intake and metabolism.

WATER BALANCE AND IMBALANCE

The amount of water in the body is constantly changing, with fluid being added and removed through the mechanisms discussed above. The body is said to be in fluid balance if a sufficient amount of fluid is present that allows for the body to function normally. Although

Figure 7.8 The Fluid Continuum

The amount of water in the body lies along a continuum, from hypohydration (too little) to hyperhydration (too much), with the optimal amount called euhydration.

the body has sensitive mechanisms to maintain fluid balance over time, it is possible to exceed the capabilities of these mechanisms either in the short or long term. In general, the amount of fluid consumed is not carefully matched to the body's daily needs. The usual overall strategy is to drink an excess of water, retain what is needed to maintain fluid balance, and excrete the excess. Deviations from this basic strategy can result in imbalances.

Euhydration, Hypohydration, and Hyperhydration. The amount of water in the body lies along a continuum, from too little to too much. Euhydration, hypohydration, and hyperhydration are terms that describe the status of body water, although these terms refer to a general condition rather than to a specific amount of water (see Figure 7.8). Because of the difficulties of measuring total body water and the variability between individuals, specific dividing lines between these conditions on this continuum have not been identified. The discussion that follows assumes that a person is healthy and has normal kidney function.

Euhydration refers to a "normal" amount of water to support fluid balance and to easily meet required physiological functions. Enough water is present to maintain osmolarity of the extracellular fluid, prevent large water shifts between compartments, and support critical processes such as cardiovascular function and thermoregulation. As previously discussed, this optimal level of hydration is typically achieved by consuming fluids in excess of need and allowing the renal system to excrete the unneeded amount.

Hyperhydration refers to body water above that considered normal and is typically a short-term condition. Acute hyperhydration can be achieved by consuming excess fluids, but the renal system usually acts quickly (within minutes to hours) to excrete the excess water by forming greater volumes of urine. For example, a person who drinks 500 ml (~18 ounces or 2.25 cups) of water with lunch will usually need to urinate by the middle of the afternoon.

Consumption of certain osmotic substances such as glycerol along with excess water may slightly prolong the state of hyperhydration. This induced hyperhydration is a strategy that may be employed by athletes to aid thermoregulation when competing in hot environments, and is discussed later in this chapter.

Consumption of large amounts of water very quickly (e.g., 3,000 ml or ~104 oz or ~13 cups in four hours, as some slow marathon runners have done) can result in a state of hyperhydration that can actually be dangerous to one's health, and can even result in death (Almond et al., 2005). The excess water dilutes the concentration of solutes in the extracellular fluid. Before the kidneys have a chance to excrete the extra water, the reduced osmolarity in the ECF provokes a shift of water from the ECF into the cells, causing them to swell. Nerve cells, especially those in the brain, are particularly sensitive to this swelling and may cease to function properly, resulting in impaired brain function, coma, or even death. This condition can occur during certain types of endurance exercise and is discussed later in this chapter (see Hyponatremia).

Hypohydration is the term used to describe body fluid levels that are below normal or optimal. It is the result of either an inadequate intake of water, excessive loss of water, or a combination of both. Hypohydration is a relative term (compared to euhydration) and is not defined as a certain amount of body water below euhydration. Hypohydration occurs initially in the ECF, which results in an increased concentration of solutes in the ECF due to a relative lack of water. Because the osmolarity of the ECF increases, water shifts from the cells to the ECF in an attempt to balance the solute concentrations between these two fluid compartments. When water levels decline in the cells, the cells shrink and this shrinkage may impair cellular function. Hypohydration may have severe adverse effects on exercise performance and thermoregulation, so athletes need to be especially conscious of ways to prevent excessive hypohydration. The term dehydration is commonly used interchangeably with hypohydration, but it is more accurate to use the term dehydration to describe the *process* of moving from a state of euhydration to a state of hypohydration.

SODIUM INTAKE AND EXCRETION

Fluid levels in the body are regulated by both the volume of water and the osmolarity of the extracellular fluid. Sodium is the most important electrolyte in the

Diuretic: Causing an increased output of urine.

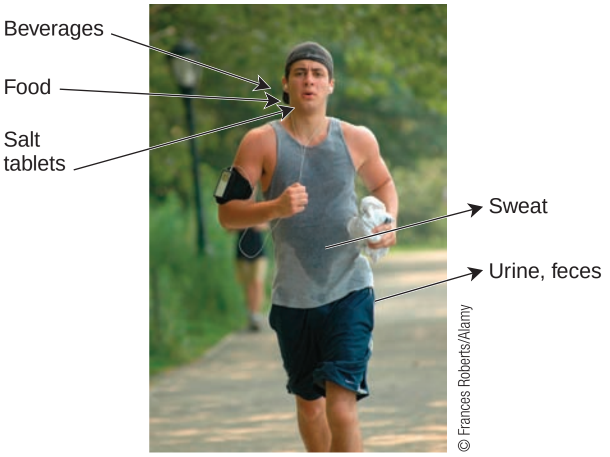

Figure 7.9 Routes of Sodium Intake and Excretion

Sodium intake occurs with the consumption of sodium-containing foods and beverages, or rarely, salt tablets. Sodium can be lost via sweat, urine, and feces.

extracellular fluid because it exists in the largest amount and directly affects osmolarity. The body must respond to changes in the amount of sodium in the ECF by adjusting water volume. An increase in sodium in the ECF will increase the volume of water and a decrease in sodium will result in a decrease in ECF water volume.

The only route of intake for sodium is by ingestion, either through foods, fluids, or rarely, salt tablets (sodium chloride). Similar to water, sodium is generally consumed in excess of the body's requirements and the body relies on the renal system to excrete what is not needed (see Figure 7.9). Many factors influence the amount of sodium in the diet, but the largest factor in industrialized countries is the consumption of processed foods at home and at restaurants. For the average American adult, processed food is the source of 77 percent of daily sodium intake. The addition of table salt (i.e., sodium chloride) to foods accounts for approximately 11 percent of daily sodium intake. The remaining sodium (~ 12 percent) occurs naturally in water and in foods such as milk, vegetables, and grains (Institute of Medicine, 2004).

There is considerable variation in sodium intakes among men and women in the United States and around the world. Consumption can be reported as either sodium or salt intake, which often causes confusion because these terms are not the same. Intakes are routinely reported in both milligrams and grams, which adds to the confusion.

The highest reported consumption worldwide is in Northern Japan where intake of sodium is estimated to be more than 10,000 milligrams (mg), or 10 g, daily due to the salting and pickling of foods. The average daily intake of sodium in the United States is approximately 4,200 mg (4.2 g) for men and 3,300 mg (3.3 g) for women.

For most people in the United States, sodium is consumed in the form of sodium chloride (e.g., salt added to food) and this sometimes leads to the reporting of salt intake rather than sodium intake. One gram (i.e., 1,000 mg) of salt contains ~ 40 percent sodium or ~ 400 mg of sodium. One-fourth teaspoon is the equivalent of 1.5 g of table salt, thus, this amount of salt contains 590 mg of sodium. It is easy to see how adding salt to food results in a high sodium intake. Reported salt intake by U.S. men is approximately 10 g per day, but for some salt intake may be as high as 25 g daily.

The Dietary Reference Intake for sodium for adults under the age of 50 is 1,500 mg (1.5 g) daily. The Tolerable Upper Intake Level is 2,300 mg (2.3 g) daily. These recommendations are made to the general population to reduce the prevalence of high blood pressure associated with aging. However, the Institute of Medicine (2004) clearly states that these recommendations do not apply to highly active individuals who lose large amounts of sweat daily. Sodium intake and hypertension are discussed in Chapter 12.

Sodium intake by athletes varies, based on caloric intake and choice of foods. Low caloric intake may mean lower sodium intake. For example, the daily energy intake of 19 New Zealand jockeys was approximately 1,500 kcal while the average sodium intake was approximately 1,900 mg (1.9 g) (Leydon and Wall, 2002). As caloric intake increases, sodium levels rise, so even an athlete who is careful about avoiding high-sodium foods (e.g., soy sauce, fast foods, salty-tasting snacks) may find that sodium intake is above 3,000 mg (3 g) daily. Some athletes consume fairly high levels of sodium (e.g., ≥ 5,000 mg or 5 g), especially if they add table salt to their food.

While sodium intake may not be carefully matched to need, urinary sodium excretion is precisely controlled to maintain proper ECF osmolarity. Sodium is regulated by the kidneys and can either be reabsorbed or excreted in the urine. Because sodium intake usually far exceeds daily needs, a large amount of sodium is excreted in the urine to maintain sodium balance. Average urinary sodium excretion is approximately 1 to 5 g per day. More information about renal function can be found in a human physiology text such as Sherwood (2007).

A small amount of sodium is lost each day in sweat and feces. This obligatory loss amounts to approximately 0.5 g (500 mg) per day. Sodium loss can increase substantially if there is heavy sweating and will be discussed later in this chapter.

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Popcorn, pretzels, nuts, and chips typically have salt (sodium chloride) added, although low-salt varieties are available.

POTASSIUM INTAKE AND EXCRETION

Potassium, the primary intracellular cation, is consumed via foods and beverages or occasionally, through the use of salt substitute (i.e., potassium chloride). Potassium is abundant is unprocessed foods such as fruits, vegetables, whole grains, beans, and milk. Low dietary potassium intake in the United States is a reflection of a low daily fruit and vegetable intake, a pattern that is typical of approximately two-thirds of the adult population. It is also a result of the high intake of processed foods; processing results in substantial potassium losses. Examples of foods with a high potassium content include bananas, orange juice, and avocadoes. Potassium found in food is well absorbed from the gastrointestinal tract (greater than 90 percent absorption).

An Adequate Intake (AI) for adults is 4,700 mg daily. The average daily intake in the United States is approximately 2,200 to 2,400 mg for women and 2,800 to 3,300 mg for men. With such low average intakes, it is likely that some adults in the United States will have a moderate potassium deficiency. Such a deficiency is associated with increased blood pressure (see Chapter 12) and increased bone turnover due to an increase in urinary calcium excretion. However, a moderate potassium deficiency is hard to detect with laboratory tests because blood potassium concentration will remain within the normal range (3.5 to 5.0 mmol/L) (Institute of Medicine, 2004).

Athletes who are concerned about the potential for a moderate potassium deficiency should focus on consuming a variety of fruits and vegetables daily. Self-prescribed potassium supplements are not recommended because of the potential for hyperkalemia (i.e., elevated blood potassium concentration), which has been occasionally reported in bodybuilders (Perazella, 2000; Appleby, Fisher, and Martin, 1994; Sturmi and Rutecki, 1995).

Hypokalemia, a severe deficiency state, is defined as a blood potassium concentration less than 3.5 mmol/L and would be a rare occurrence in an otherwise healthy individual. Symptoms include muscle weakness and cardiac arrhythmias, which can be fatal. Hypokalemia is *not* a result of low dietary intake because the amount consumed in food is high enough to prevent this condition. Rather, hypokalemia is a result of substantial potassium loss, usually through severe and prolonged vomiting or diarrhea or the use of potassium-depleting diuretic drugs without adequately replenishing potassium.

Under normal conditions the primary pathway for potassium loss is urinary excretion, while small amounts are lost in the feces and sweat. The kidneys precisely control the amount of potassium either reabsorbed or excreted. Problems occur when potassium is lost atypically. For example, an athlete who is struggling with an eating disorder may frequently self-induce vomiting, which over time could result in hypokalemia, cardiac arrhythmias, and death.

While there are several electrolytes involved in fluid and electrolyte balance, the initial dietary focus tends to be on sodium and potassium. Two other cations—calcium and magnesium—are discussed in Chapter 9. The corresponding anions, such as chloride and phosphate, receive little dietary attention. The chloride content of the diet can be reasonably well predicted from salt intake and phosphorus is widely found in food. A dietary deficiency of either would be extremely rare.

Effect of Exercise on Fluid Balance

Under normal conditions, most healthy sedentary individuals regulate their fluid balance (i.e., achieve homeostasis) relatively easily. Thirst and hunger mechanisms usually lead people to consume water in excess of the body's daily needs, with the excess being excreted. If there is a shortfall in fluid consumption, the body can respond in the short-term by reducing urine excretion, which conserves water and maintains fluid balance.

Exercise challenges fluid homeostasis because of the critical role that body fluids play in thermoregulation (maintaining an appropriate body temperature). Exercise causes an increase in body temperature, and a major mechanism for lowering body temperature is the evaporation of sweat. The loss of fluid through sweat may have a large impact on fluid balance, both in the short and long term. Physical activity or exercise, especially in hot and humid conditions, represents a substantial challenge for the regulation of body temperature, fluid homeostasis, and, subsequently, performance (Armstrong and Epstein, 1999).

In contrast to sedentary individuals who can regulate their fluid balance easily, athletes may have a difficult time preventing dehydration and severe hypohydration. These conditions can negatively impact training, performance, and health (Hargreaves and Febbraio, 1998).

WATER LOSS DURING EXERCISE

Exercise can result in water shifting between compartments within the body and in accelerated loss of body water. As the cardiovascular system adjusts to the demands of exercise to increase blood flow and oxygen delivery, the increased pressure in the blood vessels results in some of the fluid leaking into the surrounding interstitial space. This fluid is lost from the plasma and plasma volume therefore declines slightly as the water shifts within the extracellular fluid compartments. This decrease in plasma volume occurs within the first few minutes after exercise begins with the amount being largely dependent upon the exercise intensity. The decline may be up to approximately 5 percent of plasma volume if the exercise is intense. As explained earlier, an average adult male has approximately 2.8 L of plasma. A 5 percent loss would be approximately 140 ml (5 oz) of water, an amount that would not likely impair exercise performance. However, plasma volume losses up to 10 to 20 percent can occur with prolonged exercise, and losses of this magnitude may compromise cardiovascular function and ultimately reduce exercise performance (Convertino, 1987).

Exercise can cause substantial dehydration through increased sweating. The increase in energy expenditure associated with physical activity and exercise results in an increase in heat production. To prevent this heat load from causing an excessive increase in body temperature, heat loss mechanisms must be activated, one of which is sweating. As the internal (core) temperature of the body rises, sweat glands are stimulated to secrete sweat to reduce the heat load. A review of thermoregulation may be beneficial at this point (see Sherwood, 2007), but in short, when sweat evaporates from the surface of the skin, heat is transported away from the body. It is not uncommon for body temperatures to rise to 39° or 40°C (102°F to 104°F) during exercise, even in temperate climates (see Figure 7.10) (Hamilton et al., 1991).

The rate at which the body loses water through sweating depends upon a variety of factors. Exercise intensity can influence sweat rate through its independent effect on core temperature. At any given room temperature, increased exercise intensity results in higher body temperatures, and higher body temperatures will stimulate higher sweat rates. Increased exercise intensity requires higher energy expenditure, which results in

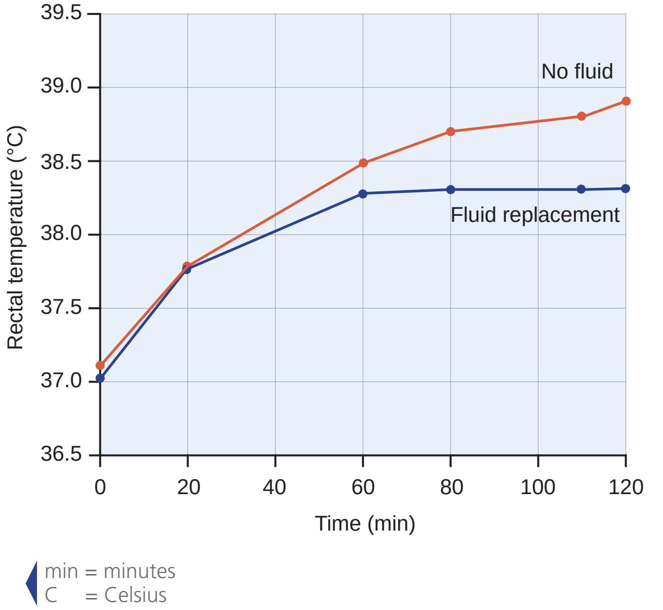

Figure 7.10 Rise in Rectal Temperature during Exercise.

Body temperature rises with exercise, but replacing fluid to prevent dehydration prevents the excessive rise in body temperature that occurs when no fluid is consumed.

a greater amount of metabolic energy being converted to heat.

Environmental conditions can also dramatically influence sweat rate. Independent of exercise intensity, higher **ambient** temperatures result in higher core temperatures and higher sweat rates. The relative humidity, or amount of water vapor in the air, can also influence sweat rate and can make fluid loss by sweating more visible. Increased water vapor in the air reduces the ability of sweat secreted onto the skin to be evaporated, and it is the *evaporation* of sweat, not just the process of sweating that leads to heat transfer. When conditions are more humid, sweating is a less effective means of thermoregulation and body temperatures may be higher, resulting in a stimulus for an even higher sweat rate.

Clothing, uniforms, and protective gear may further influence the rate of sweating by providing a barrier to heat loss. This type of clothing may provide an insulating effect, trapping more heat in the body or it may adversely affect the evaporation of sweat by reducing the surface area of the skin that is exposed. Athletes in sports with certain uniform traditions or requirements may be at greater risk for heat injury and fluid imbalances. Football uniforms provide an excellent example. They generally cover most of the skin and have thick padding in many places that can have an insulating effect. Protective gear such as helmets, arm wrappings, padding, and gloves add to the thermoregulatory challenge and may result in

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Firemen work in high temperature environments and wear protective clothing that adversely affects the evaporation of sweat.

greater fluid loss through sweat. Other examples include the fire protection gear worn by firefighters, hazardous materials suits worn by public safety workers, and chemical warfare protection suits worn by military personnel.

The training status of the athlete and the degree of acclimation to the heat are also important factors affecting sweat rate. Because of regular training and the increased demands for thermoregulation, trained athletes typically have higher sweat rates than do sedentary individuals (Armstrong, Costill, and Fink, 1987). Trained athletes will start sweating sooner as body temperature begins to increase and will sweat at a higher rate, so they have a greater potential for water loss through sweating. The advantage, of course, is that they have a more effective mechanism for controlling their body temperature. Exposure to higher ambient temperatures during training (e.g., a hotter climate) results in a number of adaptations that improve thermoregulation, one of which is an increased sweat rate.

Obviously, there are a variety of factors that can influence sweat rate, either alone or in conjunction with one another. Just how much fluid can a person lose through sweating? As discussed earlier, an adult that is performing usual occupational activities throughout the day in a temperate (normal room temperature) environment may lose approximately 0.1 L (100 ml or ~3.5 oz) of water each day as sweat. If that person performs those same daily activities in a hotter, more desertlike environment (high temperature but low relative humidity), sweat loss will increase into a range of 0.3 to 1.2 L (300–1,200 ml or ~10–43 oz or ~1–5 cups) per *hour*. The addition of protective clothing such as the firefighter's suit can result in sweat rates of 1.0 to 2.0 L (1,000–2,000 ml or 36–71 oz or ~4.5–9 cups) per hour. Sweat rates in excess of 2.5 L (2,500 ml or ~89 oz or ~11 cups) per hour have been observed in athletes competing in team sports (e.g., soccer) and in individual athletes

Nick Laham/Getty Images

This heavily favored Olympic marathoner was unable to finish the race, which was held in hot and humid conditions.

engaged in prolonged endurance sports (e.g., marathon running) in hot environments (Armstrong and Maresh, 1998).

Consider a world-class female runner competing in the Olympic Marathon, which is contested during the Summer Games, often in hot and humid conditions. She will run for a little over two hours and could lose approximately 2 L of sweat per hour or a total of 4 L of water! This may approach 10 percent of total body water or almost 10 pounds of water weight loss in a 100-pound runner if she were to consume no fluids. With such a sweat rate, it is easy to see how large amounts of fluid can be lost very quickly under certain exercise or environmental conditions. Because fluid homeostasis is a balance of water intake and loss, fluid intake is essential. But can an athlete prevent overall fluid loss when sweating heavily by drinking water or other fluids?

Unfortunately, it is very difficult to match water intake with water loss when exercising in hot and humid conditions for several reasons. Most people will experience "voluntary dehydration" and will not consume enough fluid during the activity to match the amount of fluid being lost. Voluntary dehydration occurs because the human thirst mechanism responds too slowly and does not have enough precision to stimulate drinking enough fluids to compensate for the high rate of fluid loss. If fluid loss exceeds fluid intake, athletes will gradually dehydrate, but they do not feel thirsty initially.

Even if athletes are encouraged to consume more fluid than they would likely take in of their own volition, the rate at which the water can be emptied from the

Ambient: In the immediate surrounding area.

stomach and absorbed from the gastrointestinal tract may be less than the rate of fluid loss due to sweating. The maximal rate of gastric emptying (how fast the fluid leaves the stomach) appears to be less than the maximal rate of absorption from the intestines, and therefore limits the overall rate of fluid intake (Sawka and Coyle, 1999). The maximal rate of gastric emptying for an average-sized adult male is approximately 1.0–1.5 L per hour. This rate may be slightly reduced with high-intensity exercise and with an increased heat load.

Some level of activity or movement may actually aid gastric emptying through agitation of the stomach contents, and exercise up to approximately 70 percent of an athlete's maximal oxygen consumption generally does not have an adverse effect on fluid uptake. More intense exercise may impede gastric emptying, though, and delay the replacement of water and carbohydrate. Compared to bouts of low-intensity exercise (walking), athletes that performed intermittent, high-intensity exercise that mimicked the intensity of a soccer match showed a significant decline in the gastric emptying of a beverage that contained carbohydrate as well as a noncarbohydrate beverage (Leiper et al., 2005).

Therefore, even if athletes are encouraged or even forced to consume fluids in an attempt to match fluid loss, there is usually a gradual fluid loss because intake and absorption cannot keep pace with loss. It is not uncommon for athletes exercising under these conditions to lose 2 to 6 percent of their body weight during the activity. It is important to attempt to match the amount of fluid lost during exercise with appropriate fluid intake strategies. It is also very important to pay attention to rehydration strategies after the activity to ensure a return to euhydration.

What's the point? Athletes should plan their fluid intake strategies with the goal of replacing fluid losses during exercise; however, it may not be possible to replace fluid as fast as it is being lost.

While much attention is paid to exercising in hot and humid environments, substantial fluid loss can occur with exercise in cold climates as well (e.g., winter sports, mountain climbing). Water loss from ventilation is usually greater in cold environments because the air is dry (low relative humidity) and the body must add more water vapor to the cold, dry air that is inspired. If the individual's ventilation is elevated during exercise, a large portion of this water is lost through exhalation. Activities requiring a high energy expenditure will result in elevations in body temperature even in cold temperatures. Participants need to carefully consider the clothing they wear, as clothing that is sufficiently warm at rest may prove to be too warm during exercise or activity, resulting in increased sweating and fluid loss.

EFFECT OF HYPOHYDRATION AND REHYDRATION ON CORE TEMPERATURE

Dehydration, or moving to a state of hypohydration as a result of fluid loss, can have an adverse impact on core temperature and ultimately on exercise performance (Sawka et al., 1998). When there is a loss of body water, the majority of the water comes initially from the ECF, specifically from the plasma. Therefore, as body water is lost through heavy sweating, there is a gradual loss of blood volume, a condition known as **hypovolemia.** Because sweat is hypotonic in relation to blood, fewer electrolytes and other solutes are lost in sweat in proportion to the amount of water lost. In this case, the plasma that remains is more concentrated and its osmolarity increases. Both of these conditions may adversely affect thermoregulation and exercise performance.

The main function of blood flow is to deliver oxygen-laden blood to tissues and the need for oxygen delivery is greatly increased during exercise, particularly in the exercising muscles. Blood flow also helps to control body temperature, and this thermoregulatory function is used to a greater extent during exercise in the heat. A finite and relatively small amount of blood is available to fulfill both these functions, and exercise in the heat sets up a competition for this limited resource. The situation gradually becomes worse as the athlete dehydrates because total blood volume continues to decline.

A state of hypohydration will result in an increased core temperature during exercise, in the heat and even in normal ambient conditions. A loss of only 1 percent body weight as water can result in measurable increases in body temperature, and the greater the loss of body water, the greater the increase in temperature. It is estimated that for every 1 percent of body weight that is lost as water, core temperature will be elevated 0.1°C–0.23°C (Sawka and Coyle, 1999).

It is critical for performance that athletes remain well-hydrated, because the adverse effects of hypohydration may offset the benefits gained by having a higher aerobic fitness level or by becoming acclimated to the heat. When hypohydrated, heat dissipation ability is impaired, resulting in higher body temperatures. At the same body temperature (i.e., same level of stimulus) the hypohydrated athlete will experience a decrease in whole-body sweating rate and a decrease in skin blood flow, which can substantially narrow the two main avenues of heat loss.

In addition to the declining blood volume, fluid loss may also adversely affect body temperature through the increase in osmolarity of the blood. The portion of the brain that controls the body's thermoregulatory responses is in the hypothalamus. The blood becoming hypertonic may have a direct effect on the cells in this region of the brain and their ability to maintain body temperature. The worst-case scenario of increasing core temperature and deteriorating thermoregulatory control is **hyperthermia** (abnormally high body temperature), which may lead to coma and death (e.g., heat stroke).

Some athletes manipulate fluid intake and fluid balance in an effort to "make weight." For example, wrestlers may restrict fluid and food intake while engaging in excessive exercise, wearing clothing while exercising that increases body temperature and sweating, and taking diuretics. While the goal may be weight loss through dehydration, the result may be hyperthermia. Tragically, some wrestlers have died from hyperthermia because of these practices (Centers for Disease Control and Prevention, 1998). (See Spotlight on Enrichment: Intentional, Rapid Dehydration.)

Hypovolemia: Less than the normal volume.

Hyperthermia: Abnormally high body temperature.

SPOTLIGHT ON ENRICHMENT

Intentional, Rapid Dehydration

Athletes who must meet certain weight classifications and have their weight certified before competition include wrestlers, boxers, and lightweight rowers. There is a long history in these sports of using dehydration as a rapid weight loss method. In 1990, Steen and Brownell surveyed college (n = 63) and high school (n = 368) wrestlers to assess weight loss practices and concluded that traditional practices used to "make weight" were still being employed. Some of the common practices were dehydration, fasting, and restriction of food intake. Practices that were less common but used by some wrestlers included vomiting and the use of laxatives and diuretics. The survey documented what had long been suspected: "weight" loss was rapid, large, and frequent, and after the target weight was met, rapid weight gain followed. Forty-one percent of the collegiate wrestlers reported weight fluctuations of ~11 to 20 pounds (~5 to 9 kg) each *week* throughout the season. For high school wrestlers the weekly losses were smaller, ~6 to 10 pounds (2.7 to 4.5 kg), and reported by fewer athletes (23 percent), but suggested that such practices had their roots early in the athletes' competitive careers.

In 1994, Scott, Horswill, and Dick found that collegiate wrestlers competing in the season-ending NCAA tournament gained a substantial amount of weight between weigh-in and competition (approximately 20 hours apart). In this study wrestlers gained an average of 4.9 percent of body weight, with the wrestlers in the lower weight categories gaining the most weight. In 1996, the American College of Sports Medicine (Oppliger et al., 1996) published a Position Stand on weight loss in wrestlers, in which concern was expressed about rapid and large weight losses and the methods used to achieve them and called for rule changes that would help to limit these losses.

During a one-month period in 1997, three collegiate wrestlers, ages 19, 21, and 22, died from hyperthermia. The accounts of their precompetition preparation were remarkably and tragically similar. They restricted food and fluid intake, wore vapor-impermeable suits under their warm-up clothing to promote sweating, and engaged in excessive exercise. In the case of the 19-year-old, his preseason weight was 233 lb (105.9 kg) and he was attempting to "make weight" to compete in the 195-pound weight class. He needed to lose 15 lb (6.8 kg) over a 12-hour period. The 22-year-old wrestler's preseason weight was 178 lb (80.9 kg). He had lost 8 lb (3.6 kg) in the four previous days but was attempting to lose 4 additional pounds (1.8 kg) in four hours. Rectal temperature at the time of death was 108°F (42°C). The third victim had a preseason weight of 180 lb (81.8 kg) and had lost 11 lb (5 kg) over a three-day period. He was attempting to lose 6 additional pounds (2.7 kg) in three hours so he could wrestle in the 153-pound weight class. When he began his attempt he weighed 159 lb (72.2 kg). After 90 minutes of exercise he had lost 2.3 lb (1 kg) and lost an additional 2 lb after another 75 minutes of exercise. After a short rest he began exercising again in an effort to lose the remaining weight, 1.7 lb. He collapsed and died from cardiorespiratory arrest. A postmortem laboratory analysis indicated that blood sodium concentration was 159 mmol/L, far above the normal range (136 to 146 mmol/L) and a sign of severe dehydration (Centers for Disease Control and Prevention, 1998).

These deaths were the first documented collegiate wrestling deaths, and they did for the sport what no amount of research studies, position stands, or previously expressed concerns could do—raise awareness at all levels of the sport and promote change in wrestling rules. For example, the NCAA instituted new rules for collegiate wrestlers in the 1997–98 season and high schools have since adopted rules to prevent rapid, large weight (water) losses and large weight fluctuations. By measuring specific gravity in urine and monitoring percent body fat changes over the course of the season, these sports-governing bodies are making good on their promises to try and stop the use of large and rapid fluid losses as a method of weight loss. These new rules are reducing the prevalence of rapid and large weight losses (Oppliger et al., 2006).

Hypohydration clearly affects body temperature, but what effect does it have on exercise performance? In general, a loss of more than 2 percent of body weight can be detrimental, especially when exercising in the heat, because physical and mental performance is reduced. However, there are individual variations that result in some people being more or less tolerant to changes in hydration status (Sawka et al., 2007).

Maximal aerobic power ($\dot{V}O_{2max}$) and endurance performance are reduced when an athlete is hypohydrated. With a loss of 3 percent or more of body weight as water, measurable reductions in $\dot{V}O_2$ can be observed. Losses of body water less than 3 percent of body weight are not typically associated with decreased $\dot{V}O_{2max}$ when the athlete is tested in normal ambient temperatures. When tested in the heat, however, modest fluid losses of 2 to 4 percent of body weight can result in significant declines in maximal oxygen consumption (Sawka, Montain, and Latzka, 2001).

In addition to maximal aerobic performance, endurance exercise performance is impaired when an athlete is hypohydrated (Cheuvront, Carter, and Sawka, 2003, Von Duvillard et al., 2004). The decline in performance is larger with increased distance or duration of the endurance activity. For example, performance in a marathon will decline more than in a 10-kilometer race when a runner is hypohydrated. Hypohydration can also impair performance of lesser-intensity activities such as walking or hiking in the heat. A hypohydrated athlete exercising in the heat becomes fatigued more quickly compared to an athlete exercising in a euhydrated state. Body temperatures will rise in both athletes, but the hypohydrated athlete will fatigue at a lower body temperature. When hypohydrated, thermoregulation is impaired and the athlete cannot tolerate the same amount of increase in body temperature without fatiguing.

There is good evidence to suggest that a loss of 3 to 5 percent of body weight does not reduce anaerobic performance or muscular strength (Sawka et al., 2007). However, this magnitude of body water loss does affect thermoregulation and increases the risk for potentially fatal heat illnesses such as heat stroke.

ELECTROLYTE LOSS DURING EXERCISE

Fluid loss through sweating is the major concern for the exercising athlete, but sweat is composed of more than water. Sweat contains the electrolytes sodium, potassium, and chloride; small amounts of minerals such as iron, calcium, and magnesium; and trace amounts of urea, uric acid, ammonia, and lactate. Of these, sodium is present in the largest amount. During light sweating, sodium and chloride are reabsorbed from the tubule of the sweat gland and are not lost in large amounts. During heavy sweating, however, the sweat moves through the tubule at a rate that is too fast for substantial reabsorption, so sodium and chloride losses are proportionally greater.

The sodium content of sweat ranges from 10–70 mEq per liter with the average concentration of approximately 35 mEq/L (Sawka et al., 2007). One mEq of sodium is equal to 23 mg of sodium, thus, the upper end of the range, 70 mEq/L, is equivalent to 1,610 mg or 1.6 g of sodium per liter. This rate and amount of sodium loss typically does not pose a problem for the athlete if the exercise duration is not over an hour or two. During exercise lasting less than two hours, the athlete would need to pay more attention to fluid replacement to address the water loss through sweating than to sodium replacement. Water works well as a fluid replacement beverage under these conditions. The duration is short enough that excessive electrolyte loss is not likely, and therefore electrolyte replacement is not a priority. The duration of the activity is also within the range that endogenous carbohydrate (i.e., muscle and liver glycogen) stores are not likely to be depleted, so the inclusion of carbohydrate in the beverage for exercise of this duration is likely not a necessity. Consumption of beverages that do contain carbohydrate and electrolytes are not likely to pose any problems for the athlete.

More than two hours of continuous exercise typically marks the transition when the use of fluids that contain sodium and carbohydrate becomes appropriate. As explained earlier, it is possible for athletes engaged in prolonged moderate- to high-intensity exercise in hot environments to sustain sweat rates of 1 L to over 2 L per hour, resulting in substantial sodium loss (~ 1.5–3.0 g per hour). In such cases, sodium replacement should begin during exercise by including sodium in beverages or eating salty-tasting snacks. The addition of sodium may also encourage greater voluntary drinking and may aid in the uptake of water from the small intestine. Athletes that train and compete at these distances and durations should experiment during training to determine the need for sodium and carbohydrate replacement during exercise. For example, an athlete that is a heavy sodium excreter can look for accumulation of salt on skin or clothing after training and experiment with various replacement strategies during and after exercise (Maughan, 2001). Although the focus of this chapter is water and electrolytes, the intensity and length of time of activities such as marathon running and Olympic distance triathlons also result in substantial utilization of carbohydrate stores, and the ingestion of carbohydrates to maintain the availability and use of this fuel is also important (Sawka et al., 2007).

Very-long-duration activities (i.e., $>$4 hours), such as ultramarathon running or Ironman®-length triathlons, may also result in substantial sodium loss even in athletes who are not "heavy" sweaters (Rehrer, 2001). Much lesser amounts of potassium, magnesium, calcium, and chloride are lost, even at high sweat rates (up to 0.5, 0.02, 0.04, and 2.1 g per liter, respectively). More careful consideration of both fluid and electrolyte replacement (particularly sodium) must be made by the athlete during prolonged activities. Sweat is hypotonic in relation to blood, so as water and electrolytes are lost in sweat, there is a proportionally greater loss of water. Therefore, as the athlete dehydrates, the blood becomes more hypertonic. The combination of dehydration and hypertonicity may significantly impair performance, so the athlete must have a strategy to prevent or delay these, and the fatigue that can accompany them, from occurring.

One strategy for sodium replacement during prolonged exercise when there are large sodium losses through sweating is the use of sodium supplements in the form of salt tablets. Triathletes competing in Ironman®-length events may be exercising vigorously in a thermally challenging environment for eight to 12 hours or more, experiencing substantial fluid and sodium loss. As these athletes have become aware of the dangers of hyponatremia that may occur in these events (see section on hyponatremia), some have attempted to counter the sodium loss by consuming it in the more concentrated form of salt tablets (Speedy et al., 2003). A number of commercial products are marketed for this purpose; examples include Lava Salts™ and Succeed! Caps. A 1-gram capsule of Succeed! contains 314 mg of sodium and 21 mg of potassium, with a recommended dose of not more than two capsules per hour. Research on the effectiveness of this strategy for preventing the occurrence of hyponatremia is not extensive, although the results of two studies (Hew-Butler et al., 2006; Speedy et al., 2003) suggest athletes supplementing with salt tablets during an Ironman™-length triathlon do not have significantly different serum sodium concentrations than athletes that consumed a placebo. As an alternative to salt tablets, ultraendurance athletes may consume sodium as part of a carbohydrate-containing beverage. An example is the consumption of Gatorade Endurance Formula™. Eight ounces of this product provides 200 mg of sodium as well as 90 mg each of chloride and potassium, 6 mg of calcium, and 3 mg of magnesium.

EXERCISE-RELATED MUSCLE CRAMPING

Athletes may experience painful muscle cramps during or immediately after exercise, technically known as exercise-associated muscle cramping (EAMC). It has long been believed that such cramping is due to dehydration, changes in electrolyte concentrations, or both. Potassium, calcium, and magnesium supplements are advertised to athletes as a way to prevent or recover from muscle cramps. Despite a widespread belief that EAMC in all athletes is caused by dehydration and electrolyte loss, there is no body of scientific literature that supports this theory. The American College of Sports Medicine (ACSM) (Sawka et al., 2007) position paper notes that recommendations to avoid dehydration and sodium deficits to prevent muscle cramps is based on consensus and usual practice (i.e., Evidence category C) not experimental evidence (i.e., Evidence categories A and B).

Schwellnus et al. (2004) studied 72 male ultramarathon (56 km) runners to determine if hydration status or changes in electrolyte concentrations were associated with EAMC. Twenty-one of the runners experienced muscle cramps (often in hamstring and quadriceps muscles) during the ultramarathon. When compared to runners who had no muscle cramps, there were no significant differences in hydration status or sodium, potassium, calcium, and magnesium concentrations in the blood. The authors suggest that EAMC in ultradistance athletes have a different cause than dehydration or electrolyte imbalance.

Case studies of tennis and football players suggest that heat cramps (total body cramping when exercising in the heat) may be the result of rapid and large losses of fluid and sodium. The cramping appears to be caused by sodium depletion and dehydration as well as muscle fatigue. Those who fall into this group, known as "salty sweaters," appear to benefit from sodium-containing beverages during exercise and the consumption of an adequate amount of sodium and water after exercise (Bergeron, 2003; Eichner, 2002). As there are many causes of EAMC, including nonnutritional causes (e.g., lack of stretching), each athlete should determine the likely causes of their cramping and, through trial and error, institute strategies that are known to prevent the causative factors.

Replenishment of Water and Electrolytes

Exercise and physical activity can have a substantial impact on fluid balance. Water and electrolyte loss must be compensated for to maintain long-term fluid homeostasis. Single events or bouts of exercise may cause large disruptions in fluid balance and need immediate attention. However, many athletes experience small deficits on a daily basis and these small cumulative deficits become more pronounced deficits over several days or weeks. Athletes should develop a practical approach to monitoring their hydration status and a strategy for water and electrolyte replacement to maintain a status of euhydration and appropriate osmolarity.

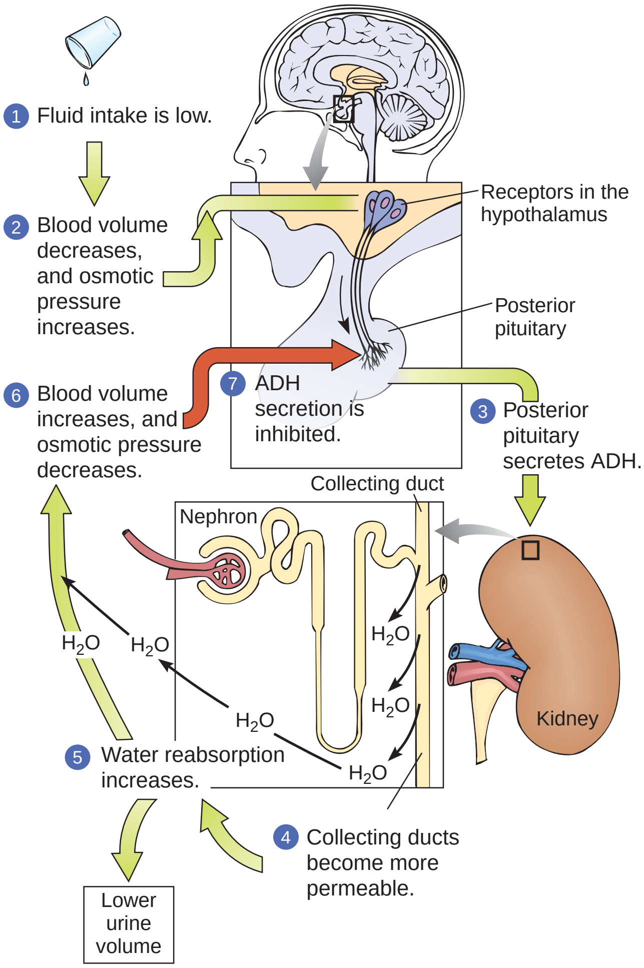
MONITORING HYDRATION STATUS

There are a variety of ways to monitor the body's hydration status. These methods have varying degrees of accuracy, difficulty, and expense. Typically, the methods that are the most accurate are also the most difficult and time-consuming to perform and the most expensive. These methods are best suited for use in research studies and are rarely practical for day-to-day use by athletes or those who exercise or compete recreationally. Daily monitoring requires an approach that is practical, and easy to administer and understand (Armstrong, 2005).

To precisely determine an individual's hydration status, the amount of total body water and the osmolarity of the plasma must be known. Accurate measures of total body water are often determined using isotope dilution, most commonly deuterium oxide (also discussed in Chapter 2). When a known volume of water having a known radioactivity level is consumed, it is diluted as it is absorbed and distributed throughout the water compartments of the body. After distribution and equilibration, a sample of body water can be taken and analyzed for its radioactivity. Total body water volume can then be determined from the degree of dilution of radioactivity. This method, while accurate, is expensive and time-consuming, requires trained personnel, and is not suitable for daily monitoring.

A second method of testing fluid balance involves measuring plasma solutes. The plasma osmolarity level associated with euhydration is 285 mOsm/kg (Institute of Medicine, 2004). In order to determine this value, however, a blood sample is needed, as well as access to a clinical laboratory for analysis. This method is also not very practical or desirable for frequent monitoring because of the time, expense, and necessity for drawing blood, but it is often used in research settings.

Because the renal system is the major physiological mechanism for regulating fluid balance (see Figure 7.11), an analysis of urine can also provide information about hydration status. When an individual becomes hypohydrated, the amount of urine produced is often lower than usual due to water conservation by the body. A 24-hour urine collection can easily measure volume, but this can be a time-consuming and unpleasant task and one that is not practical for an athlete to perform on a regular basis. However, in the hypohydrated individual the urine also has a higher specific gravity (concentration of particles), higher osmolarity, and a darker color. Urine specific gravity of ≤ 1.020 and urine osmolality of ≤ 700 mOsm/kg are considered consistent with euhydration (ACSM, 2007). In the past, such measurements required specific equipment or a clinical laboratory, but the availability of inexpensive urine testing strips now allows athletes to easily test urine for specific gravity as well as the presence of other compounds (e.g., glucose, protein).



ADH = antidiuretic hormone

Figure 7.11 Regulation of Urine Volume

Observation of urine color is more subjective and may not be as precise as laboratory measures, but is a more practical approach that can be easily conducted whenever the athlete urinates (Armstrong et al., 1998). It is typically recommended that athletes observe the color of the first void (urination) of the day after awakening from a night's sleep. Armstrong (2000) has suggested the use of a urine color scale (Figure 7.12) to estimate the degree of hypohydration. Although it lacks precision, urine color may be an easy, practical marker that an athlete can use in conjunction with other markers to assess hydration status. Urine color may be affected by diet (e.g., consumption of beets), dietary supplements, or medications and these reduce the accuracy of a color test.

Weight loss that occurs as a result of a single exercise bout is likely due to fluid loss; thus, changes in body weight can be used as a marker of short-term fluid loss and as a benchmark for subsequent rehydration. Changes in body fat or lean body mass over time complicate the use of this marker, but daily weight loss or gain over the course of a single workout can be used to determine

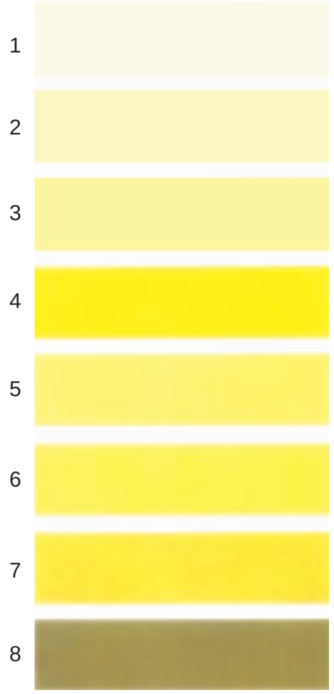


Figure 7.12 Urine Color Chart

A urine color chart can be used as a general assessment of hydration status. A urine sample collected the first thing in the morning can be viewed against a white background in good light and the color compared to the chart. A lighter urine color, in the 1, 2, or 3 range can be considered well-hydrated, while a darker urine color, in the 6, 7, or 8 range can be considered hypohydrated. Other factors, such as the use of medications or vitamins may also affect urine color; therefore, this method should be used cautiously and in conjunction with other methods such as acute changes in body weight.

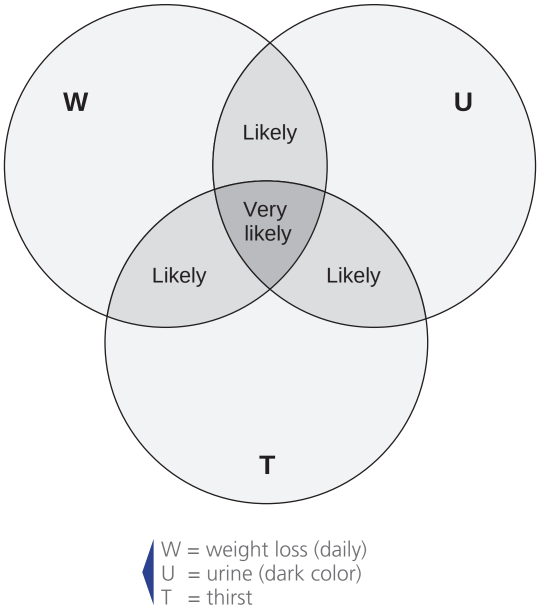


Figure 7.13 Hydration Assessment Tool

Each morning, athletes need to evaluate whether: 1) they are thirsty, 2) their urine is dark yellow, and 3) their body weight is noticeably lower than the previous morning. If one of these conditions is present, then they *may* be hypohydrated; if two conditions are present, then it is *likely* they are hypohydrated, and if all three conditions are present, then it is *very likely* they are hypohydrated.

water loss with reasonable accuracy. One liter of water weighs approximately 1 kg (2.2 lb). If an athlete completes a hard workout lasting approximately one hour and loses 2 kg (4.4 lb) of body weight, it can be assumed that approximately 2 L of fluid have been lost (2 kg × 1 L/kg). If this athlete takes a scale weight the next morning and has gained back only 1 kg (2.2 lb), it is likely that not enough fluids were consumed over the intervening day. Weight is easy to track and when used in conjunction with other markers may provide a reasonably accurate and practical method for monitoring hydration status. However, checking body weight every day may be detrimental if an athlete is struggling with disordered eating, an eating disorder, or anxiety related to degree of body fatness. These athletes may misinterpret a 1-kg (2.2-lb) weight gain as a gain in body fat and not an increase in body water. In such cases, taking daily weights would be discouraged and urine color may be the most appropriate measure of hydration status.

Cheuvront and Sawka (2005) have suggested a simple, logical approach using a combination of factors: thirst, body weight loss, and dark urine color (see Figure 7.13). The presence of any one of these factors may not provide sufficient evidence of inadequate hydration, but there is increasing probability with the overlap of two or all three factors. Each morning, athletes need to evaluate whether: 1) they are thirsty, 2) their urine is dark yellow, and 3) their body weight is noticeably lower than the previous morning. If one of these conditions is present, then they *may* be hypohydrated; if two conditions are present, then it is *likely* they are hypohydrated, and if all three conditions are present, then it is *very likely* they are hypohydrated. Rehydration strategies can then be pursued accordingly.

TYPE, TIMING, AND AMOUNT OF FLUID AND ELECTROLYTE INTAKE

Each athlete should have an individualized plan for consuming water and/or electrolytes before, during, and after exercise (Shirreffs, Armstrong and Cheuvront, 2004). Many athletes also need to consume carbohydrate during these periods, and having carbohydrate in a beverage makes doing so convenient. It is critical that each athlete plan a strategy for obtaining the nutrients needed and then test that plan during training under various environmental conditions. Because heat and humidity are substantial factors influencing fluid loss, athletes need to determine usual losses and successful rehydration strategies under different environmental conditions. A plan for adjusting fluid intake is especially important if competition is held in an environment with higher heat and humidity than the usual training setting. A basic plan, with adjustments for changing environmental conditions and the stress of competition, helps the athlete to be proactive in preventing or delaying dehydration and other nutrient-related problems. Trial and error is important for determining the ways in which the athlete will meet the ultimate goal: proper consumption of fluids, electrolytes, and/or carbohydrates.

Intake Prior to Training and Performance. Athletes should be conscious of being adequately hydrated at the beginning of an exercise session or competitive event by consuming adequate fluids throughout the previous day. Pre-exercise fluid consumption should begin at least four hours prior to training or performance, if possible. Assuming that the athlete has adequately re-hydrated from the previous day's exercise, the slow intake of fluids is recommended. Although the amount will depend on the individual, a rule of thumb for fluid intake is ~5–7 ml/kg at least four hours prior to exercise (Sawka et al., 2007). For example, a 50-kg (110 lb) female may establish a goal of consuming 250–350 ml (~8–12 oz or 1–1½ cups) of fluid before exercise. This amount of fluid four hours prior should be sufficient to maintain euhydration and allow for urination prior to training or competition. When this same rule of thumb measure is applied to larger athletes, such as a 260-lb (118 kg) male, an appropriate goal may be ~600–800 ml (~20–27 oz), highlighting the difficulty in making general recommendations for athletes.

The pre-exercise fluid intake strategy is different if the athlete is not euhydrated. Entering exercise in a state of hypohydration may be due to inadequate restoration of fluid from the previous day's exercise, multiple exercise bouts in hot and/or humid conditions, or the voluntary restriction of fluid to reduce body weight prior to weight certification. In such cases a more aggressive approach to pre-exercise fluid intake is needed. In addition to the rule of thumb recommendation outlined above, ~3–5 ml/kg two hours prior is recommended. Using the previous example, a 50-kg (110 lb) female might want to consume an additional 150–250 ml (5–12 oz), while the 260-lb (118 kg) male may need ~350–600 ml (~12–20 oz) more.

In most cases, water is sufficient. However, sodium does help to stimulate thirst, retain body water, and encourage people to drink more, so a pre-exercise source of sodium may be beneficial. If obtained in a beverage, the recommended amount is 20–50 mEq/L or 460–1,150 mg/L of sodium. If the athlete is also attempting to optimize carbohydrate stores, the ingestion of a carbohydrate-containing beverage or a small carbohydrate meal may be beneficial.

The amount and timing of the fluid ingestion prior to exercise should be determined on an individual basis during training by trial and error. Too little fluid intake may leave the athlete with a suboptimal hydration status and may allow for a greater degree of dehydration during the activity, predisposing the athlete to potentially poorer performance. Ingesting too much fluid may pose problems as well. The athlete may feel too full or bloated, potentially leading to gastrointestinal disturbances during exercise. An overabundance of fluid intake may also lead to excess urine production, discomfort, or interruption of training or competition. Each athlete's situation is really an experiment of one and he or she needs to determine the most appropriate amount and timing of fluid consumption before exercise. The stress of competition may result in a need to alter one's usual pattern of intake before exercise.

Intake During Training and Performance. As athletes lose fluid during exercise they should attempt to replace these losses to maintain fluid balance (Sawka and Montain, 2000). This is the easy and logical answer, but replacing fluids equal to those lost during exercise is not always possible, at least during the activity. Voluntary fluid replacement often falls short of fluid losses, in part due to "voluntary dehydration." Athletes may not be able to, or may not want to take time from their sporting activity to drink fluids. Certain activities, such as cycling, provide the means to carry more fluids and greater opportunity to consume them during the activity. Contrast this with activities such as running, during which fluid and/or food consumption is difficult. Some team sports may have time-outs, substitutions, or other breaks in the action that provide an opportunity to drink, but often voluntary fluid intake does not compensate for large fluid losses.

There is also a physiological reason that makes it difficult to avoid hypohydration—the inability to empty water from the stomach and absorb it into the blood as fast as it is being lost. While the maximal rate of gastric emptying and fluid uptake in adults approximates 1 L (~36 oz (~4.5 cups) per hour, water may be lost in sweat at rates twice that (over 2 L of sweat per hour) with very heavy sweating. In some situations it is not physically possible to take in enough fluid to match what is lost. A recognized goal is to prevent *excessive* dehydration (i.e., >2 percent of body water loss) and *excessive* changes in electrolyte balance (Sawka et al., 2007).

In the past, a recommended guideline for fluid replacement during exercise was to consume 150 to 350 ml (~6–12 ounces) of fluid at 15- to 20-minute intervals, beginning at the onset of exercise (Convertino et al., 1996). The ACSM (Sawka et al., 2007) now recommends a customized plan that considers sweat rate, sweat composition, duration of exercise, clothing, and environmental conditions. Recognizing that the lack of

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Some athletes can more easily consume fluids during competition than others.

recommendations regarding specific amounts to be consumed make it difficult for many athletes to determine the amount of fluid needed, the ACSM recommends as a starting point that marathon runners consume 0.4–0.8 L of fluid per hour. To avoid overconsumption of water and hyponatremia, it is further recommended that the lower end of the range would be more appropriate for slower paced, lighter weight runners competing in cooler environmental temperatures while the upper end of the range would be more appropriate for faster paced, heavier weight athletes running in hotter, more humid conditions. This range is only a guideline, and it is well recognized that the lower or upper ends of the range could result in over or under consumption of fluid by a particular runner. The need for an individualized plan for fluid replacement cannot be overemphasized.

Guidelines have not been developed for sports other than marathon runners but the principles used to establish the guideline for marathon runners do have application for other athletes. For example, an interior lineman in the National Football League may need the equivalent of 0.8 L of fluid per hour because of a large body size, a high sweat rate, clothing that prevents the evaporation of sweat, and environmental conditions at the competition site that are hotter and more humid than the athlete is accustomed to.

From a practical perspective, the amount of fluid consumed will vary depending upon the rate of fluid loss and the individual's tolerance for fluid intake during the activity. Liquids that are cool are generally better tolerated than those that are warmer (although their coldness has no noticeable effect on body temperature). People can also generally better tolerate small amounts of fluid consumed more frequently than large amounts consumed less frequently. Frequent drinking of small amounts of fluid will maintain an amount of fluid in the stomach that will stimulate gastric emptying and fluid uptake by the body. However, each athlete must find his or her "gastric tolerance." Again, the frequency and volume of fluid replacement should be determined during training so as not to introduce a new, unfamiliar process during competition.

If the athlete consumes a typical amount of dietary sodium, there is little need for the fluid replacement beverage to contain sodium unless the exercise duration is more than two hours and there is a very high sweat rate. In such cases, it is recommended that 1 g of sodium per hour be consumed. This recommendation is made to endurance athletes who sweat heavily and whose sweat contains a large amount of sodium (i.e., "salty sweaters") (Murray, 2006). However, a sodium content of 20–30 mEq/L (460–690 mg/L) may be beneficial for endurance athletes exercising in the heat who do not sweat heavily because the sodium stimulates thirst, stimulates voluntary consumption of more fluid, increases the palatability of a beverage, and promotes body water retention (Sawka et al., 2007).

Similarly, if the athlete has adequate carbohydrate stores, there is little need for the fluid to contain carbohydrate if the exercise duration is less than two hours. If exercise is in excess of two hours, however, it is recommended that carbohydrate be consumed as well as sodium.

If consuming carbohydrate, the carbohydrate content of the beverage should be less than 10 percent (<10 g of carbohydrate in 100 ml of water) for more effective fluid replacement and thermoregulation. Many sports beverages contain 6 to 8 percent carbohydrate, a concentration that does not induce gastric distress for many people. However, some athletes find that they need more dilute solutions based on their individual tolerances. Carbohydrate concentrations greater than 10 percent may slow gastric emptying and fluid uptake if consumed during exercise. However, there may be times that the carbohydrate concentration of the beverage may be greater than 10 percent. For example, ultraendurance athletes may benefit from large amounts of glucose during competition because the need for carbohydrate is so great. These athletes will need to experiment with more concentrated carbohydrate solutions during training. Trial-and-error experimentation will help ultraendurance athletes test their gastric tolerance for beverages containing more than 10 percent carbohydrate. More information about carbohydrate intake during exercise is found in Chapter 4.

Replenishment after Training and Performance. Fluid balance is typically compromised during exercise training or performance, so athletes must pay particular attention to rehydration strategies after exercise is complete (Shirreffs and Maughan, 2000; Shirreffs, 2001). It is recommended that athletes drink approximately 1.5 L (~50 oz or ~6 cups) of fluid per kg body weight lost, beginning as soon after exercise as is practical. In other words, a 2.2 lb loss of scale weight requires ~1.5 L fluid intake (Sawka et al., 2007). In the past, a rule of thumb for rehydration was "a pint, a pound," a catchy way of reminding athletes to consume 1 pint (2 cups) of fluid for each pound of scale weight lost. However, a pint is ~480 ml and is not enough to restore a 1 lb water loss, which requires ~700 ml to replenish. "A pint, a pound" is typically not enough, especially if the athlete began the exercise session in a mild state of hypohydration. Water is not as effective in achieving euhydration as a beverage that contains some sodium, because sodium increases the body's drive to drink and results in a temporary decrease in urine output (Murray, 2006). The sodium in beverages and foods consumed after exercise also help to replenish electrolytes lost during exercise. It is recommended that athletes who lose large amounts of sodium in sweat salt their food or consume salty-tasting snacks after exercise.

Is the Athlete Generally Euhydrated?

If yes, 24-hour fluid intake appears to be appropriate.

If no, total daily fluid intake should be evaluated and adjusted.

What Are the Athlete's Goals prior to Exercise?

If euhydration only, water intake is sufficient.

If carbohydrate is needed, choose between a sports beverage, carbohydrate gel and water, or carbohydrate-containing food and water.

What Are the Athlete's Goals during Exercise?

If only fluid is needed, water may be sufficient

If carbohydrate is also needed, choose a sports beverage or carbohydrate gel and water, or carbohydrate-containing food and water.

If sodium is also needed, choose a sodium-containing sports beverage or sodium-containing food and water.

What Are the Athlete's Goals after Exercise?

Replenish water, carbohydrate, and sodium as needed with a combination of foods and beverages.

Figure 7.14 Assessment and Establishment of a Fluid, Electrolyte, and Carbohydrate Replenishment Plan

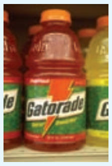
APPLICATION OF FLUID AND ELECTROLYTE GUIDELINES

One of the challenges for athletes and professionals who work with them is to translate scientifically based recommendations into practice. Athletes have many questions about water, sports beverages, and foods that may be used to replenish fluid, electrolytes, and carbohydrates. No single strategy or product is "best" for all athletes. An analysis of the athlete's needs and knowledge of the ingredients in beverages and foods provide important information for developing an individualized plan.

Some evaluation questions are listed in Figure 7.14. For example, is the athlete generally euhydrated? If yes, an appropriate plan for fluid replenishment may already be established and only fine-tuning is needed as conditions change. In many cases, however, athletes are in a routine state of hypohydration and overall daily fluid intake needs to be increased. One simple adjustment may be to drink more water during the course of a day. Some substantial adjustments may also need to be made.

Prior to exercise, some athletes are concerned only about maintaining euhydration and not about consuming additional carbohydrate. In such cases water is an appropriate pre-exercise beverage. As an example, a sprinter may drink only water during the warm-up period and while waiting for the competition to begin. Athletes engaged in prolonged exercise may choose a carbohydrate-containing beverage, because both carbohydrate and fluid are needed during exercise. These athletes will experiment during training with various carbohydrate concentrations, finding the sports beverage or food-and-water combination that provides sufficient carbohydrate without creating gastrointestinal distress. Similarly, a sports beverage can also provide sodium, a nutrient that may be needed during prolonged or ultraendurance exercise. Postexercise intake should reflect the water and nutrients lost during exercise and beverages play an important role. Since each athlete has different requirements, it is important to determine the amount of fluid and other nutrients needed and then choose foods and beverages accordingly.

For illustration purposes, consider two marathon runners who have the same fluid and carbohydrate goals during the race but achieve them in different ways. The first runner prefers to consume only a sports beverage throughout the race. This preference is based on convenience (e.g., always available along the course, easy to consume while running), taste, and predictability (e.g., known nutrient content, no history of gastrointestinal distress, no disruption to mental routine). The second runner prefers to consume a variety of carbohydrate and fluid sources—sports beverages, sports gels, bananas, and water (see Figure 7.15). This runner experiences taste fatigue and voluntary dehydration if limited to just sports beverages and prefers a variety of tastes and textures during the marathon. She also wants to be able to match food and beverage intake to how she is feeling during the run (e.g., blood glucose concentration and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8 ounces of a 6% carbohydrate beverage provides: ~7.5 ounces of water, 50 kcal, 14 g carbohydrate, 110 mg sodium, 30 mg potassium.


Christina Micek

1 packet of GU® plus 8 ounces of water provides: ~8 ounces of water, 100 kcal, 25 g carbohydrate, 40 mg sodium, 35 mg potassium.


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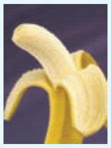
1 large juicy orange provides: ~5 ounces of water, 86 kcal, 22 g carbohydrate, 0 mg sodium, 333 mg potassium.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7- to 8-inch banana plus 6 ounces of water provides: ~8 ounces of water, 105 kcal, 27 g carbohydrate, 5 mg sodium, 422 mg potassium.

Figure 7.15 Comparison of Selected Food/Water Combinations to a Sports Beverage

Legend: kcal = kilocalorie; g = gram; mg = milligram

degree of gastrointestinal stress), and increasing or decreasing fluid, semisolid, and solid food intake is part of her racing strategy. Each of these athletes has developed an individualized plan that appropriately meets their fluid and carbohydrate goals, but the plans are very different even though they are in the same sport.

Fluid, electrolyte, and carbohydrate guidelines are often given as ranges and athletes use these ranges to create and fine-tune an individualized plan through trial and error. The nutrient composition of food and beverages is important information needed to make wise decisions about the specific foods and beverages to include. All beverages provide water, but athletes must check the label to determine carbohydrate (amount and source), electrolyte (e.g., sodium, potassium), caffeine, and energy (kcal) content. Additionally, athletes may need information about carbohydrate concentration or glycemic response, which is not on the label but may be stated in promotion materials. The athlete that wants to consume ~15 g of sugar and some sodium in 8 oz of water can choose from a number of traditional carbohydrate/electrolyte beverages. However, if the athlete wants the carbohydrate source to be a glucose polymer to provide a slower glycemic response, then fewer choices will be available.

Athletes frequently consume four types of fluids: water, sports beverages, fruit juices, and soft drinks. The advantages and disadvantages of each are listed in Figure 7.16. Carbohydrate-electrolyte beverages (the original sports beverages) provide water, carbohydrate, sodium, chloride, and potassium. In addition to traditional ingredients, sports beverages may also contain some of the following in varying amounts: proteins, fats, electrolytes such as magnesium or calcium, antioxidant vitamins, B-complex vitamins, glycerol, and central nervous system stimulants, such as caffeine. Fruit juices provide water, carbohydrate, and potassium, but the concentration of carbohydrate is much greater than a traditional sports beverage. Soft drinks, also concentrated carbohydrate sources, are carbonated, which may cause gastrointestinal discomfort. Fruit juices and soft drinks are usually not consumed during exercise but can be part of overall daily fluid intake. An important point is that athletes choose beverages that provide water and nutrients in the quantities they need and do not contain unwanted or excess substances. Various beverages are compared in Table 7.2. A detailed discussion of the need for carbohydrate before, during, and after exercise is found in Chapter 4.

Two areas of concern may be the sugar and caffeine content of beverages, especially of "energy" drinks (see Spotlight on Enrichment: "Energy" Beverages: What Are Athletes Getting?). Sport beverages and energy

Advantages of Water

Noncaloric
Refreshing taste
Widely available (bottled, drinking fountains, hoses)
Depending on hardness or softness, may provide some electrolytes

Disadvantages of Water

Provides no carbohydrate
Electrolyte content of unbottled water not known and variable

Advantages of Sports Beverages

Provide carbohydrate
Sweet taste
Contain electrolytes in known quantities
Rapid rate of absorption due to sugar and sodium content
Convenient

Disadvantages of Sports Beverages

Could provide unwanted calories if overconsumed

Advantages of Fruit Juices

Provide carbohydrate
Sweet taste
Often high in potassium
May contain vitamins, minerals, and phytochemicals

Disadvantages of Fruit Juices

High concentration of carbohydrate
May cause some gastrointestinal distress
Could provide unwanted calories if overconsumed
In children, may displace milk intake

Advantages of Soft Drinks

Provides carbohydrate
Sweet taste
Widely available
Provide stimulatory effect if caffeinated

Disadvantages of Soft Drinks

High concentration of carbohydrate
Carbonation may contribute to gastrointestinal distress
Low nutrient density
A source of excess calories for many adults and children
In children, may displace milk intake
Provide unwanted stimulatory effect if caffeinated

Figure 7.16 Advantages and Disadvantages of Popular Beverages

SPOTLIGHT ON ENRICHMENT

"Energy" Beverages: What Are Athletes Getting?

"Energy" drinks are marketed to individuals who are mentally or physically fatigued. Trained and recreational athletes, as well as people with demanding work schedules can experience fatigue. The athlete's fatigue may be caused by insufficient caloric (energy) or carbohydrate intake, hypohydration, iron-deficiency anemia, lack of sleep, overtraining, increased body temperature, or a combination of these factors. Athletes routinely struggle with fatigue, so it is very tempting to buy a drink that simply promises more "energy."

Table 7.2 includes the energy, carbohydrate, and caffeine content of some popular energy drinks. Most provide about 28 to 35 g of carbohydrate and 110 to 140 kcal in an 8-oz serving. For an athlete whose source of fatigue is low kilocalorie and carbohydrate intake, such beverages can provide both. However, the immediate feeling of "energy" is most likely due to the presence of a neurological stimulant, usually caffeine. The stimulant(s) is often from herbal sources, such as guarana, kola nuts, or maté. U.S. law does not require the amount of caffeine to be stated on the label, but the caffeine content of an 8-oz "energy" drink is frequently 75 to 80 mg, although it may be considerably more.

For those who are caffeine-naïve (never or rare users) or caffeine-sensitive, a large dose of caffeine can cause a jittery, nervous response. They feel "overstimulated" rather than "energized," which may be detrimental to training, performance, or sleep. In some individuals, caffeine can cause an irregular heartbeat. Athletes should be aware of their caffeine threshold for adverse side effects and cognizant of their daily intake. A 12-oz caffeinated soft drink provides approximately 30 to 50 mg of caffeine, less caffeine than an "energy" beverage. The caffeine content of an 8-oz cup of black caffeinated coffee can vary considerably and may be as low as 35 mg and as high as 225 mg (Center for Science in the Public Interest, 2007).

Although the exact mechanisms are not known, caffeine may impact performance because of central nervous system stimulation that alters perception of fatigue. But altering perception will not offset substantial contributors to fatigue such as low muscle glycogen stores or iron deficiency anemia in endurance athletes. Athletes who mask fatigue with stimulants are encouraged to determine and address the fundamental causes of their fatigue (Dunford, 2002).

drinks fall along the sweetened beverage continuum that runs from flavored water to highly concentrated carbohydrate solutions (see percent carbohydrate [CHO %] column in Table 7.2). Many drinks contain high-fructose corn syrup and have a low nutrient density. In some cases, the drinks are a source of excess kilocalories and water may be a better choice because it is noncaloric. This may be the case for those participating in low-energy-expenditure sports and includes athletes (e.g., pinch hitter in baseball), occasional exercisers, and children (e.g., T-ball). Not everyone engaged in a "sport" needs a "sports beverage."

Table 7.2 Composition of Selected Beverages

Beverage	Serving Size (oz)	Energy (kcal)	CHO (g)	CHO (source)	CHO (%)	Cations (mg)	Caffeine (mg)	Other
Carbohydrate-electrolyte beverages (4–7% carbohydrate)								
Hydrade	8	55	10	HFCS	4	Na^+: 91 K^+: 77	0	5.1% glycerol; some vitamin C
Gatorade Original Thirst Quencher	8	50	14	Sucrose syrup; glucose–fructose syrup	6	Na^+: 110 K^+: 30	0	
Gatorade Endurance Formula	8	50	14	Sucrose syrup; glucose–fructose syrup	6	Na^+: 200 K^+: 90	0	Some calcium and magnesium
Accelerade	8	80	14	Sucrose, maltodextrin, fructose	6	Na^+: 133 K^+: 43		Some magnesium, vitamin C, E; 5 g protein
All Sport Body Quencher	8	60	16	HFCS	7	Na^+: 55 K^+: 50	0	Vitamin C; some B vitamins
POWERade	8	64	17	HFCS, glucose polymers	7	Na^+: 53 K^+: 32	0	Some B vitamins
Lightly sweetened waters with vitamins added								
Propel Fitness Water	8	10	3	Sucrose syrup	1	Na^+: 35 K^+: 0	0	Some B vitamins; May have added calcium; Contains sucralose*
Vitamin water	8	50	13	Fructose	5.5	Na^+: 0 K^+: 0	0	Vitamins A, C, and some B vitamins; lutein
Soft drinks								
Coca Cola	8	97	27	HFCS	11	Na^+: 33 K^+: 0	23	
Pepsi	8	100	27	HFCS and/or sugar	11	Na^+: 25 K^+: 10	25	
Mountain Dew	8	110	31	HFCS, orange juice concentrate	13	Na^+: 50 K^+: 0	37	
Fruit juices								
Orange juice	8	110	27	Sucrose, fructose, glucose	11	Na^+: 15 K^+: 450	0	Naturally occurring vitamins and minerals
Unsweetened apple juice	8	116	28	Primarily fructose, some glucose and sucrose	11.5	Na^+: 8 K^+: 296		Naturally occurring vitamins and minerals

continued

Table 7.2 Composition of Selected Beverages (continued)

Beverage	Serving Size (oz)	Energy (kcal)	CHO (g)	CHO (source)	CHO (%)	Cations (mg)	Caffeine (mg)	Other
Energy drinks								
AMP Energy Drink	8	110	29	HFCS and/or sugar	12.5	Na^+: 65 K^+: 7	71 (guarana)	Some B vitamins, taurine, ginseng
Red Bull	8.3	110	28	Sucrose, glucose, glucuronolactone	11	Na^+: 200	80	Some B vitamins
Rock Star Energy	8	140	31	Surcose, glucose	13	Na^+: 40	80 (25 mg guarana)	Some B vitamins, taurine, herbs (e.g., milk thistle, ginseng, ginkgo)
SoBe Adrenaline Rush	8.3	140	37	HFCS	15	Na^+: 115 K^+: 20	86 (50 mg guarana)	Vitamin C; 50 mg ginseng
Venom Energy Drink	8.3	130	29	HFCS	11.5	Na^+: 10 K^+: 28	~100 (250 mg mate 50 mg guarana	Vitamin C, some B vitamins, taurine, bee pollen, ginseng
Other								
Extran	6.75	320	80	Glucose syrup	42	Na^+: 20 K^+: 50		Concentrated CHO source for ultradistance events

Nutrient information obtained from company websites and product labels.

Legend: oz = fluid ounces; kcal = kilocalories; CHO = carbohydrate; g = grams; mg = milligrams; HFCS = high fructose corn syrup; Na^+ = sodium; K^+ = potassium

*Sucralose (Splenda) is an artificial sweetener.

HYPONATREMIA

A potentially serious medical complication that may occur in endurance athletes during prolonged exercise such as ultramarathons or triathlons is hyponatremia (Noakes et al., 1985; Armstrong et al., 1993). Clinically, hyponatremia occurs when plasma sodium concentration falls below 135 mmol/L (from a typical level of 140 mmol/L). Exercise-associated hyponatremia is often characterized by a rapid drop to 130 mmol/L or below and is particularly serious when it drops rapidly and remains low. Because of the important role sodium has

SPOTLIGHT ON A REAL ATHLETE

Hyponatremia in a Boston Marathon Runner

The *Wall Street Journal* (2005) recounted the harrowing story of a 27-year-old male running his first Boston Marathon. The projected temperature for the 2004 race was 90°F and his goal was to finish the race in less than four hours. The runner knew that he sweated heavily in warm weather and was concerned that he would dehydrate quickly. He drank more than a gallon of water prior to the race and water at every rest stop. He was on pace at mile 19 when he developed nausea and leg cramps. By mile 23 he was unable to run but walked to the finish line. After finishing he drank approximately 2 quarts of water but felt worse and experienced vomiting and diarrhea. On the subway ride home, the vomiting continued so he continued to drink water and a carbohydrate-electrolyte beverage. At home he became unconscious and fell (breaking his shoulder). Relatives called 911 and he was transported to the hospital, during which time he was given IV fluids as he was incorrectly diagnosed as being hypohydrated. He lapsed into a coma and was placed on life support for four days. In the hospital he was correctly diagnosed as having hyponatremia. Happily, this condition was reversed and he recovered.

in maintaining osmotic and fluid balance between body water compartments and in the electrochemical gradient necessary for the transmission of nerve impulses, large disruptions in plasma sodium concentration can have serious physiological and medical consequences. Low sodium concentration in the extracellular fluid will stimulate the movement of water by osmosis from the plasma into the intracellular spaces, causing cells to swell. If nerve cells swell too much they cease to function properly, which can result in symptoms of dizziness, confusion, seizure, coma, and even death (see Spotlight on a Real Athlete: Hyponatremia in a Boston Marathon Runner).

Although rare in occurrence in shorter events, hyponatremia has been reported in up to 10 percent of runners in certain ultraendurance running events and in as many as 29 percent of triathletes in the Ironman Triathlon (Speedy, Rogers, Noakes, Thompson et al., 2000). Note that these events involve endurance exercise lasting over seven hours of duration, often in conditions of high heat and humidity, resulting in significant sweat loss. The physiological mechanism of this exertional hyponatremia is not completely understood, but a leading hypothesis is that it is due to a combination of loss of sodium through heavy sweating and an overconsumption of hypotonic fluids, particularly water (Noakes et al., 2005; Noakes, 1992, Speedy, Rogers, Noakes, Wright et al., 2000). When dehydration is prevented by copious consumption of water, sodium lost in sweat is not replaced, leading to a dilution of the sodium in the extracellular fluid. Hyponatremia can also occur in slow marathon runners, who are on the course for five or more hours, all the while consuming water or other beverages with a low sodium content (Almond et al., 2005).

The strategy to prevent hyponatremia is twofold: replacement of sodium and prevention of fluid overload or overdrinking. If exercise is to extend beyond two or three hours, sodium replacement should be considered along with fluid replacement, either in a beverage, as a supplement, or with salty-tasting foods. The recommended amount is 0.5 to 0.7 g of sodium per liter of fluid (American College of Sports Medicine, American Dietetic Association and Dietitians of Canada, 2000). Athletes may simply add salt to traditional sports beverages. For example if an athlete adds ¼ teaspoon of table salt to 32 ounces (~960 ml or 4 cups) of a sports beverage, 590 mg of sodium will be added. The additional sodium is ~0.6 g of sodium per liter of fluid, the midpoint of the guideline.

Athletes should be encouraged to consume enough fluid to match fluid loss and prevent performance-attenuating hypohydration, while not exceeding the amount of fluid lost. A substantial reduction in the incidence of hyponatremia in an ultradistance triathlon was observed after participants were educated about appropriate fluid intake and access to fluids during the race was decreased slightly by reducing the number of fluid stations and increasing the distance between them (Speedy, Rogers, Noakes, Thompson, et al., 2000) Because the body's fluid balance mechanisms can be temporarily overwhelmed, an athlete's fluid and sodium intake is an important part of fluid homeostasis.

What's the point? Most athletes do not need to be concerned with hyponatremia; however, this condition cannot be overlooked because it is potentially fatal. The keys are to avoid overdrinking and to replace sodium lost in sweat.

THE EXPERTS IN. . .

Fluid and Electrolyte Balance

Lawrence E. Armstrong, Ph.D., conducts research of athletes performing in extreme environments. Some of these research data have been collected in the medical tents of major marathons. In addition to his scientific studies, Dr. Armstrong has written extensively for consumer audiences and has created practical tools for athletes to assess hydration status. Timothy D. Noakes, M.D., heads an exercise science and sports medicine research unit in South Africa. He has conducted extensive research, including elucidating the factors associated with hyponatremia.

Michael N. Sawka, Ph.D., is an expert in heat stress physiology. His research focuses on the effect of heat, cold, and altitude on exercise physiology, including temperature regulation, blood volume response, and fluid and electrolyte balance. Robert Murray, Ph.D., is an exercise physiologist whose specialty is the effect of fluid and carbohydrate intake on performance. As the director of the Gatorade Sports Science Institute, he oversees the work of many researchers in the area of fluid and electrolyte balance. Suzanne Nelson Steen, D.Sc., R.D., is a sports nutritionist at an NCAA Division I school. Dr. Steen works with athletes from many sports but has developed special programs for wrestlers and athletes who sweat heavily and lose large amounts of water and sodium. As head of sports nutrition services and an adjunct faculty member, Dr. Steen is an example of a person who both conducts research and develops effective individualized fluid and electrolyte plans for athletes.

HYPERHYDRATION

Dehydration can have an adverse effect on training and performance, thus athletes have attempted to manipulate body fluid levels prior to exercise by hyperhydrating. The idea is to increase the amount of body water prior to exercise so when fluid is lost during exercise, a critical level of hypohydration is not reached as quickly. Theoretically, this could prevent or delay a decline in performance.

Short-term hyperhydration can be achieved relatively easily by fluid overload, the consumption of excess fluids in the hours before exercise. This overconsumption results in an increase in total body water, an increase in plasma volume, and a potential improvement in thermoregulation and exercise performance in the heat. Because the kidneys react quickly to an overload of fluid, urine production is increased and the resulting full bladder and need to urinate may be an interfering factor for the upcoming exercise. Consumption of large quantities of fluid may also result in gastric discomfort. Hyponatremia may also be a concern if very large volumes of hypotonic fluid are consumed.

Glycerol Loading. Another strategy for hyperhydrating involves the ingestion of an osmotically active, water-retaining molecule along with the increased amounts of fluid prior to exercise. One such compound is glycerol. Glycerol is easily absorbed and distributed throughout fluid compartments in the body where it exerts an osmotic force to attract water.

A typical glycerol loading regimen is to consume 1.0–1.2 g of glycerol per kg body weight along with 25–35 ml of water per kg body weight. For a 150-lb (~68 kg) runner this would be approximately 80 g of glycerol and 2 L (2,000 ml or ~71 oz or ~9 cups) of water. This approach generally results in fluid retention and hyperhydration of approximately 500 ml (~18 oz or ~2¼ cups) more than with fluid overload alone. However, it is unclear if this additional water "storage" prior to the onset of exercise improves

The Internet Café

Where Do I Find Reliable Information about Water and Electrolytes?

Several organizations have published position papers on the replenishment of water and electrolytes by athletes. These position papers outline general recommendations for fluid and electrolyte intake before, during, and after exercise. However, since body size varies tremendously among athletes, these guidelines must be individualized so that the amount of fluid consumed is well matched to the amount of fluid lost.

American College of Sports Medicine Position Stand, "Exercise and Fluid Replacement," **www.acsm-msse.org/**

American College of Sports Medicine, American Dietetic Association, and Dietitians of Canada Position Statement, "Nutrition and Athletic Performance," **www.acsm-msse.org/**

USA Track and Field, "Proper Hydration for Distance Running—Identifying Individual Fluid Needs," **www.usatf.org/**

The Gatorade Sports Science Institute **(www.gssiweb.com/)** produces a large amount of excellent materials intended for professional audiences such as exercise physiologists, sports dietitians, strength and conditioning coaches, and athletic trainers. This is a commercial website and features products made by Gatorade.

KEEPING IT IN PERSPECTIVE

Fluid and Electrolyte Balance Is Critical

Athletes must keep many aspects of nutrition in perspective, including their intake of energy, carbohydrates, proteins, fats, alcohol, vitamins, and minerals. What makes the fluid and electrolyte perspective different is that balance can change to imbalance quickly and the impact on health can be immediate and potentially fatal. There is no "one size fits all" approach to fluid balance, so each athlete must consider fluids and electrolytes from an individual perspective. Well-meaning advice—"drink as much as you can"—does not consider the case of the slow-paced endurance athlete. "Reduce sodium intake" does not consider the athlete who loses large amounts of sodium in sweat. "Drink a pint, a pound" does not consider the athlete who was hypohydrated before exercise began. "Just sweat it out and you'll make weight" does not consider the athlete's body temperature or degree of dehydration.

The proper perspective is to match fluid and electrolyte intake with fluid and electrolyte losses, although an exact "match" is often not possible or necessary. Part of maintaining a proper perspective is to recognize changing environmental conditions and needs and adjust accordingly. There can be a lot of trial and error involved; however, severe errors (e.g., hyponatremia, elevated core temperature) can be fatal. That makes the fluid and electrolyte perspective more time-critical and an everyday concern for the athlete who is training and competing.

performance. Theoretically, the additional body water would provide extra fluid for sweating and maintaining blood volume to enhance the control of body temperature without unduly compromising the cardiovascular function needed to sustain exercise performance. While a small number of studies have shown this to be the case, the scientific literature lacks a sufficient number of studies with similar results to support a strong consensus opinion (Burke, 2001).

The potential adverse effects that may accompany glycerol loading must be considered, particularly the weight gain that results from hyperhydration. Excess body weight may negatively affect performance, particularly in weight-bearing activities such as running. Consumption of glycerol may also result in gastrointestinal upset and nausea, as might the ingestion of large amounts of fluid. This hyperhydration strategy may have some benefit, but should only be attempted by an athlete under the supervision of a sports medicine professional. This practice should first be instituted during training to ascertain the potential effects, both positive and negative, on performance.

Summary

Water is critical to the normal physiological functioning of the body. Optimal fluid balance is of further importance to the athlete, as exercise can place severe demands on the body to maintain fluid homeostasis. Substantial water losses can occur during exercise and activity, particularly if the environmental conditions are severe. Water losses can compromise the body's ability to regulate body temperature, which may in turn impair training, performance, and health. Extreme losses of water and electrolytes may be dangerous or fatal due to severe **hypohydration** and an inability to keep body temperature from rising. Athletes should be conscious of water losses and employ strategies to ensure adequate hydration and electrolyte replacement before, during, and after exercise. Water in excess of need can also be problematic, as in the case of hyponatremia.

Recommendations for fluid and electrolyte consumption before, during, and after exercise are good guidelines for intake but must be individualized. Many sports beverages provide a convenient way to consume water and sodium, as well as carbohydrate, although food and water combinations are also used. Trial and error during training helps athletes determine the most appropriate fluid and electrolyte intake before and during competition. The athlete's usual rehydration strategy may need adjustment when environmental conditions change, especially increases in heat and humidity.

Post-Test: Reassessing Knowledge of Water and Electrolytes

Now that you have more knowledge about water and electrolytes, read the statements and decide if each is true or false. The answers can be found in Appendix O.

1. The two major aspects of fluid balance are the volume of water and the concentration of the substances in the water.
2. Now that sports beverages are precisely formulated, it is rare that water would be a better choice than a sports beverage for a trained athlete.
3. Athletes should avoid caffeinated drinks because caffeine is a potent diuretic.
4. A rule of thumb for endurance athletes is to drink as much water as possible.
5. Under most circumstances, athletes will not voluntarily drink enough fluid to account for all the water lost during exercise.

Review Questions

1. Why is water so critical to athletic performance?
2. How is water distributed throughout the body? How does the body maintain fluid balance between the extracellular and intracellular compartments?
3. Compare and contrast euhydration, hypohydration, and hyperhydration. Discuss the reasons athletes might attempt to be hypohydrated or hyperhydrated and the ways in which they achieve these states. What are the dangers associated with hypohydration and hyperhydration?
4. Compare and contrast the intake, physiological roles, and excretion of sodium and potassium.
5. What effect does exercise have on fluid balance? What effect does hypohydration have on exercise performance? On health?
6. Outline the ways that hydration status can be monitored. Which ways are easy and practical for athletes to use?
7. Choose an athlete in a sport that you are familiar with and devise a plan for fluid and/or electrolyte intake before, during, and after exercise. What are the important considerations given the demands of the sport and the environmental conditions under which training and performance occur? Why might an athlete not like the plan that you created?

8. What is the current recommendation for caffeine intake by athletes?
9. What is hyponatremia? In which sports are athletes at risk for developing hyponatremia? How can this condition be prevented?

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