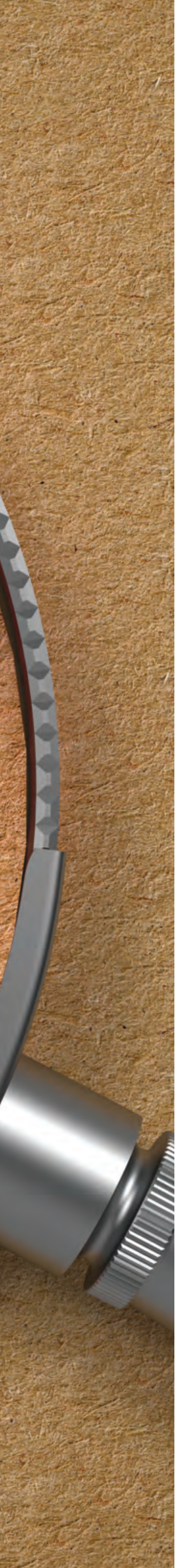

Chapter 2

Neurological and Genetic Bases of Behavior

Chapter Outline

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Psychological Applications: *If You Are Left-Handed, Is Your Brain Organized Differently from That of a Right-Hander?*

It's like waking up, sort of like waking up in the world. You're waking, trying to push things together yourself, reaching back. And you wonder at times yourself just, well, what it is and what it isn't. (Hilts, 1995, p. 239)

Have you ever had the experience of waking from a dream feeling disoriented, not quite sure where you were or what was happening? If so, then perhaps you can relate in some small way to the life of an extraordinary man—Henry Molaison.

At the age of 16, Henry experienced his first major grand mal epileptic seizure. By age 27, he was having as many as 11 seizures per week and was unable to hold a job or live on his own. Faced with a future filled with such incapacitating convulsions, Henry decided to have a radical operation that his doctors believed would cure his epilepsy. Following his mother's advice, on an August morning in 1953 and at the age of 27, Henry underwent the procedure.

My own brain is to me the most unaccountable of machinery—always buzzing, humming, soaring, roaring, diving, and then buried in mud. And why? What's this passion for?

—Virginia Woolf, British novelist, 1882–1941

Henry's physician drilled two holes into Henry's skull above the eyes and inserted metal spatulas into the holes to lift the frontal lobes of the brain slightly. With the front of the brain raised, the physician next inserted a silver straw deep into Henry's brain and sucked out a fist-sized piece of it that contained nearly the entire mass of the *hippocampus* and the regions leading up to it. What is even more horrifying about this procedure is that Henry was awake the entire time, since he was anesthetized only on his scalp. Because the brain has no sensory receptors, Henry felt no pain.

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After brain surgery in 1953 accidently removed Henry Molaison's ability to create new memories, scientists learned a great deal about how the brain creates memories by studying him over the next 50 years.

The surgery did indeed diminish Henry's epileptic seizures, but it had an additional unintended consequence—Henry lost his memories. Prior to this surgery, no one realized that the hippocampus is a part of the brain that plays a critical role in memory (see Section 2.3b). Henry was now a man with a memory frozen in time. His memories of people and events prior to his surgery were intact. Yet now, when Henry stopped thinking about something that had just happened to him, the memory disappeared, as if it never occurred (Corkin, 1984; Milner et al., 1968). Commenting on Henry's sorry state of mind, his physician sadly noted, "Guess what, I tried to cut out the epilepsy of a patient, but took his memory instead! What a trade!" (Hilts, 1995, p. 100).

In describing his state of mind in the years following surgery, Henry said it was like perpetually waking from a dream and not knowing what day it was or what he should be doing on that day. With this confusion came a tug of fear and concern. As he confided on one occasion to the scientists who were studying him:

> *Right now, I'm wondering, have I done or said anything amiss? You see, at this moment everything looks clear to me, but what happened just before? That's what worries me. (Hilts, 1995, p. 138)*

Until his death in 2008 at the age of 82, Henry Molaison remained ignorant of all the changes and advances in the world around him (Corkin, 2013). He was unaware not only that his mother and father had died or that people had walked on the moon, but also that his tragic life circumstances had dramatically increased the scientific community's understanding of the neuropsychology of memory. Indeed, over the years, Brenda Milner and other neuroscientists learned a great deal about the functioning of the human brain by studying Henry and other people like him whose brains have been damaged in some manner (Augustinack et al., 2014; Eichenbaum, 2013.

The brain comprises only about 2% of your total body weight, yet it controls most of the complex aspects of your behavior and mental life. Evidence of the brain's importance is demonstrated by the fact that it uses more energy than any other human organ, accounting for up to 20% of the body's total energy consumption (Breedlove et al., 2007). In this chapter, we continue our journey of discovery by examining this most marvelous organ. Yet before analyzing the brain's larger structures and functions, we first need to examine the complex network of nerve cells, or *neurons,* that account for all human thought and action. After investigating the basic structure and function of these nerve cells, we will see how they are organized in our *central nervous system* and *peripheral nervous system* (Woolsey et al., 2008). Finally, we will end our analysis of the biology of behavior by examining its genetic basis.

2.1 The Neuron

The nervous system has specialized cells, called **neurons**, which send and receive information throughout the body. They are the nervous system's building blocks. One of the first people to discover that neurons were separate and distinct units—and not simply a thick clump of cell matter—was Spanish neuroanatomist Santiago Ramón y Cajal (1852–1934). The amazing thing about Cajal's discovery was that he made it while working in a makeshift laboratory in his attic and using a $25 microscope and a single box of slides! His resulting theory on how the brain processes information earned him the Nobel Prize for Physiology and Medicine in 1906.

Neurons
Specialized cells in the nervous system that send and receive information

[The neuron is] the aristocrat among the structures of the body, with its giant arms stretched out like the tentacles of an octopus to the provinces on the frontier of the outside world, to watch for the constant ambushes of physical and chemical forces.

—Santiago Ramón y Cajal, Spanish scientist credited with discovering the neuron, 1852–1934,

2.1a Neurons Are the Nervous System's Building Blocks.

The human nervous system contains about 85 billion neurons. Approximately 98.8% of these neurons reside within the brain, with the remaining 1.2% (over 1 billion neurons) distributed throughout the spinal cord (Nicholls et al., 2012). On average, each neuron transmits information to tens of thousands of other neurons, which means that there are trillions of different neural connections in the brain. Although these elementary units of the nervous system come in hundreds of shapes and sizes, researchers have identified three basic types:

1. **Sensory neurons** detect stimuli inside the body (for example, a headache or strained muscle) or in the external world (for example, another person's voice). They send this information from sensory receptors to the brain, usually by way of the spinal cord.
2. Going in the opposite direction, **motor neurons** send commands from the brain to glands, muscles, and organs, directing them to do, cease, or inhibit something.
3. Finally, the vast majority of neurons are **interneurons**, those that connect sensory neurons, motor neurons, or other interneurons to one another. One of their most important functions is to link the sensory neurons' input signals with the motor neurons' output signals.

Sensory neurons
Neurons that send information from sensory receptors to the brain, usually by way of the spinal cord

Motor neurons
Neurons that send commands from the brain to glands, muscles, and organs to do, cease, or inhibit something

Interneurons
Neurons that connect the sensory neurons' input signals with the motor neurons' output signals

2.1b A Neuron Consists of a Soma, Dendrites, and an Axon.

Neurons have different functions, but most share common structural features. As illustrated in Figure 2-1, neurons have three basic parts. The central part of the neuron is the **soma**, which is the Latin word for "body." This cell body contains the *nucleus,* or control center of the neuron, and other components of the cell that preserve and nourish it. Attached to the soma are branchlike extensions, known as **dendrites** (the Greek word for "trees"), which receive information from other neurons and bring it to the soma. As previously noted, each neuron may have hundreds or thousands of dendrites. After integrating this information, the soma

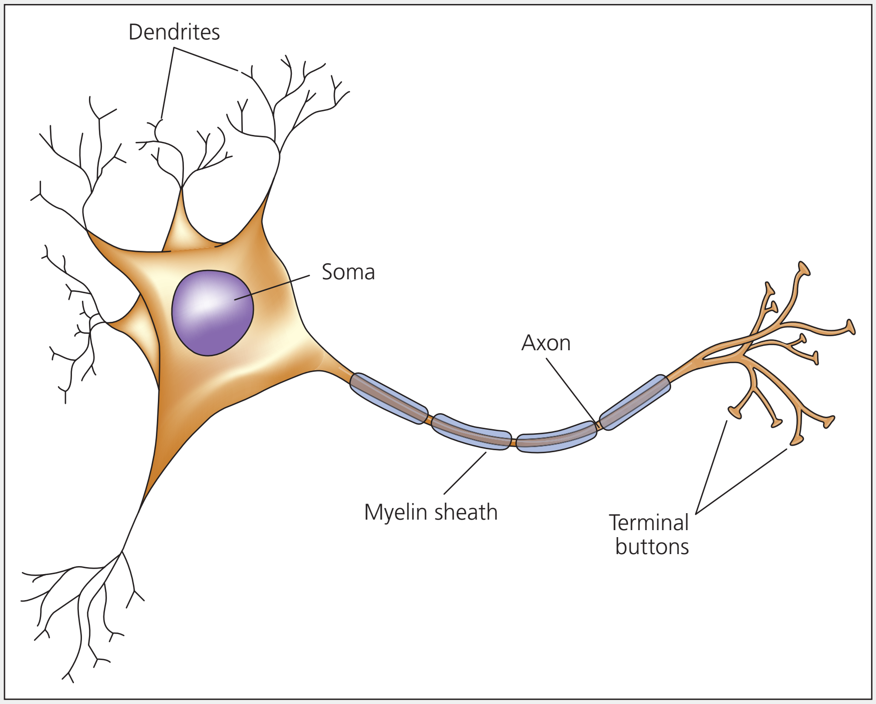
Soma
The cell body of the neuron which contains the nucleus and other components that preserve and nourish it

Dendrites
Branchlike extensions of the soma that receive information from other neurons

FIGURE 2-1

Structure of a Neuron

The primary components of the specialized cell known as the neuron are the soma, dendrites, and axon. The soma contains the nucleus of the cell, the dendrites receive information from other neurons, and the axon passes this information to other neurons. Do you know the range in length of our axons?



Axon
An extension of the soma that sends information in the form of electrochemical impulses to other neurons

Myelin sheath
A protective coating of fatty material around an axon that hastens the transmission of the electrochemical charge

transmits it to a tubelike extension called an **axon** (Greek for "axle"), which carries the information from the soma to the other end of the axon in the form of an electrochemical impulse (Rutishauser, 2008). Axons can range in length from 1/32 of an inch to more than 3 feet. To give you some idea of the relative size and length of the soma, dendrites, and axons of some of the longer neurons, visualize a tennis ball with a number of shoelaces attached to one side of it and a thin rope 14 miles long attached to the other side. The tennis ball is the soma, the shoelaces are the dendrites, and the long rope is the axon.

Many axons are covered with a protective coating of fatty cells known as a **myelin sheath** that hastens the transmission of the electrochemical charge (Lévy et al., 2015). In certain diseases, such as multiple sclerosis, the myelin sheath is slowly destroyed, causing impairment to brain-to-muscle communication and the loss of muscle control (Moll et al., 2011).

INFO-BIT

Scientists believe that the myelin sheath developed in humans as our brains evolved and became larger, making it necessary for information to travel faster over longer distances in the nervous system. Part of the reason children cannot learn and respond as quickly as adults in many cognitive and motor tasks is that their axons have not yet been fully covered by these neural speed-enhancing fatty cells. Neural axons in regions of the brain involved in abstract thinking may not become fully covered with myelin until a person reaches the age of 20!

At the end of each axon are branches with knoblike tips called *terminal buttons* that closely approach, but do not touch, the dendrites of other neurons. The space between the axon's terminal buttons and the dendrites is less than a millionth of an inch wide and is known as the synaptic cleft. The entire area composed of the terminal button of one neuron, the *synaptic cleft,* and the dendrite of another neuron is known as the **synapse**, which in Greek means "to clasp." In Section 2.1d, you will see how neurons communicate at this synapse through a complex process of electrical and chemical (electrochemical) changes.

Synapse
The entire area composed of the terminal button of one neuron, the synaptic cleft, and the dendrite of another neuron

This brief outline of the neuron's structure is greatly simplified. In fact, there are some neurons with many axons and some without any axons at all. In addition, some neurons do not synapse on dendrites but instead do so on axons or somas. Despite these exceptions, in general, dendrites receive information from other neurons and pass it through the soma and then along the axon to the dendrites of other neurons at the synapses. In this capacity as the receiver, integrator, and transmitter of neural information, the neuron truly earns its reputation as the workhorse of the nervous system.

One last important point is worth mentioning. Santiago Cajal also discovered that the brain and spinal cord are not solid masses of neurons. Nerve tissue throughout the nervous system is composed of two kinds of cells: neurons and supporting **glial cells** (*glial* in Greek means "glue"), which supply the neurons with support, nutrients, and insulation. Glial cells have no axons or dendrites. If you think of the brain as a house, then the glial cells are the floors, walls, and supporting beams, while the neurons are the electrical wiring. In essence, the glial cells hold the brain together while the neurons send and receive information throughout the brain structure. The myelin sheath that covers most axons is made up of glial cells. Glial cells also help form the *blood-brain barrier,* which is a semipermeable membrane-like mechanism that prevents certain chemicals in the bloodstream from reaching the brain. Interestingly, there are 10 times more glial cells in the nervous system than there are neurons, although they are much smaller than neurons and constitute about half the brain's total mass (Zhang et al., 2012). Now that you understand the makeup of neurons and their supporting glial cells, let's examine how information travels within a single neuron.

Glial cells
Non-neuron cells that supply the neurons with support, nutrients, and insulation

2.1c A Neuron Is in Either a Resting or a Firing State.

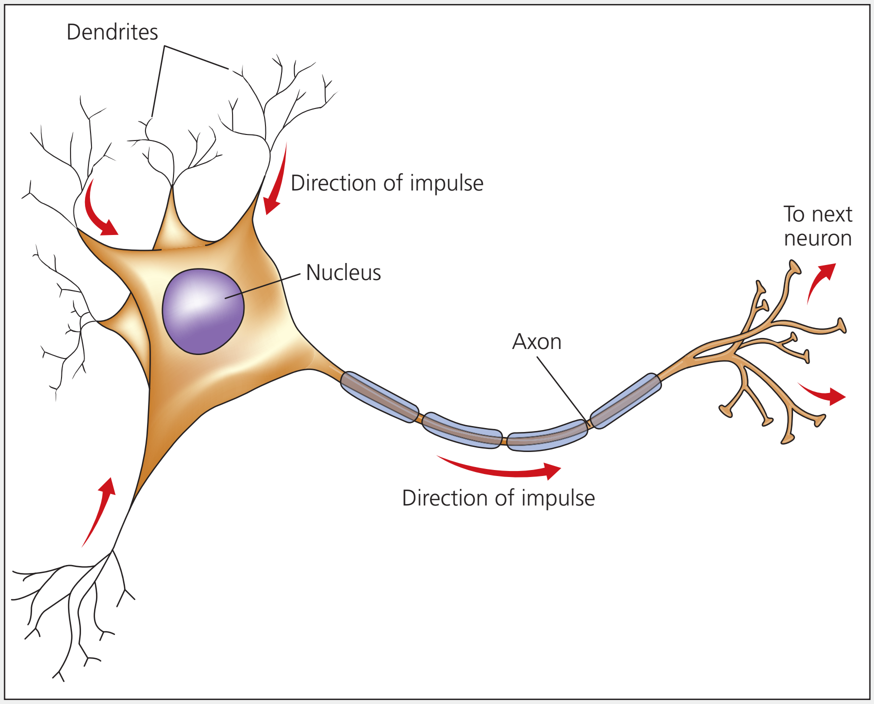
A neuron is always in either a resting or a firing state—there is no in-between condition. Whether the neuron fires an electrochemical impulse depends on whether the combined stimulation received by the dendrites exceeds a certain minimum intensity, or *threshold.* If the threshold is exceeded, the neuron's membrane transmits an electrochemical impulse. If the threshold is not exceeded, nothing happens. This effect is known as the *all-or-none law.*

One useful way to think about a neuron is that it is like a liquid-filled balloon surrounded by a slightly different kind of liquid. The axon part of this "balloon" is stretched to form a very long, thin tube. A neuron's electrochemical impulse results from positively and negatively charged particles, called *ions,* moving back and forth through specialized pores, referred to as *ion channels,* in the axon's membrane walls. The important ions in the inside and outside liquids are positively charged sodium and potassium ions and negatively charged chlorine ions. When the neuron is in a resting state, the ions floating inside the axon are mostly negatively charged, whereas those outside the axon's membrane are mostly positively charged. The reason there are more negative ions inside is that, in its resting state, the cell membrane of the axon resists the passage of positive sodium ions through its ion channels into the cell. In this stable resting state, there is a tiny negative electrical charge—about 1/20 of a volt, or –70 millivolts—within

FIGURE 2-2

Structure and Operation of the Neuron

When the combined stimulation received by the dendrites exceeds a certain minimum intensity, or threshold, an electrochemical impulse is transmitted down the axon. This impulse results from positively and negatively charged ions moving back and forth through the axon's membrane walls. How does the diameter of the axon and the myelin sheath covering it affect the speed of the impulse?



the axon, making it a storehouse of potential energy (Koester, 1995). When the inactive neuron is in this chemical balancing state—more positive ions outside of the membrane and more negative ions inside—its tiny electrical charge is known as the **resting potential**.

Resting potential
The stable, negative charge of an inactive neuron

How is this resting potential changed? As previously stated, in its resting state the axon's cell membrane does not allow positive ions through its gates. Yet, just as the negative pole of a magnet attracts the positive pole of another magnet (an event called *polarization*), the negative ions inside the axon attract positive ions along the external wall of the cell membrane. As illustrated in Figure 2-2, when a neuron receives sufficient stimulation through its dendrites from other neurons, the neural membrane nearest where the axon emerges from the soma opens its gates, allowing the clustered positive sodium ions to rush in. For an instant, the charge inside this part of the axon switches from negative to positive (an event known as *depolarization*), eliminating the resting potential and sending a brief electrochemical charge or impulse down to the next section of the axon farther away from the soma. This electrical disturbance—which transpires in about 1/1000 of a second—is called the **action potential** and is analogous to a pulse of electricity traveling along a wire (Wilson, 2015). As soon as the resting potential has been eliminated, the axon membrane gates in this area again open; this time, however, they pump the positive sodium ions back out, restoring the positive-outside and negative-inside polarization. At the same time this is transpiring, the action potential has traveled farther down the axon, causing the gates there to open in the next axonal section so that it too depolarizes, setting off a domino-like chain reaction down the entire length of the axon.

Action potential
The brief shift in a neuron's electrical charge that travels down the axon

This flood of electrically charged ions in and out of each section of the axon constitutes the neural impulse—which, you remember, was all started by stimulation to threshold at the dendrite side of the neuron. In different neurons, the speed of the impulse varies from 2 to over 200 miles per hour, but its speed is always constant within a given neuron. The larger the diameter of the axon is and the more myelin surrounding its outer surface, the faster the impulse. Although this neural impulse speed may seem fast, consider that the speed of an electric current passing through a wire is 3 million times faster. The fact that electrical wire transmission is so much faster than neural impulse speed explains why we can build machines that respond faster than our bodies.

Neurons not only differ in the speed at which the impulse moves down the axon but also in their potential rate of firing. Some neurons can reachieve their action potential within milliseconds after firing and can fire as many as 1,000 times per second. Other neurons take a great deal longer to recover their action potential. Thus, while it is true that a bright light or a loud sound causes a higher rate of firing in neurons than a less intense stimulation, some neurons will not fire as rapidly as others due to their slow recovery rate.

2.1d Neurons Communicate with One Another by Releasing Chemicals.

Now that you understand the basic operation of a single neuron, how do the billions of neurons in the nervous system work together to coordinate the body's activities? To explore this process, you need to examine how neural impulses get from one neuron to another.

As noted earlier (see Section 2.1b), at the end of each axon are *terminal buttons* that closely approach, but do not touch, the dendrites of other neurons. Most of these terminal buttons contain a number of tiny round sacs called *synaptic vesicles.* When an action potential arrives at the axon's terminal buttons, it causes these vesicles to release varying amounts of chemical messengers, called **neurotransmitters**, which travel across the synaptic cleft. As the neurotransmitters arrive at the receiving neuron's dendrites—within 1/10,000 of a second of being released by the synaptic vesicles—they fit into *receptor sites* like keys fit into locks. Just as specific keys can fit into only specific kinds of locks, each kind of neurotransmitter has a unique chemical configuration that allows it to fit into only one specific type of receptor site on the dendrites of the receiving neuron. This neural communication process, which is known as *synaptic transmission,* is illustrated in Figure 2-3.

Neurotransmitters
Chemical messengers released by the synaptic vesicles that travel across the synaptic cleft and either excite or inhibit adjacent neurons

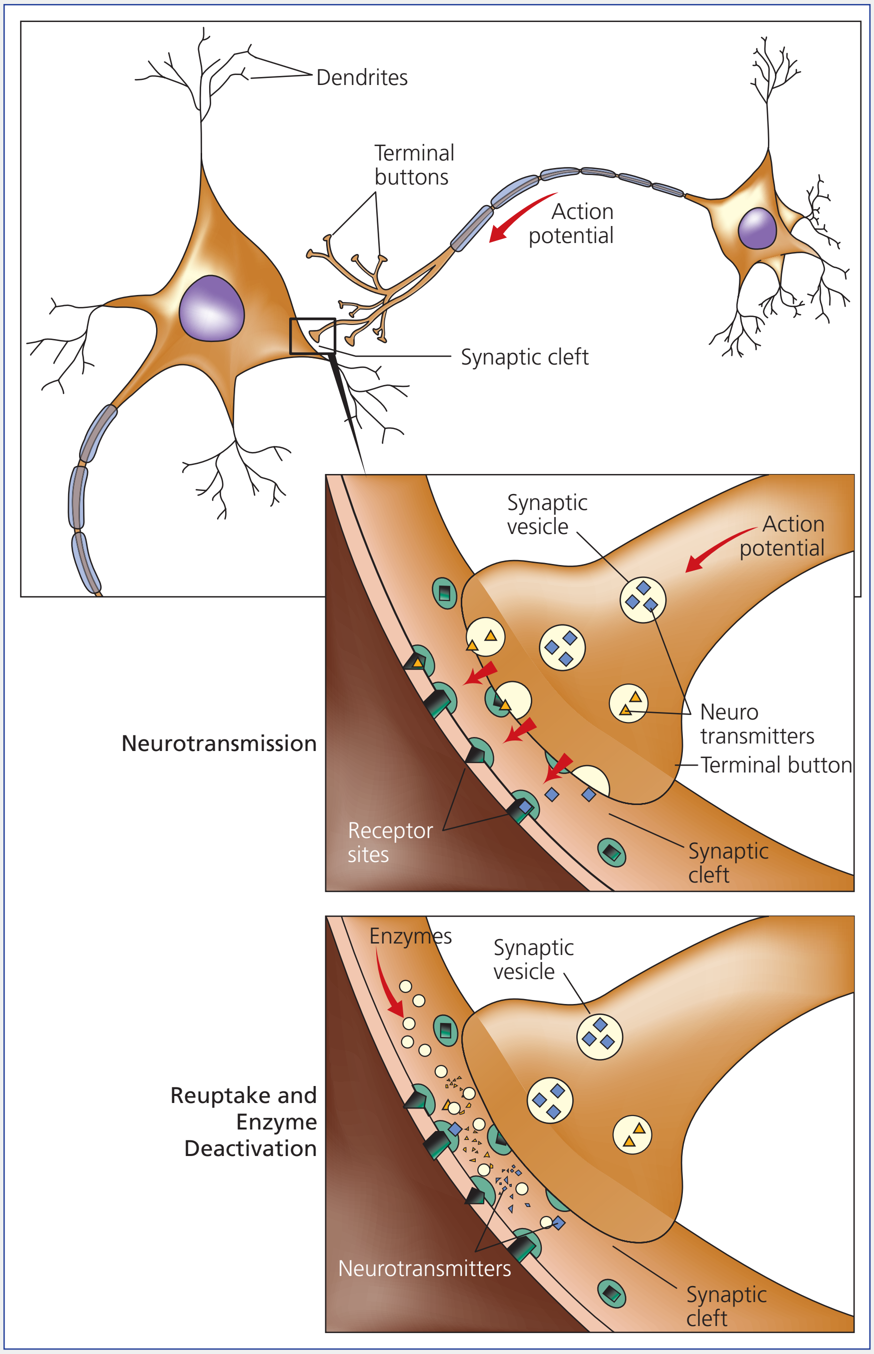
Once a neurotransmitter fits into a receptor site, it unlocks tiny channels that permit either positively or negatively charged ions to enter the receiving dendrite, which affects the probability that the neuron will fire. *Excitatory messages* increase the probability of an action potential, and *inhibitory messages* reduce the likelihood of neural firing. Because the dendrites of a neuron receive both excitatory and inhibitory messages simultaneously from different receptor sites, whether the neuron fires will depend on which type of message is in greater abundance. If a neuron receives many more excitatory than inhibitory messages, it will fire. However, if the number of inhibitory messages is greater than that of the excitatory ones, the neuron will remain in a resting state.

What happens to the neurotransmitters after they lock into the receptor sites and either excite or inhibit the firing of the dendrites of the receiving neuron? This is an important question. If the neurotransmitters are not quickly removed from the synaptic cleft, they will block the transmission of any additional signals to the receiving neuron other than their own excitatory or inhibitory messages. The primary way the synapse is cleared is by taking the neurotransmitters back into the terminal buttons from which they came, repackaging them into new synaptic vesicles, and using them again. This recycling process, which is called *reuptake,* is also used on many of the neurotransmitters that fail to reach the receptor sites. When not recycled, neurotransmitters are broken down and removed from the synaptic cleft by enzymes in a process called *enzyme deactivation* (see Figure 2-3).

FIGURE 2-3

Synaptic Transmission

The axon's terminal buttons house synaptic vesicles that contain chemical messengers called neurotransmitters. Neurotransmitters travel across the synaptic cleft to the receiving neuron's dendrites, where they fit into receptor sites and deliver either excitatory or inhibitory messages. Excitatory messages increase the likelihood of an action potential, whereas inhibitory messages decrease this likelihood. After delivering their messages, neurotransmitters are either repackaged into new synaptic vesicles (reuptake), or they are broken down by enzymes and removed from the synaptic cleft (enzyme deactivation).



The emerging knowledge of how neurotransmitters function in the brain has enabled scientists to develop drugs that are structurally similar to naturally occurring neurotransmitters. When such a drug is ingested into the body and reaches the appropriate receptor site in the brain, it may cause an action potential, just as the real neurotransmitter would do. Similarly, another drug may mimic a neurotransmitter that blocks the same receptor site, thus reducing the likelihood of neural transmission at the synapse. Still other drugs reduce the amount of the neurotransmitter that is recycled into the terminal buttons in the reuptake process, which keeps the neurotransmitter active in the synapse longer, thus increasing or decreasing the probability of neural transmission (Davis, 2006). One such drug that delays the reuptake of the neurotransmitter serotonin is Prozac®, which is widely used in treating depression (see Chapter 12, Section 12.7b).

To date, more than 100 neurotransmitters have been identified, but neuroscientists believe that many more will be discovered in the future (Shigematsu et al., 2008). One of the most prominent neurotransmitters identified so far is **acetylcholine (ACh)**, which is an excitatory transmitter found throughout the nervous system. ACh is the chemical key that transmits excitatory messages to our skeletal muscles. Its continuing presence at the appropriate receptor sites enables us not only to walk, talk, and blink our eyes but also to breathe. If it is prevented from reaching receptor sites or too much of it floods the synapses between motor neurons and muscles, the results can be disastrous. For example, the botulin bacterium, a poison found in improperly processed food, blocks the ACh receptors, which leads to respiratory paralysis and suffocation. In contrast, the venom from a black widow spider—if of sufficient dosage—causes these same receptors to be flooded, triggering severe muscle contractions, convulsions, and even heart failure. Besides its central role in the functioning of skeletal muscles, ACh also appears to play a critical role in cognition and the formation of new memories (Hasselmo & Bower, 1993). Researchers believe that the memory loss exhibited in the degenerative brain disorder known as *Alzheimer's disease*—which afflicts 11% of people over the age of 65—is partly caused by a sharp reduction in the supply of this neurotransmitter (Karim et al., 2011).

Acetylcholine (ACh)
A neurotransmitter involved in muscle contraction and memory formation

Another important neurotransmitter is **dopamine (DA)**, which is involved in controlling large muscle movements as well as influencing pleasure and motivation. Such pleasurable activities as eating, drinking, and having sex are associated with activation of dopamine receptors (Wang et al., 2003). Too much or too little dopamine in the brain results in a wide variety of debilitating effects, ranging from jerky muscle movements to psychotic hallucinations. Researchers have found that degeneration of dopamine-producing neurons in the brain causes *Parkinson's disease,* a disorder affecting many elderly adults. The main symptoms of this disease are uncontrollable tremors, slowness of movement, altered body posture, and depressed mood (Rao et al., 1992). When Parkinson's disease patients are given the L-dopa drug, their brains convert it to dopamine; this helps them regain control over their muscles (Parkinson Study Group, 2002). Another potentially useful treatment for Parkinson's disease is transplanting fetal tissue into the brains of patients. Researchers hope that the transplanted healthy fetal tissue will produce dopamine, thereby reducing patients' motor problems. Initial studies suggest that such transplants can help people regain the ability to walk and perform everyday activities (O'Keeffe et al., 2008).

Dopamine (DA)
A neurotransmitter that promotes and facilitates movement as well as influencing thought and emotion

Although the destruction of the brain's dopamine-producing system appears to be the cause of Parkinson's disease, increasing evidence shows that an overactive central dopamine system may be the root cause of *schizophrenia,* a psychological disorder we will examine more closely in Chapter 11, Section 11.2d. Drugs that block the reception of dopamine have proven effective in reducing schizophrenic symptoms in those suffering from this disorder (Murray et al., 2008). Unfortunately, because these drugs reduce dopamine levels in several brain areas, their long-term use sometimes produces symptoms like those of Parkinson's disease.

One group of neurotransmitters important in experiencing pleasure and controlling of pain are chemical substances known as **endorphins** (Pert, 1986). The brain produces endorphins in response to injury and many forms of physical stress, such as intense exercise and the labor of childbirth. During such times of bodily stress, the increase in endorphins not only temporarily provides the body with a natural

Endorphins
A family of neurotransmitters that are similar to morphine and that play an important role in the experience of pleasure and control of pain

TABLE 2-1 Major Neurotransmitters

Neurotransmitters	Involved In
Acetylcholine (ACh)	Walking, talking, breathing
Dopamine (DA)	Large muscle movement, pleasure, motivation, schizophrenia\
Endorphins	Pain suppression, pleasure
Epinephrine	Blood pressure, heart rate
GABA (gamma-aminobutyric acid)	Relaxation, anxiety
Norepinephrine (NE)	Stress, wakefulness, mood
Serotonin	Sleep, arousal, depression, schizophrenia

painkiller but also may explain the state of euphoria many runners experience following a strenuous workout, as well as the pain-reducing effects of *acupuncture,* an ancient Chinese medical technique that involves inserting needles into the body.

Serotonin
A neurotransmitter that is important in regulating emotional states, sleep cycles, dreaming, aggression, and appetite

Another neurotransmitter that is involved in a number of psychological processes is **serotonin**. This chemical messenger is especially important in regulating emotional states, aggression, appetite, and sleep onset. Depressed and anxious moods, aggressiveness, and food cravings are associated with low levels of serotonin in the brain (Paulus & Mintz, 2012). As previously mentioned, drugs that keep serotonin active in the synapse longer by blocking reuptake are used to elevate depressed moods, as well as to inhibit violence and overeating. Research also indicates that increasing the body's levels of *tryptophan,* the amino acid needed by the brain for synthesis of serotonin, facilitates sleep induction (Hartman, 1978). Because milk is a good source of tryptophan, Grandma's advice to drink a glass of milk before going to bed may be the ticket to a good night's rest.

As you will discover in later chapters, other neurotransmitters play important roles in controlling aggression, sexual activity, blood pressure, sleep cycles, and food and water intake, as well as learning and immune responses (see Table 2-1). The mysteries of neurotransmitter functioning revealed to date will no doubt be overshadowed by the discoveries yet to come as neuroscientists continue their studies of these key factors in synaptic transmission.

- Neurons are specialized cells in the nervous system that send and receive information throughout the body.
- The soma is the central part of the neuron.
- Dendrites are branchlike extensions at one end of the soma that receive electrical impulses from other neurons.
- The axon is a tubelike extension at the other end of the soma that carries impulses to other neurons.

- A neuron fires if it receives many more excitatory than inhibitory messages from other neurons.
- Neurotransmitters are chemicals that deliver excitatory or inhibitory messages to neurons.
- Some of the more important neurotransmitters are acetylcholine, dopamine, endorphins, and serotonin.

2.2 Neural and Hormonal Systems

Now that we have examined the structure and function of neurons, let's inspect the structure and function of the nervous system that neurons combine to form. The nervous system is our body's primary information system and is divided into two major portions, the *central nervous system* and the *peripheral nervous system* (Figure 2-4). One thing you will notice as you study these two divisions is that they also consist of a series of systems of twos. In addition to exploring the nervous system, we will explore a second communication system within the body that is interconnected with the nervous system, namely, the *endocrine system*.

2.2a The Peripheral Nervous System Connects the Brain and Spinal Cord with Body Organs and Tissues.

The **peripheral nervous system** consists of all the nerves located outside the brain and spinal cord. Its function is to connect the brain and spinal cord with the organs and tissues of the body. It accomplishes this task by conducting neural impulses into and out of the central nervous system.

Peripheral nervous system That portion of the nervous system containing all the nerves outside the brain and spinal cord

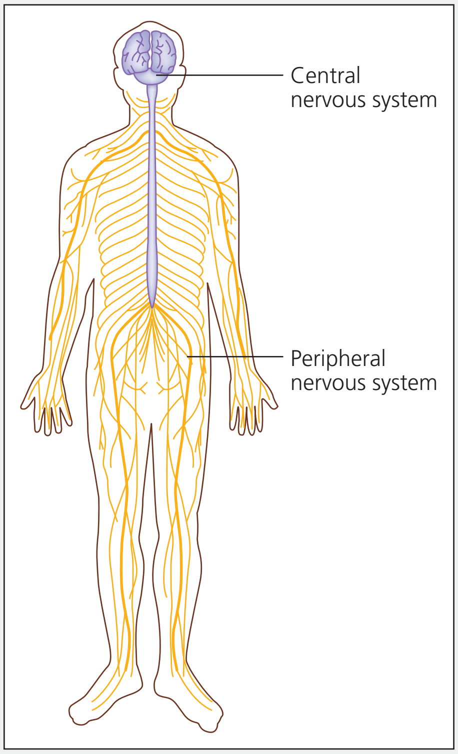


FIGURE 2-4

The Central and Peripheral Nervous Systems

The human nervous system is divided into two major portions, the central nervous system, which consists of the brain and spinal cord, and the peripheral nervous system, which consists of the remaining nerves in the body.

Because the peripheral nervous system is made up of a network of nerves, you might be wondering whether nerves are the same thing as neurons. The answer is no. While a neuron is a single cell, a **nerve** is a bundle of axons from many neurons that are routed together in the peripheral nervous system. Just as a single telephone line from your home is bundled together with thousands of other users' lines to form a telephone cable, so too are thousands of axons from many neurons bundled together to form a single nerve. Due to their sheer number, many neurons in this bundle could be destroyed without adversely affecting nerve function; however, the destruction of the entire nerve—for example, the optic nerve controlling vision—would certainly be much more problematic.

Nerve
A bundle of axons from many neurons that are routed together in the peripheral nervous system

The peripheral nervous system is also composed of two major divisions: the somatic nervous system and the autonomic nervous system. The **somatic nervous system** transmits commands to the voluntary skeletal muscles by way of the *motor neurons* and receives sensory information from the muscles and the skin by way of the *sensory neurons* (refer back to Section 2.1). The commands to the skeletal muscles control our movement, whereas the messages received from the muscles and the skin provide us with the sense of touch, the sense of position in our surroundings, and the perception of temperature and pain. As you are reading these words, for example, the movement of your eyes is being controlled by the somatic nervous system. Likewise, your ability to actually *see* the words and *feel* the book (or the "mouse," if you are reading this online) in your hands is aided by this same division of the peripheral nervous system.

Somatic nervous system
A division of the peripheral nervous system that transmits commands to the voluntary skeletal muscles and receives sensory information from the muscles and skin

The word *autonomic* means "self-governing." Thus, the **autonomic nervous system** commands movement of involuntary, nonskeletal muscles—such as the heart, lungs, and stomach muscles—over which we have little or no control. The primary function of this self-governing system is to maintain *homeostasis,* the body's steady state of normal functioning.

Autonomic nervous system
A division of the peripheral nervous system that controls the movement of nonskeletal muscles, such as the heart and lung muscles, over which people have little or no voluntary control

The autonomic nervous system is further divided into two separate branches—the *sympathetic* and *parasympathetic systems* (Figure 2-5)—which tend to work in opposition to each other in regulating many of our body functions. In general, the **sympathetic nervous system** activates the body's energy resources to deal with threatening situations. If something angers or frightens you, the sympathetic system will prepare you for "fight or flight" by slowing your digestion, accelerating your heart rate, raising your blood sugar, and cooling your body with perspiration. In contrast, the **parasympathetic nervous system** acts to conserve and maintain the body's energy resources. Thus, when the threat ceases, parasympathetic nerves slow the autonomic system back down to its normal levels of functioning.

Sympathetic nervous system
The part of the autonomic nervous system that activates the body's energy resources to deal with threatening situations

Parasympathetic nervous system
The part of the autonomic nervous system that acts to conserve and maintain the body's energy resources

In summarizing this discussion, it is important to emphasize that although the sympathetic and parasympathetic systems produce opposite effects, together they keep the nervous system as a whole in a steady state of normal functioning. In this case, opposites are indeed attractive... to our overall health.

2.2b The Spinal Cord Connects the Peripheral Nervous System to the Brain.

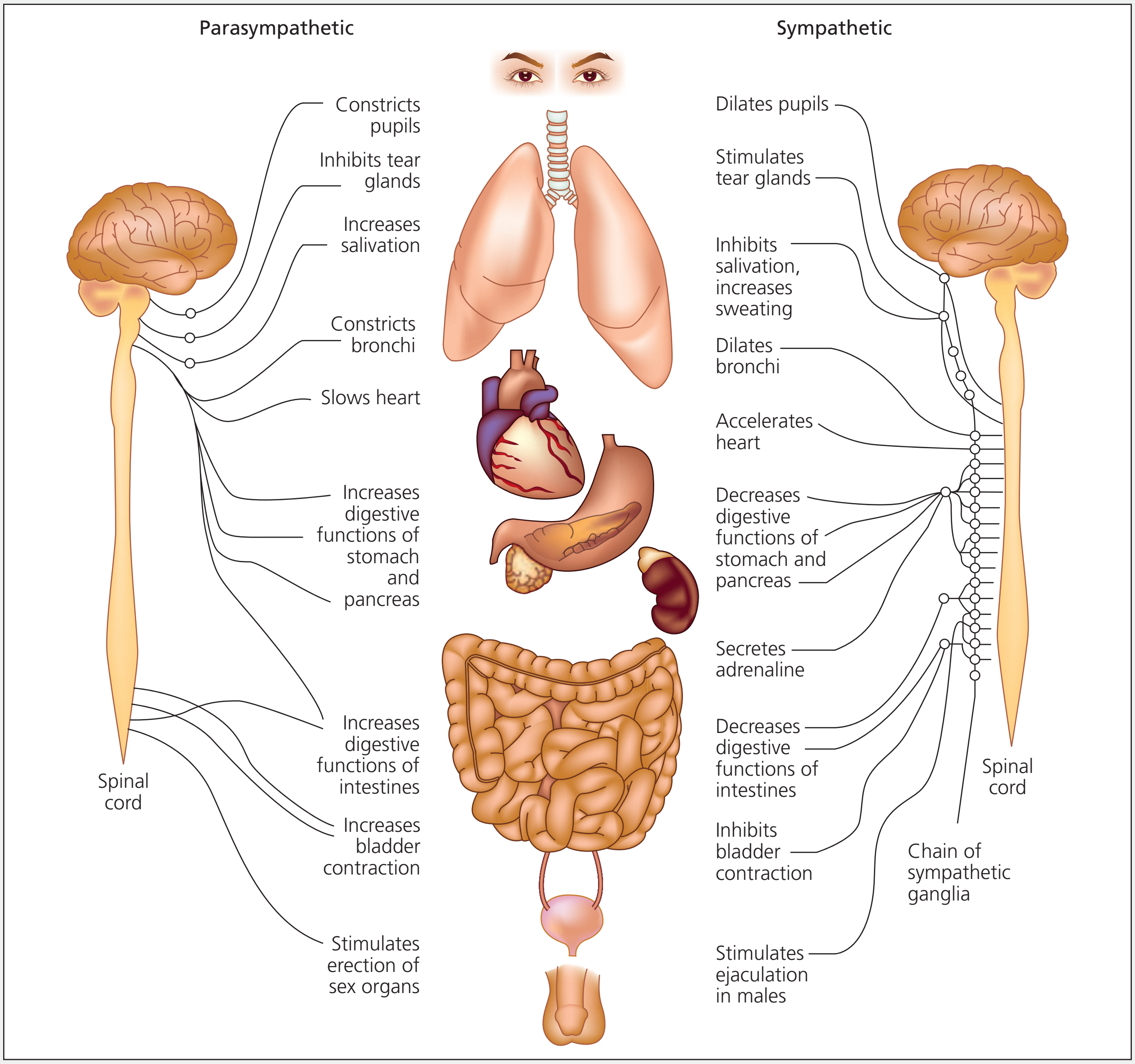
The **central nervous system** is that portion of the nervous system located in the bony central core of the body and consists of the brain and spinal cord. Besides being encased in bone and swaddled in three protective membranes (called *meninges*), the central nervous system is further cushioned and shielded from injury by a clear solution known as **cerebrospinal fluid**, which is secreted by the brain.

Central nervous system
That portion of the nervous system located in the bony central core of the body and consisting of the brain and spinal cord

Cerebrospinal fluid
A clear, cushioning fluid secreted by the brain and circulated inside and around the brain and spinal cord

FIGURE 2-5 **The Dual Functions of the Autonomic Nervous System**

The sympathetic and parasympathetic divisions of the autonomic nervous system often stimulate opposite effects in the body's organs. The sympathetic nervous system prepares your body for action, while the parasympathetic nervous system calms the body. Can you explain how these two systems respond to threat?



INFO-BIT

The protective cerebrospinal fluid, which circulates inside and around the brain and spinal cord, has a specific gravity that is slightly greater than that of the brain, allowing the brain to literally float inside the skull. In this floating state, the brain's 3-pound "air weight" is reduced to only a few ounces, significantly reducing the pressure it exerts on the spinal cord. The importance of the cerebrospinal fluid in supporting and cushioning the brain is dramatically demonstrated when patients have it drained away during brain surgery. Until the brain replenishes this fluid, the patients suffer terrible headaches and experience intense pain whenever they move their heads abruptly.

Spinal cord
The slender, tube-shaped part of the central nervous system that extends from the base of the brain down the center of the back and is made up of a bundle of nerves

The **spinal cord**, which is a bundle of nerves the thickness of a pencil, connects the brain to the rest of the body through the peripheral nervous system. Encased within the vertebrae of the spinal column and bathed in cerebrospinal fluid, the nerves of the spinal cord transmit information from sensory neurons up to the brain and from the brain down to motor neurons that initiate movement. Every voluntary action, such as walking and moving one's arms, requires a message from the brain to the spinal cord and from the spinal cord to the muscles.

The spinal cord extends from the base of the brain to slightly below the waist. By and large, the upper segments of the spinal cord control the upper parts of the body, while the lower segments control the lower body. If a segment of the spinal cord is ever severed, the person loses all sensation and muscle control below the injury. Some 11,000 people in the U.S. injure their spinal cords each year. The higher up the spine an injury occurs, the greater the extent of paralysis. Thus, when the late actor Christopher Reeve—who played the role of Superman in several 1970/80s films—severed his spinal cord just below the base of his neck in a 1995 horse-riding accident, he not only lost the ability to breathe on his own and to move any part of his body below the injury point but also lost feeling in these areas as well. When such injuries occur, the central nervous system cannot repair itself. However, advances in neural stem cell procedures provide hope that the neural circuitry of the spinal cord can be surgically regenerated. Reeve recovered some sensation and muscle control below his injury prior to his death in 2004 from complications due to his paralysis; more recently, others suffering from quadriplegia have regained some motor and sensory function following stem cell surgery.

Reflexes
Automatic, involuntary responses to sensory stimuli

In addition to transmitting information to and from the brain, the spinal cord controls some automatic, involuntary responses to sensory stimuli called reflexes. **Reflexes**, of which the *knee-jerk response* is one example, involve no interaction with the brain. Thus, when you accidentally place your hand on a hot stove and immediately pull it away, your ability to respond so quickly is because your action involves no thinking—that is, no input from the brain. The pain message does continue traveling up the spinal cord to the brain, so that within a second, you will respond with a cry of pain; the action of removing your hand from the burner, however, is achieved by the spinal nerves. Such quick reflexive responses by the spinal cord enable the body to avoid serious injury.

2.2c *The Endocrine System Communicates by Secreting Hormones.*

Endocrine system
A network of glands in various parts of the body that secrete hormones directly into the bloodstream

Hormones
Chemical signals, secreted into the blood by the endocrine glands, that help regulate bodily activities

The **endocrine system** is interconnected with—but not actually part of—the nervous system. It consists of a network of glands in various parts of the body that secrete chemical messengers, known as **hormones**, directly into the bloodstream (see Table 2-2). Because the blood carries these hormones throughout the body, and because the membrane of every cell has receptors for one or more hormones, these chemical messengers have a direct effect on many different body activities and organs, including the brain. Hormones affecting the brain influence our interest in food, aggression, and sex. However, unlike neural impulses that rely on electrochemical transmission and can be measured in thousandths of a second, hormonal communications traveling through the bloodstream often take minutes to reach their destinations. Although the endocrine system generally affects bodily organs more slowly than the nervous system does, the effects of hormonal stimulation typically have a longer duration than those of neurotransmitters. Besides regulating body activities, hormones also organize the nervous system and body tissues at certain stages of development. Puberty is perhaps the most noticeable time in life when hormones trigger important physical changes.

TABLE 2-2 Major Endocrine Glands and Some of Their Hormones

Gland	Hormone	Effects
Pituitary gland	Growth hormone	Stimulates growth (especially of bones) and metabolic functions
	Oxytocin	Stimulates contraction of uterus and mammary gland cells, and may possibly promote prosocial behavior
Thyroid gland	Thyroxin	Stimulates and maintains metabolic processes
Adrenal glands	Epinephrine and norepinephrine	Increase metabolic activities and blood glucose and constrict certain blood vessels
Gonads (male testes and female ovaries)	Androgens (males), estrogens (females)	Support male sperm formation, stimulate female uterine lining growth, and stimulate development and maintenance of secondary sex characteristics, such as chest hair growth in men and breast development in women

The most influential endocrine gland is the **pituitary gland**, a pea-sized structure located in the base of the brain and controlled by a nearby brain area called the *hypothalamus* (see Section 2.3b). The pituitary is often referred to as the "master gland" because it releases about ten different hormones that stimulate and regulate the rest of the endocrine system. The pituitary gland also releases another hormone that influences growth. At puberty, the pituitary gland increases its secretion of this *growth hormone,* which acts directly on bone and muscle tissue to produce the adolescent growth spurt (Zhou et al., 2005). Throughout life, growth hormone also plays an important role in tissue repair and muscle growth. However, in adulthood, the pituitary gland produces less and less growth hormone each year, and this depletion is thought to contribute to body aging. Because growth hormone helps bone, cartilage, and muscle tissues grow and regenerate following injury, abuse of this hormone in performance-enhancing drugs has become a serious problem in both amateur and professional sports (Bollmann et al., 2007).

Pituitary gland
The body's "master" gland, located in the base of the brain, whose hormones stimulate and regulate the rest of the endocrine system

Another hormone released by the pituitary gland is *oxytocin,* which causes the uterus to contract during childbirth and the mammary glands to produce milk. When a mother begins nursing her infant, the hypothalamus signals the pituitary gland to produce oxytocin, which results in the "let down" of milk into the nipple. Surprisingly, men also have significant amounts of oxytocin in their bodies, but for what purpose? Besides the role it plays in childbirth and nursing, animal research indicates that this hormone also influences social and sexual behavior, as well as parental behavior (Norman et al., 2012). Animals with higher levels of oxytocin more strongly desire companionship, are more sexually active, and take better care of their young than do those with lower levels (Young, 2002). A possible implication of these findings is that oxytocin is an *affiliative hormone,* promoting prosocial behavior in both humans and other animals, regardless of their sex.

Other notable glands in the endocrine system are the *thyroid gland,* the *adrenal glands,* and the *gonads* (see Table 2-2). The **thyroid gland**, located just below the larynx in the neck, produces the hormone *thyroxin,* which controls metabolism—that is, the rate at which the food we eat is transformed into energy. People with an

Thyroid gland
The gland located just below the larynx in the neck that controls metabolism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Human growth hormone performance-enhancing drugs increase the growth of bone, cartilage, and muscles, therefore giving a competitive advantage to users. Such use can cause dangerous side effects—including heart damage, arthritis, diabetes, and impotence.

underactive thyroid—a condition known as *hypothyroidism*—tend to be lethargic and depressed, whereas those with an overactive thyroid tend to be very excitable, be easily agitated, and have short attention spans.

Adrenal glands
Two glands, located near the kidneys, that secrete epinephrine and norepinephrine, which activate the sympathetic nervous system

The **adrenal glands**, located near the kidneys, secrete *epinephrine* (also called *adrenaline*) and *norepinephrine* (also called *noradrenaline*) when you feel anxious or threatened. These hormones complement and enhance the effects of the sympathetic nervous system, thus making the heart beat faster, slowing digestion, and increasing the rate at which the body uses energy. Interestingly, epinephrine and norepinephrine also act as neurotransmitters, stimulating neural firing in the sympathetic nervous system. The fact that epinephrine and norepinephrine levels remain high following stressful events explains why it takes considerable time to calm down from such experiences.

Gonads
The two sex glands, called ovaries in females and testes in males

Finally, the **gonads** are the two sex glands (Hagenauer et al., 2011). The two male gonads are called *testes,* and they produce sperm cells. The two female gonads are known as *ovaries,* and they produce ova, or eggs.

In men, the testes secrete male sex hormones called *androgens,* which are the body's natural anabolic steroids. Androgens are important in muscle and bone growth, the enhancement of sexual arousal, and in the development of male secondary sexual characteristics such as hair growth on the face and body and the deepening of the voice. The most important androgen is *testosterone,* which is also secreted by the adrenal glands in both women and men. A number of well-known male and female athletes have been accused of using artificial steroids that act like testosterone by adding muscle weight and increasing strength. While these drugs enhance performance, they are extremely dangerous because they can cause cancer, heart damage, strokes, and violent behavior.

In women, the ovaries secrete *estrogen* and *progesterone,* two hormones that balance each other in the body. Both hormones are important in the development of secondary sex characteristics such as enlarged breasts and widened hips. They also regulate women's menstrual and reproductive cycles. Progesterone is essential during pregnancy, not only because it ensures the normal functioning of the mother's placenta, but also because it passes into the developing fetus' circulatory system where it is converted into other useful hormones.

REVIEW

- The central nervous system consists of the brain and spinal cord.
- The peripheral nervous system encompasses all the nerves outside the central nervous system.
- The two major divisions of the peripheral nervous system are: the somatic nervous system (transmits commands to the voluntary skeletal muscles by way of the motor neurons and receives sensory information from the muscles and the skin by way of the sensory neurons) and the autonomic nervous system (controls movement of involuntary, nonskeletal muscles, such as the heart and lung muscles).
- The autonomic nervous system is divided into two separate parts: the sympathetic system, which activates the body's energy resources in threatening situations, and the parasympathetic system, which conserves and maintains the body's energy resources.
- The endocrine system is a network of glands throughout the body that manufactures and secretes hormones directly into the bloodstream.

2.3 The Brain

Imagine how Henry Molaison's life would have been different had he undergone medical treatment today rather than in the 1950s, when neuroscientists knew so little about the brain. One primary reason we now know so much more about brain function is that contemporary neuroscientists have the ability to eavesdrop on the brain without causing it harm (Moses & Stiles, 2002). In this section of the chapter, before exploring specific brain regions, let us examine the different technologies used to study the brain.

2.3a *Modern Technology Measures the Brain's Electrical Activity, Structure, Blood Flow, and Chemistry.*

Technological advances now allow researchers to use *brain imaging techniques* that provide pictures—or scans—of this body organ. These techniques generate "maps" of the brains of living people by examining their electrical activity, structure, blood flow, and chemistry (Roth et al., 2008).

The most widely used technique is the **electroencephalograph (EEG)**, which records "waves" of electrical activity in the brain by using metal electrodes placed on a person's scalp. EEG measurement has provided researchers with invaluable information on brain functioning, especially in the areas of sleep, different states of awareness, and brain disease. The one drawback of the EEG is that it measures the overall electrical activity of many different areas of the brain at once, making it difficult to pinpoint the exact location of specific brain wave activity. However, although it is difficult to determine exactly *where* an electrical event is taking place in the brain, the EEG is very good at determining *when* it happens. The technological cousin of the EEG is the *magnetoencephalogram (MEG),* which records magnetic fields instead of electrical activity.

Electroencephalograph (EEG) A brain imaging technique that records "waves" of electrical activity in the brain using metal electrodes placed on a person's scalp.

Computerized axial tomography (CAT) scan
A brain imaging technique that combines thousands of X-ray brain photographs to construct a cross-sectional picture of the brain

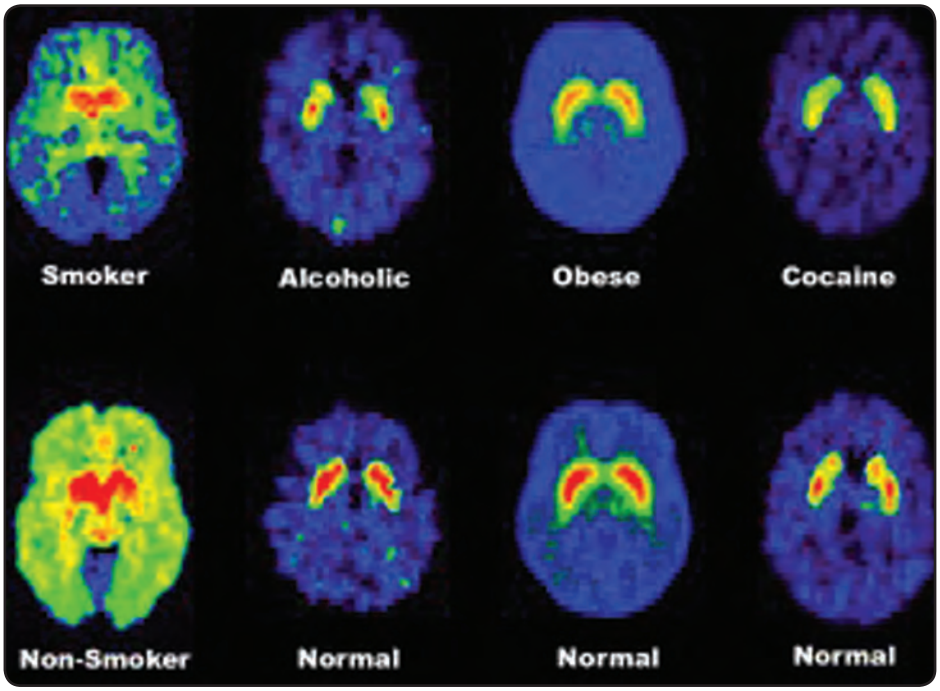
Magnetic resonance imaging (MRI)
A brain imaging technique that produces three-dimensional images of the brain's soft tissues by detecting magnetic activity from nuclear particles in brain molecules

Positron emission tomography (PET) scan
A brain imaging technique that measures, over several minutes, the average amount of neural activity in different brain regions by showing each region's consumption of the sugar glucose, the brain's chemical fuel

A more revealing look at the functioning brain is obtained by the **computerized axial tomography (CAT) scan**, which takes thousands of X-ray photographs of the brain while the person lies very still on a table with her or his head in the middle of a doughnut-shaped ring. A computer combines these many X-ray images to construct a cross-sectional brain picture. CAT scans are particularly helpful in detecting brain abnormalities, such as swelling and enlargement of certain areas.

Another brain imaging technique is **magnetic resonance imaging (MRI)**, which produces 3-dimensional images of the brain's soft tissues by detecting magnetic activity from nuclear particles in brain molecules. MRI provides greater accuracy in the diagnosis of diseases of the brain than does the CAT scan, and this has led to some ground-breaking discoveries. For example, as we will discuss more fully in Chapter 11, Section 11.2d, MRI researchers have found that there may be an association between enlarged ventricles (hollow, fluid-filled cavities) in the brain and schizophrenic disorders (Suddath et al., 1990).

Unlike CAT or MRI scans, which document the brain's structure, the **positron emission tomography (PET) scan** measures the amount of brain activity. Neural activity in different brain regions is measured by showing each region's consumption of glucose, a sugar that is the brain's chemical fuel. These readings are obtained by injecting a person with a safe level of radioactive glucose liquid and then monitoring its consumption in the brain. PET scans can reveal which parts of the brain are most active in such tasks as talking or listening to others, reading, listening to music, and solving math problems. Thus, this technique has been especially useful in revealing localization of brain function.



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These PET scans show chemical differences in the brains of people with addiction disorders (top row) and non-addicts (bottom row). Addicts have fewer than average dopamine receptors in their brains, so that weaker dopamine signals are sent between cells.

One disadvantage of the PET scan is that the picture of brain activity it provides is an average of the activity that occurs over several minutes. Another disadvantage is that it exposes people to small amounts of radioactivity, thus making extensive scanning somewhat risky. A newer technology, called **functional magnetic resonance imaging (fMRI)**, does not suffer from these drawbacks (Chen et al., 2007). It can produce a picture of neural activity averaged over seconds, not minutes, and it measures fluctuations in naturally occurring blood oxygen levels, not fluctuations in ingested radioactive glucose. The images produced by fMRI scans are also much sharper than those in PET scans; thus, they can be used to identify much smaller brain structures.

Functional magnetic resonance imaging (fMRI) A brain imaging technique that measures, over a few seconds, the average neural activity in different brain regions by showing fluctuations in blood oxygen levels

As you see, these brain imaging techniques are providing researchers with the means to make new discoveries about our most important body organ. Improvements in neuroscientists' ability to "peek" into the brain provide them with the necessary information to better prevent the type of surgical calamity experienced by Henry Molaison. However, the ability to measure the workings of the human brain is also raising growing concerns about how such technology might be abused by tapping into people's private thoughts without their consent. Closer Look 2-1 introduces the new field of *neuroethics.*

Closer LOOK 2-1

Is Privacy an Issue in Brain Imaging?

Would you be concerned if brain imaging techniques could "read" people's minds and determine their sexual orientation, their degree of racial prejudice, or their truthfulness when answering specific questions? Is this possibility purely science fiction? Maybe not. Brain imaging studies have found that certain areas of the brain are more active when people lie (Priori et al., 2008). Scientists are now trying to determine whether this knowledge can be used to produce an effective lie detector that would outperform the conventional polygraph machine (see Chapter 13, Closer Look 13-1).

Another brain imaging study was able to detect unconscious racism among white people in the U.S. (Phelps et al., 2000). In this research, white college students who had previously stated that they held no conscious racial prejudice toward black people were shown photos of familiar or unfamiliar black and white faces. When viewing unfamiliar black faces as compared to unfamiliar white faces, brain scans indicated greater activation of the amygdala, the brain area associated with fear and emotional learning. No heightened amygdala activity occurred when viewing familiar black faces. These findings suggest that, despite not consciously reporting any negative attitudes toward African Americans, these white students perhaps unknowingly felt some level of fear and negativity toward black people. Similar findings have also been obtained from black students when they viewed photos of white faces (Hart et al., 2000). One possible implication of these studies is that brain imaging technology may one day be able to peel back the surface of human thought and emotion and reveal "unconscious racism."

Are there dangers in employing such methods? Some experts think so. Privacy issues raised by brain imaging are becoming an important topic of discussion in the new field of *neuroethics* (Coch, 2007). Arthur Caplan, director of the University of Pennsylvania's Center for Bioethics, states that the need to discuss brain privacy is urgent (Goldberg, 2003): "If you were to ask me what the ethical hot potato of this coming century is, I'd say it's new knowledge of the brain, its structure and function." Although the current media focus is on genetic privacy, Caplan contends that most people feel a greater need for privacy in regard to their brains than their genes because brain activity is more associated with the immediate "here and now" than is genetic functioning.

continues

continued

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Modern brain imaging technology provides important information on how specific brain areas function. Although such advances help neurosurgeons avoid mistakes like those made during Henry Molaison's brain surgery in 1953, what are some of the ethical concerns raised by these technological advances?

Today, the automobile-sized MRI machines used to create brain images cost approximately $3 million and thus are much too expensive to be used by most nonscientists or nonmedical personnel. However, certain well-funded marketing research firms are using these machines to try to determine consumers' unconscious preferences for certain products. There have also been recent scientific advances that increase the likelihood that brain imaging technology will one day be able to detect brain activity from afar. For example, scientists have already demonstrated the ability to remotely detect brain activity from a distance of about 3 feet (Farahany, 2008). While scientific limitations to usable remote brain scanning still exist, it is very possible that these will be overcome in the not-too-distant future.

Does it concern you that police officers and airport security personnel may one day be remotely examining your brain activity so that they better understand your current emotional and cognitive states? Would this be an unacceptable invasion of your privacy, or just the price you would be willing to pay to live in a more safe and secure world? If the brain privacy debate follows the same path as the genetic privacy debate, new laws may soon be proposed to protect the public from the misuse of this fascinating and powerful new technology.

2.3b Three Major Brain Regions Are the Hindbrain, Midbrain, and Forebrain.

The names for the three major brain regions—*hindbrain, midbrain,* and *forebrain*—come from their physical arrangement in the developing human embryo. In the embryo, the central nervous system begins its development as a long, hollow *neural tube,* but within 5 weeks, this tubular cluster of neurons changes its shape into these three distinct regions (see Figure 2-6). The forebrain is the farthest forward, near where the face will develop. The midbrain comes next, just above the hindbrain, which is near the back of what will become the neck. The remainder of the neural tube develops into the spinal cord. This section of the chapter first briefly describes each of these major brain regions and then focuses attention on that part of the forebrain that dominates the rest of the brain, namely, the *cerebral cortex.*

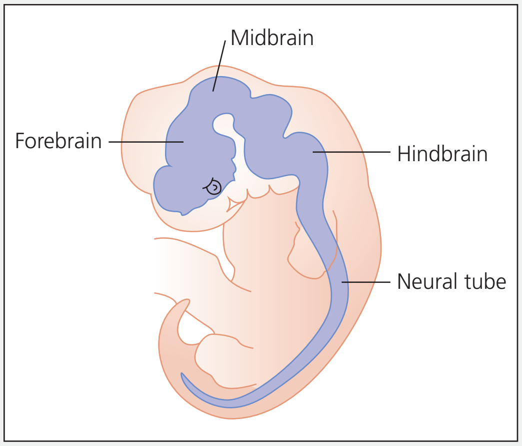

FIGURE 2-6
Development of the Brain
During embryonic development, the neural tube forms distinct regions called the forebrain, midbrain, and hindbrain. In the photograph of a 12-week old embryo on the right, you can see the long, hollow neural tube from which these three brain regions develop.

Journey of Discovery

You have probably heard the following statement many times: "We use only 10% of our brains." Based on what you have learned about brain functioning, do you think this statement is true? In pondering the merits of this expression, consider another type of human functioning: athletic performance. Do athletes use only 10% of their muscles when competing?

The Hindbrain

Figure 2-7 shows that, at the bottom of the brain, directly above the spinal cord, is the **hindbrain**, consisting of the medulla, pons, and cerebellum (Mendoza & Foundas, 2008). From an evolutionary perspective, the hindbrain is the brain's oldest region and it controls our most basic functions. The **medulla**, which looks like a swelling at the top of the spinal cord, controls our breathing, heart rate, swallowing, and digestion. It also allows us to maintain an upright posture. Besides controlling these functions, the medulla is the place in the brain where the nerves from the left side of our body cross over to the right side of the brain and the nerves from the right side of our body cross over to the left side of the brain. (Yes! We are cross wired!) The **pons**, located just above the medulla, is concerned with sleep and arousal. Behind the medulla and pons is the **cerebellum** (meaning *little brain*), which not only is important in the regulation and coordination of body movement but also appears to play a role in learning. Damage to this area of the brain results in jerky and poorly coordinated muscle functioning and causes severe disturbances in balance, gait, speech, and the control of eye movement. The cerebellum is also one of the first brain structures affected by alcohol, which explains why intoxicated individuals are uncoordinated and have slurred speech.

The Midbrain

The **midbrain** (see Figure 2-7) is a small neural area located in the middle of the brain, above the hindbrain, that is associated with vision, hearing, sleep, and alertness. The most important structure in the midbrain is the **reticular formation**, a finger-shaped network of neurons involved in the regulation and maintenance

Hindbrain
Region of the brain above the spinal cord that controls our most basic functions

Medulla
A part of the hindbrain that controls breathing, heart rate, swallowing, and digestion, and allows us to maintain an upright posture

Pons
A part of the hindbrain that is concerned with sleep and arousal

Cerebellum
A part of the hindbrain that regulates and coordinates basic motor activities and may also play a role in learning

Midbrain
The region of the brain above the hindbrain that is associated with vision, hearing, sleep, and alertness

Reticular formation
A part of the midbrain involved in the regulation and maintenance of consciousness


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Dancers rely on the cerebellum to coordinate the movements necessary to execute complicated dance routines. Why would it not be a good idea for dancers to consume alcohol prior to performing?

of consciousness, including sleep. Actually, the reticular formation extends into the hindbrain, where it makes up a portion of the pons. When you are startled by a loud noise, it is the reticular formation that causes your heightened state of arousal. Likewise, when you sleep through familiar sounds in your surroundings, it again is the reticular formation that filters out these background noises. The reticular formation's ability to respond to incoming stimuli can be shut down. This is exactly the function of anesthetics used in surgery. *Anesthetics* are chemicals that prevent certain "locks" from being opened at the synaptic level. Also, if the reticular formation is damaged, a permanent coma can result.

The Forebrain

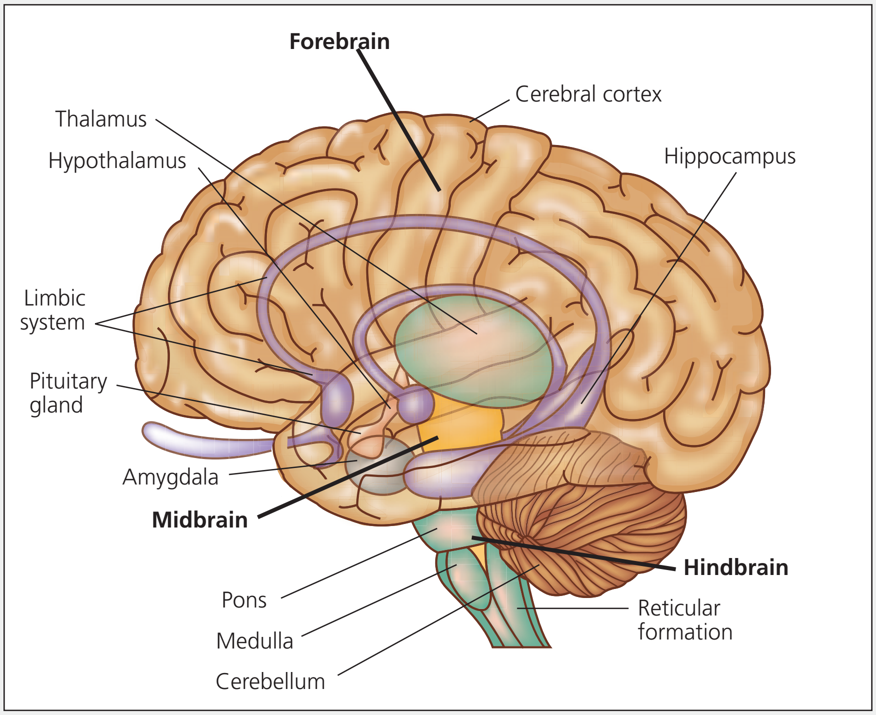
Forebrain
Region of the brain above the midbrain that allows us to engage in complex emotional reactions, cognitive processes, and movement patterns

Thalamus
A part of the forebrain that is the brain's sensory relay station, sending messages from the senses to higher parts of the brain

As we move up past the first two brain regions, we come to the most interesting—and the most evolutionarily recent—region, namely, the **forebrain**. The forebrain allows us to engage in complex emotional reactions, cognitive processes, and movement patterns. It consists of such important structures as the *thalamus, hypothalamus,* and *limbic system.* On top of these structures is the *cerebral cortex,* the most complex part of the brain.

The **thalamus**, looking like a joined pair of eggs, is the brain's sensory relay station, sorting and sending messages from the eyes, ears, tongue, and skin to the cerebral cortex. The thalamus, working closely with the reticular formation, also plays

FIGURE 2-7
Main Brain Regions and Associated Structures



an important role in the control of sleep and wakefulness by closing the pathways of incoming information from the senses during sleep so that this information does not pass to the rest of the brain and wake us up.

The **hypothalamus** (*hypo* means "beneath") is located under the thalamus and is less than 1/10 its size (less than 1 cubic centimeter). One of its most important functions is acting as the control center of the autonomic nervous system, meaning that it controls that part of the nervous system governing the involuntary muscles (see Section 2.2a). As the control center, the hypothalamus ensures that the autonomic nervous system provides *homeostasis,* which is the maintenance of a constant internal body state. Your relatively steady body temperature, blood pressure, and body fluid volume are a result of the hypothalamus coordinating the autonomic regulatory activities of the body. Another important function of the hypothalamus is providing a critical link between the central nervous system and the endocrine system. As discussed in Section 2.2c, by exercising control over the release of hormones from the endocrine system's pituitary gland, the hypothalamus influences hormone release by other glands throughout the body. Last, but not least, this small brain structure also regulates several motivated behaviors, including eating, drinking, and sexual activity. In addition, it plays an important role in the experience of emotion, stress, and pleasurable reward; and it is strongly affected by certain addictive drugs, such as cocaine. All in all, this is one cubic centimeter of the brain that you cannot function without.

Hypothalamus
A part of the forebrain involved in regulating basic biological processes, such as eating, drinking, sexual activity, emotion, and a stable body temperature

A series of interrelated doughnut-shaped neural structures, located at the border of the brain's older parts and the soon-to-be-discussed *cerebral cortex,* is the **limbic system**. Its two main structures are the *amygdala* and *hippocampus.* The amygdala (which means "almond" in Greek) consists of two almond-shaped neural clusters that influence fear and aggression. Damage to—or electrical stimulation of—this part of the brain can result in either intense fear or uncontrollable rage, depending on what part of the amygdala is activated (Fanselow & Poulos, 2005). Such damage can also short-circuit these feelings. For example, monkeys with destroyed amygdalas lose their fear of natural predators. The other limbic structure, the hippocampus, is central in the acquisition and consolidation of new information in memory (Suchan et al., 2008). This is exactly the part of the brain that was surgically removed in Henry Molaison to control his seizures, leaving him unable to form new memories. Although acquiring new memories is no longer possible with such damage, acquisition of *implicit* memories—those outside of conscious awareness—is not affected (Cohen et al., 1985). Thus, Henry was able to learn new skills, such as reading mirror writing or solving mazes and puzzles—but he was not able to remember having done so!

Limbic system
A part of the forebrain consisting of structures that influence fear and aggression (amygdala) and the acquisition and consolidation of new information in memory (hippocampus)

As you have learned, many vital functions are controlled and regulated by the hindbrain, midbrain, and selected parts of the forebrain. Yet, despite the complexity of these different brain areas, what sets us apart from all other animals and makes us "humans" is the forebrain structure known as the *cerebral cortex,* which is the subject of Section 2.3c.

INFO-BIT

Would it surprise you to learn that about 200,000 neurons in your brain die each day of your life? It's true. Fortunately, because you were born with so many neurons and because some neurons are replenished, you will lose only about 6% of your original supply over 80 years (Dowling, 1992).

2.3c The Cerebral Cortex Is the Crowning Achievement of Human Evolution.

There are five different primate groups: prosimians, new-world monkeys, old-world monkeys, apes, and hominids. *Homo sapiens* (or humans) are the only surviving species of the hominid line (Tattersall, 2007). Today, our nearest living relatives are the great apes, which include chimpanzees, bonobos, gorillas, and orangutans. According to existing fossil records, hominids and apes diverged in their evolutionary lineage when hominids became bipedal—that is, developed the habit of walking on two legs—approximately 7 million years ago (Lemonick & Dorfman, 2002). The evolved ability of our hominid ancestors to walk erect was an important environmental adaptation because the upright posture allowed them to explore a much larger expanse of territory and secure many new resources.

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Humans (*Homo sapiens*) are the only surviving species of the hominids. Around 7 million years ago, hominids began walking on two legs and diverged from gorillas, bonobos, orangutans, and chimpanzees in their evolutionary lineage. Why was walking upright an important evolutionary adaptation?

Besides the ability to walk erect, the second important adaptation in the evolution of the human species was the increase in brain size (Eccles, 1989). When scientists first studied the evolution of the human brain, they assumed that brain size was closely related to intellectual capacity. However, this assumption quickly ran into problems (Harvey & Krebs, 1990). First, although humans believed themselves to be the most intelligent of all creatures, their brains of about 1,350 grams weighed far less than those of less intelligent species, such as elephants (8,000 grams). Second, adult human brains vary between 1,000 and 2,000 grams, but there is no indication that the "heavy brainers" are more intelligent than the "light brainers." Another approach was to examine brain weight as a percentage of total body weight. Although this formula resulted in humans leaping ahead of elephants (2.33% versus 0.20%), they were now outdistanced by the shrew (3.33%), which is a mouse-sized mammal related to the mole.

Instead of comparing brain weight, researchers began to compare the evolution of different brain regions. Of all the brain regions studied, the most dramatic differences between humans and other animals can be seen in the relative sizes of the brain stem—which includes the hindbrain and midbrain—and the cerebral cortex. As previously discussed, the brain stem regulates basic life processes, such as heart rate, respiration, digestion, and sleep. In contrast, the **cerebral cortex**, located in the uppermost portion of the forebrain, is the "thinking" center of the brain, coordinating and integrating all other brain areas into a fully functioning unit. Its name is derived from two Latin words—*cerebrum,* meaning "brain," and *cortex,* meaning "bark." Basically, the cerebral cortex is the part of the brain that looks like the bark of a tree.

Cerebral cortex
The largest structure in the forebrain; largely responsible for higher-order mental processes

The surface of the cerebral cortex has a gray appearance because it primarily contains gray nerve cell bodies and unmyelinated fibers. Although it is only 1/8 of an inch thick, this densely packed system of interneurons is mostly responsible for our ability to plan, reason, remember, speak, and analyze ourselves. Right below this thin layer of *gray matter* is *white matter,* consisting mostly of the axons of the cortical neurons (Seldon, 2005). They appear white because the axons are covered and insulated by the white myelin sheath discussed in Section 2.1b.

As you can see in Figure 2-7, the cortex of humans has a great number of *convolutions* (folds), allowing a greater volume of it to fit into the skull cavity. Indeed, if you were able to unfold the cortex, it would cover four sheets of typing paper. In comparison, a chimpanzee's flattened cortex would cover only one sheet, a monkey's would cover a postcard, and a rat's would cover a postage stamp. The relative sizes of the cerebral cortex and brain stem of species with different evolutionary ages indicate that most of the growth has occurred in the cerebral cortex (Parker, 2000). Not only do humans have a larger cerebral cortex than other species but a human's cerebral cortex also has a great deal more convolutions. When scientists compared sequences of brain-related genes in mice, rats, monkeys, and humans, they discovered a set of genes primarily associated with the cerebral cortex that evolved more rapidly among the primates, with the most rapid brain evolution occurring among humans (Dorus et al., 2005; Pratihar et al., 2010). About 90% of our cerebral cortex evolved relatively recently (Kaas, 2008).

INFO-BIT

Mammals are about 10 times brainier than reptiles and amphibians. Two orders of mammals have significantly larger brains than the rest: primates and toothed whales. Among the primates, the brain of a human is 3 times bigger than that of an ape of the same body size (Lewin, 1993).

As the size of the cerebral cortex increased in our hominid ancestors, the brain required more oxygen to keep it alive. By examining the imprint left by the brain's blood vessels on the inside surface of our ancestors' fossilized skulls, paleontologists have been able to observe the evolution of this blood supply to the brain. What they discovered was a dramatic increase in the number of blood vessels supplying oxygen to the brain from our early hominid ancestors to modern-day *Homo sapiens*. As the number of oxygen-delivering blood vessels increased, our ancestors exhibited increased brain growth, which in turn required even more oxygen to be carried by the blood to the brain. This cycle continued, and today we have large brains with a complex and very dense network of surrounding blood vessels.

I was taught that the human brain was the crown glory of evolution so far, but I think it's a very poor scheme for survival.

—Kurt Vonnegut Jr., science fiction author, 1922–2007

What made this brain of mine, do you think? Not the need to move my limbs; for a rat with half my brain moves as well as I.

—George Bernard Shaw, Irish dramatist and socialist, 1856–1950

Figure 2-8 compares the size and shape of the brain of *Homo erectus,* a hominid that became extinct about 300,000 years ago, with the modern human brain (Parker, 2000). Although 20% smaller than our brains, the *erectus* brain has the characteristic football shape found in the more recent hominids (Neanderthals and *Homo sapiens*). This modern look was primarily caused by an expansion of two regions of the cerebral cortex: the *occipital lobe* at the back of the brain and the *frontal lobe* at the front of the brain (see Section 2.3d). Evolutionary scientists believe that the expansion of these two brain lobes of the cortex was associated with our hominid ancestors' increasing reliance on sight and complex thinking to survive in their environment. The football shape of the modern human brain has a more bloated look than the *erectus* brain, largely due to the evolutionary expansion of the parietal lobe, which, among other things, is important in perceiving the spatial layout of the environment and effectively moving through it (Joseph, 2000).

2.3d The Cerebral Cortex Consists of Specialized Regions, or Lobes.

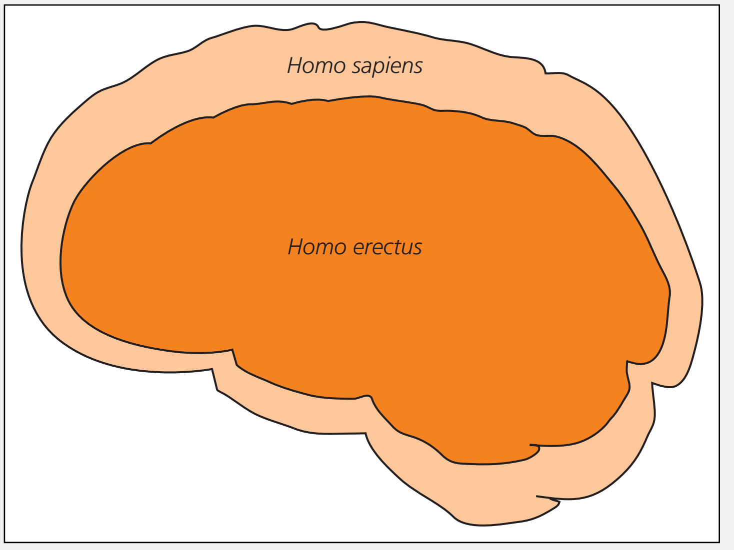
The cerebral cortex is divided into two rounded halves, called the cerebral hemispheres, one on the left side of the brain and the other on the right These hemispheres are connected at the bottom by the **corpus callosum**, a thick band of over 200 million white nerve fibers that transmit information between the two

Corpus callosum
A thick band of nerve fibers connecting the right and left cerebral hemispheres that transmits information between them

FIGURE 2-8

The Hominid Brain

Based on molded casts of the inside surface of fossilized skulls, scientists are able to compare the size and shape of our modern-day brains (Homo sapiens) with those of Homo erectus, a hominid that became extinct about 300,000 years ago.



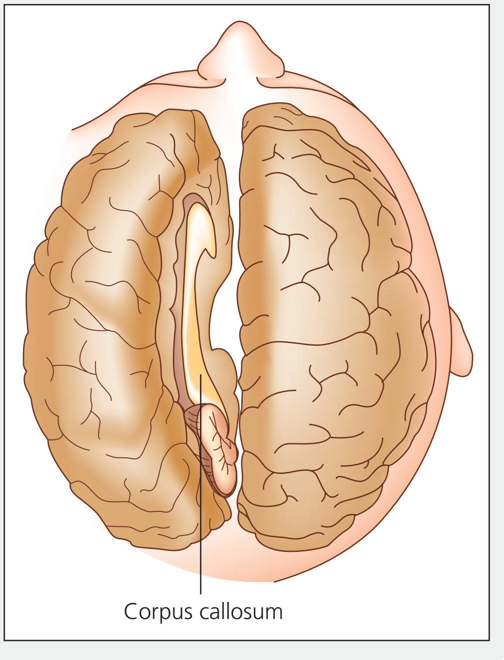
hemispheres (Figure 2-9). As mentioned earlier, our brain is cross wired, meaning that the right hemisphere controls movement and feeling of the left side of the body and the left hemisphere controls the right side of the body.

Both hemispheres can be divided into four major sections called *lobes*: the frontal, parietal, temporal, and occipital (see Figure 2-10). Thus, you have a right and a left lobe of each of these hemispheric divisions. These lobes are not distinct, independent parts of the cortex but are convenient regions named for the bones of the skull covering them. If you make your left fist and hold it up with the thumb pointing toward the front, the fist can represent the brain's right hemisphere as it is positioned in the skull (again, refer to Figure 2-10).

FIGURE 2-9

The Corpus Callosum

The corpus callosum is the dense band of nerve fibers connecting the right and left cerebral hemispheres. What would happen if this transmission bridge were cut?



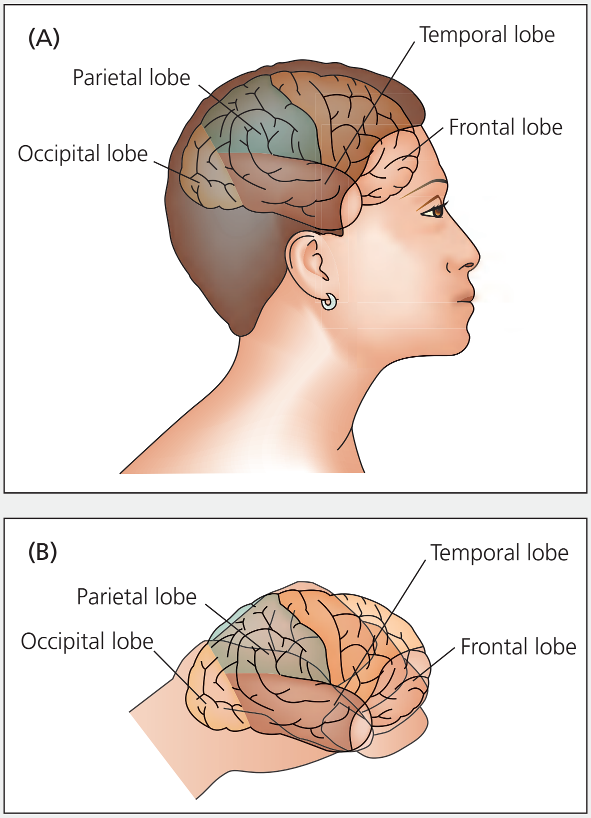


FIGURE 2-10
The Lobes of the Cerebral Cortex
(A) Each hemisphere of the cerebral cortex can be divided into four lobes: the occipital lobe, the parietal lobe, the temporal lobe, and the frontal lobe. (B) Your left fist can serve as a guide to the location of the right hemisphere's cerebral lobes. Do these lobes represent distinct, independent parts of the cortex?

The **occipital lobes**, located at the back of the cerebral hemispheres, are the visual regions of the brain. Here, we experience shapes, color, and motion in our world. Damage to the occipital lobes can cause blindness, even if our eyes and optic nerves are healthy. The **parietal lobes**, situated in front of the occipital lobes, are involved in touch sensation and in the monitoring of the body's position in space. The area of the parietal lobes which controls touch sensation is the *somatosensory cortex*. Damage to this area of the parietal lobes can destroy people's sense of touch, making it impossible for them to feel objects placed in their hands. The lips, tongue, and hands have a larger part of the somatosensory cortex devoted to them, which is why these body areas are more sensitive than other body areas. The **temporal lobes** are located below the parietal lobes, near the temples (hence, the name). These regions of the cerebral hemispheres are important in audition (hearing) and language. Damage to what is called *Wernicke's area* in the left temporal lobe can cause difficulty understanding what words and sentences mean. People with such damage may speak smoothly and expressively, but their sentences consist merely of "word salad," which is meaningless words strung together. Finally, the largest lobes in the human brain are the **frontal lobes**, which are situated in the front of the cerebral hemispheres, just behind the forehead. These regions of the cerebral cortex are involved in the coordination of movement and higher mental processes, such as planning, social skills, and abstract thinking.

Damage to the frontal lobes can result in dramatic personality changes, as was first discovered in 1848 when a Vermont railroad worker named Phineas Gage suffered severe damage to this area of his brain. While using an iron tamping rod to pack gunpowder into a boulder, Gage accidentally ignited the gunpowder, rocketing the tamping rod up into his left cheek, through the frontal lobe of his brain, and

Occipital lobes
One of the four major sections of the cerebral cortex, located at the back of each cerebral hemisphere and primarily responsible for visual processing

Parietal lobes
One of the four major sections of the cerebral cortex, situated in front of the optical lobe in each cerebral hemisphere and involved in touch sensation and in monitoring the body's position in space

Temporal lobes
One of the four major sections of the cerebral cortex, located below the parietal lobe and near the temple in each cerebral hemisphere; important in audition and language

Frontal lobes
One of the four major sections of the cerebral cortex, situated in the front of each cerebral hemisphere and behind the forehead; involved in the coordination of movement and higher mental processes

Using measurements of Phineas Gage's skull and modern neuroimaging techniques, Hanna Damasio and her coworkers (1994) reconstructed Gage's accident and the likely path taken by the metal tamping rod as it traveled through his brain.

out the top of his head. Unbelievably, Gage survived this accident and was pronounced cured in less than 2 months. Yet, despite his outward recovery, Gage no longer possessed the same personality. Before the accident, he was a friendly, popular, hardworking, and emotionally mature adult. Following the accident, he was irresponsible, disrespectful, profane, and unable to control his own impulses. The sort of dramatic alteration seen in Gage's personality is common among people with frontal lobe damage.

In later studies of patients with similar frontal damage, researchers have found that these patients not only tend to be unable to make sound decisions in their personal lives but also lack the ability to experience strong emotions (Shamay-Tsoory, 2007). Although these people might well have been warm, loving, considerate, and responsible individuals prior to their illness or accident, they are now uniformly cold, distant, inconsiderate, and irresponsible. Although these declines in reasoning and emotional abilities do not affect their basic attention, memory, intelligence, and language ability, these people are no longer who they once were.

This link between the frontal lobes and emotional expression was further explored in an interesting set of studies conducted by Richard Davidson and his colleagues (Henriques & Davidson, 1990; Tomarken et al., 1990). Testing both infants and adults, they found that the left frontal lobe governs more positive feelings, while the right frontal lobe controls more negative moods, even as early as 10 months of age. They also discovered that people with more active left frontal lobes tend to be happier and more cheerful, optimistic, sociable, and self-confident than those with more active right frontal lobes. Table 2-3 lists some of the effects of damage to the frontal lobes, as well as the other lobes.

2.3e *The Right and Left Cerebral Hemispheres Function Differently.*

Although the right and left hemispheres of the brain look very much alike, they make different contributions to our mental lives. The term **cerebral lateralization** refers to the degree to which the right or left hemisphere controls various cognitive and behavioral functions. Much of what we now know about these different functions has come about by studying people who have undergone a very rare and unique surgical procedure.

Cerebral lateralization
The degree to which the right or left hemisphere controls various cognitive and behavior functions

TABLE 2-3 Possible Consequences of Damage to Different Areas of the Cerebral Cortex

Damaged Area	Effects
Occipital Lobes	Blindness
Parietal Lobes	Loss of touch sensation
Temporal Lobes	Inability to understand the meaning of words and sentences
Frontal Lobes	Dramatic personality changes; inability to plan and reason

What would happen if the lobes of the cerebral cortex were healthy, but the right and left hemispheres could not transmit information to each other through the bundle of nerves that make up the corpus callosum? This was the question asked by psychologists Roger Sperry (1964, 1968) and Michael Gazzaniga (1970, 1989) when they began studying *split-brain* patients. In most cases, these were patients in whom the nerves of the corpus callosum had been surgically cut in a now-outmoded treatment for severe epileptic seizures. The technique was drastic, but the patients did improve rapidly, and their personality and behavior did not undergo major changes. However, now these patients had two brain hemispheres, acting more or less independently. What Sperry and Gazzaniga discovered was that these patients essentially had two minds.

BVT Lab

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The practical problem with a severed corpus callosum for split-brain patients is that sometimes one hemisphere will initiate a behavior that conflicts with the other hemisphere's intentions. Now, without a direct line of communication between the right and left hemispheres, each has its own separate and private sensations, perceptions, and impulses to act. For example, shortly following surgery, split-brain patients were often surprised to find that while dressing, their right hands (controlled by the left hemisphere) would reach for one article of clothing only to be brushed aside by their left hands (controlled by the right hemisphere), which had a different choice in mind. Despite these occasional hemispheric conflicts, split-brain patients generally behave normally.

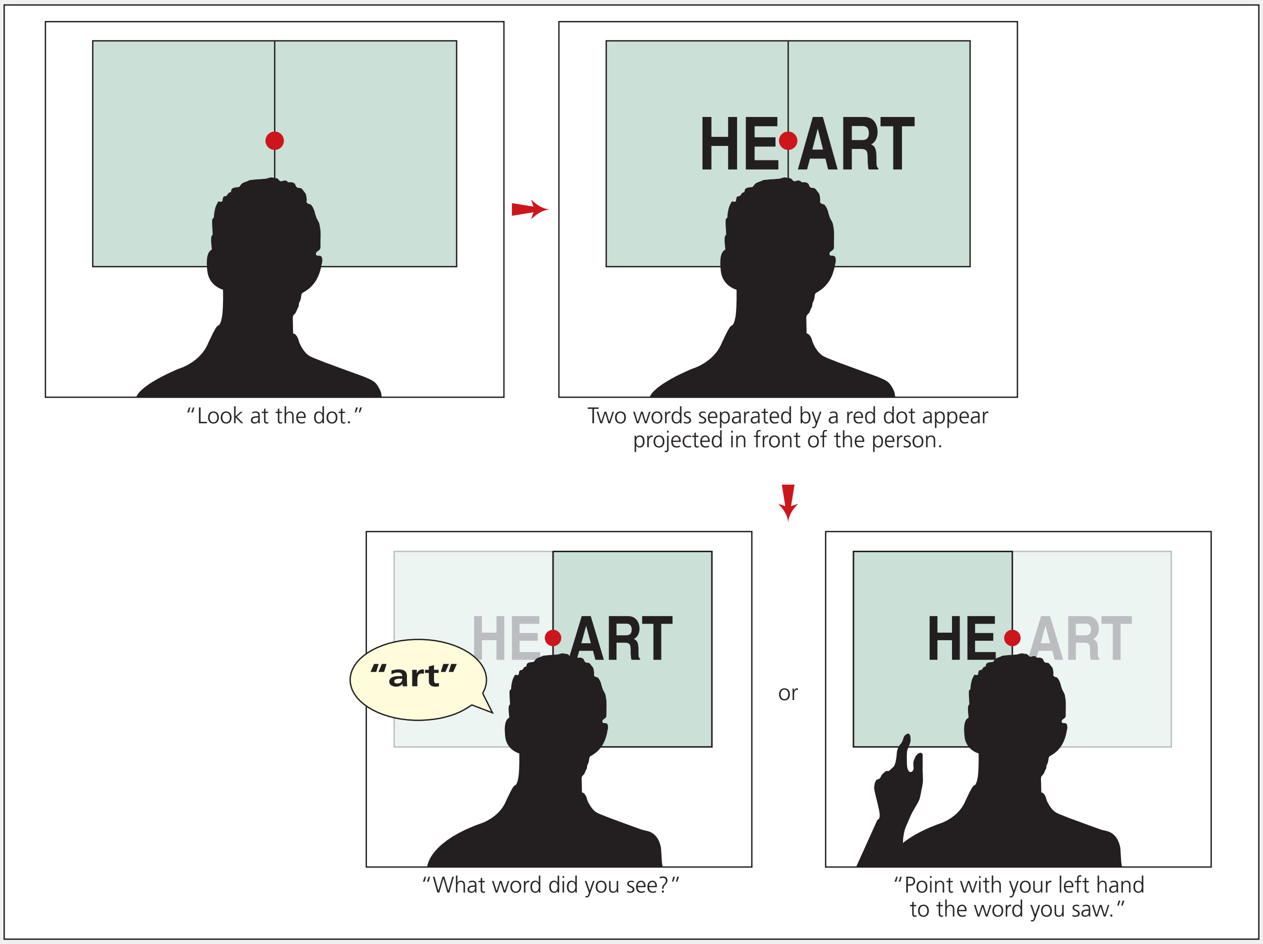
When split-brain patients have been studied in the laboratory, certain interesting effects have provided scientists with a clearer understanding of the right and left hemispheres' abilities (Walsh, 2000). For example, in one experiment, Gazzaniga (1967) had split-brain participants stare at a dot while the word *HEART* was flashed across their visual field, with *HE* in the left visual field of each eye (which is processed by the right hemisphere) and *ART* in the right visual field (which is processed by the left hemisphere). The word could be seen for only about 150 milliseconds, providing insufficient time for the eyes to move and process the entire word in each hemisphere. Participants were asked first to report verbally what they saw and then to indicate with their left hands what they saw. When people with an intact corpus callosum performed this task, the right and left hemispheres passed the different information between them and the word *HEART* was seen and reported. Yet, with split-brain people, something very interesting occurred. As depicted in Figure 2-11, split-brain individuals said they saw the word *ART,* but their left hands pointed to the word *HE.*

In another task in this same study, when the word *PENCIL* was flashed in their right visual field, the split-brain participants could easily read aloud the word—but not when it was flashed in their left visual field. What Gazzaniga discovered was that the right hemisphere did perceive and comprehend the word *PENCIL,* but the participants could not verbalize what they saw. However, using the left hand—which was controlled by the right hemisphere—the split-brain participants could easily pick out a pencil from a host of unseen objects.

Further research on the intact brain using brain imaging techniques examined in greater detail the question of cerebral lateralization (Berninger et al., 2002; Federmeier & Kutas, 2002). Although generalizations should be made with caution, it appears that the right hemisphere is superior to the left in completing visual and spatial tasks, recognizing nonlinguistic sounds (such as music and environmental noise), identifying faces, and perceiving and expressing emotions (Ewbank et al., 2008). In contrast, the left hemisphere excels at using language, employing logic, and providing explanations for events. Indeed, Gazzaniga (1988) describes the left hemisphere as

FIGURE 2-11 Testing the Split Brain

When the word HEART flashes across the visual field of split-brain patients, they verbally report seeing the portion of the word transmitted to their left hemispheres (ART). However, when asked to indicate with their left hands what they saw, they point to the portion of the word transmitted to their right hemispheres (HE).



being the brain's "interpreter," always striving to assign some rational meaning to behavior, even when there is none. Thus, when reading a map, listening to music, looking for a friend in a crowd, or laughing and crying at life's ups and downs, it's likely that there is more neural firing occurring in your right hemisphere than in your left hemisphere. By contrast, when talking on the phone, balancing your checkbook, or explaining to your parents why you need extra money for your spring vacation, your left hemisphere is probably the most active.

Having made the case that each of the two hemispheres appears to be more in control of certain functions than the other, it is important to add that these different specialized abilities are almost always relative differences, not absolute differences (Reuter-Lorenz & Miller, 1998). That is, whatever the task we work on, both hemispheres are activated to some extent (see Self-Discovery Questionnaire 2.1).

SELF-DISCOVERY 2.1
Questionnaire

Do You and Your Friends Use Different Patterns of Brain Activity to Recognize One Another's Faces?

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Which of these faces looks happier to you?

Like most people, you probably perceive the face in the photo with the smile on the left side as the happier face. This is because most people more accurately recognize visual stimuli presented to the left visual field, which is processed first in the right hemisphere. Exercises like this one suggest that the right hemisphere generally plays a larger role in recognition of facial expression than the left hemisphere. Of course, because virtually everybody has an intact corpus callosum, both hemispheres will quickly share this information. Yet until they do, the right hemisphere will exert greater influence in recognizing facial features.

Is right-hemisphere dominance for facial expression true for everyone? No. Some people fail to show a left visual field advantage, while others actually demonstrate an advantage for the right visual field. To demonstrate individual differences in the lateralization of brain function, ask as many people as possible to complete this exercise. Are there any of them who do not show this right-hemisphere preference?

2.3f *There May Be Sex Differences in Hemispheric Organization.*

Try two simple tasks. First, mentally run through the alphabet and count as quickly as possible the number of letters, including the letter e, that when silently pronounced contain the sound "ee." Next, and again as quickly as possible, mentally count the number of letters that contain curves when they are printed as capitals. Writing or speaking out loud is not permitted.

Which task was harder for you: counting sounds or counting curves? Your answer may partly depend on whether you are a woman or a man (Hall et al., 2008). Women tend to be more accurate and slightly faster in the sound task, and men tend to do better in the shape task, which suggests that there are sex differences in verbal and spatial abilities (Kimura, 1992). Because language abilities are more associated with the left hemisphere and spatial abilities are more closely aligned with right-hemisphere functioning, researchers wondered whether women and men differ in hemispheric dominance.

If the cerebral hemispheres function somewhat differently in women and men, it is likely that these differences will be reflected in the effects of brain injury. Support for this reasoning comes from studies of damage to the left hemisphere following stroke. A stroke causes damage to the brain by starving it of needed oxygen when its blood supply is temporarily interrupted. Men are 3 times more likely than women to develop **aphasia**, which is the inability to recognize or express language (McGlone, 1978). Some studies suggest that the reason women are less susceptible to aphasia is that their brains are more *bilateralized* for language—that is, they are more likely than men to use both hemispheres for this cognitive function (Reuter-Lorenz & Miller, 1998). For instance, when women and men were asked to process and compare sounds, PET scans indicated that an area of the left hemisphere was activated in both sexes. However, in a majority of the women—but in none of the men—the same area in the right hemisphere was also activated (Shaywitz et al., 1995). This study's finding that women's language functions are less likely to be located solely in the left hemisphere of the brain (less lateralized) may explain why women experience fewer language deficits than men when their left hemispheres are damaged by stroke. It may also partly explain why women tend to be less adept at spatial tasks than men. Put simply, because the right hemisphere tends to control spatial functioning, and because women are more likely than men to also use part of this hemisphere for language functioning, this bilaterality in language function may result in less proficient processing of spatial tasks (Sanders et al., 2002). In assessing these possible sex differences, we need to keep in mind not only that they appear to be very small but also that the similarities in brain function between women and men far outweigh the differences (Rogers, 2001).

Aphasia
The inability to recognize or express language as a result of damage to brain tissue, such as after a stroke

What might explain these differences? One possibility is that evolutionary pressures played a decisive role. (Levy, 1972). Because our species evolved with women being principally responsible for raising the young, verbal bilateralization may have given them a more developed communication system that fostered their survival. In contrast, because men have historically been more involved in the hunting and gathering of food and other resources, having male spatial functioning clearly separate from verbal functioning in the brain may also have benefited their survival. Although this different hemispheric arrangement between women and men may no longer provide any survival value for us, we still inherit and exhibit these biological differences because there is considerable "lag time" in the genetic changes that occur in a species when environmental changes occur.

Even though there is evidence of sex differences in brain organization, no one knows what these differences mean for the general abilities and behavior of women and men in their daily lives (Hoptman & Davidson, 1994). It is also true that culture profoundly shapes people's skills and interests. Consistent with *dynamic systems theory* (see Chapter 1, Section 1.2f), research finds that the different manner in which girls and boys are typically socialized often has an important impact on what specific abilities are nurtured. The greater verbal abilities of females today, for example, may have nothing at all to do with evolutionary factors and more to do with the fact that girls typically receive greater encouragement to talk during infancy and early childhood (Brody & Hall, 1993; Lewis & Weintraub, 1979). It is possible that this relatively high amount of verbal attention given to girls may foster greater elaboration of neural interconnections in certain areas of the brain.

2.3g Left-Brain and Right-Brain Descriptors of People Are Too Simplistic.

Beyond possible sex differences in cerebral lateralization, a number of popular "New Age" writers claim that people can be identified as being "left-brainers" or "right-brainers." Books with such titles as *Educating the Right Brain, Drawing on the Right Side of the Brain,* and *At Left Brain Turn Right* give advice on how to increase creative thinking by both tapping into unused right-brain potential and suppressing left-brain activity. This idea of right-brainers and left-brainers is also perpetuated by YouTube™ TED® talks, such as neuro-anatomist Jill Bolte's presentation based on her book, *My Stroke of Insight.* Both the book and her TED talk chronicles Bolte's recovery from a stroke and how she realized that the left and right cerebral hemispheres have distinct personalities and that anyone can achieve inner peace by simply "stepping to the right of our left brains." Is this sound advice?

As previously discussed, the left hemisphere exerts a greater influence on verbal skills such as reading, writing, math, and logic, while the right hemisphere exercises greater control over nonverbal activities such as spatial tasks, music, art, and face recognition. But does this imply that some people are logical and scientific because they rely mostly on their left hemispheres, while others are creative and artistic because they mostly use their right hemispheres? Despite the simplistic appeal of this description of brain functioning, there is no sound evidence that individuals significantly differ in their reliance on one hemisphere over the other (Hellige, 1990). Those making such claims are falsely assuming that various cognitive functions are completely localized within the left and right hemispheres. However, research clearly shows that while certain tasks may activate one hemisphere somewhat more than the other, both hemispheres are involved in the completion of any task a person might perform (Reuter-Lorenz & Miller, 1998). This literal side-by-side exchange of information is the hallmark of the healthy brain (Gazzaniga, 2000). Thus, the idea that a given person relies significantly more on one hemisphere than on the other—and that you can train yourself to activate and suppress hemispheric functioning—remains an interesting, but wholly unconfirmed, hypothesis. The simple truth is that there is no scientific evidence that people tend to have a stronger left- or right-sided brain network. Given this cautionary reminder, Figure 2-12 lists the different abilities generally associated with one hemisphere more than another, as well as their shared general functions.

2.3h The Brain Can Alter Its Neural Connections.

What happens when one part of the brain is severely damaged or destroyed? Are the cognitive functions associated with that brain area lost forever? The answers to these questions are partly being found by following the remarkable lives of children who have undergone a *hemispherectomy*—having one of their cerebral hemispheres surgically removed to control life-threatening epileptic seizures (Kossoff et al., 2003). Although this surgery may appear even more foolhardy than the procedure performed on Henry Molaison 60 years ago, we now know a great deal more about how the brain functions because of the advances made in neuroscience. Specifically, we understand that although normal functioning is not possible without a hippocampus, it is possible to live a relatively normal life following the loss of an entire cerebral hemisphere (Lettori et al., 2008). For example, in the case of hemispherectomy of the left cerebral hemisphere, although half the skull is now filled with nothing but cerebrospinal fluid, the only visible effects of the operation are often a slight limp, limited use of one of the hands and arms, no right peripheral vision in either eye,

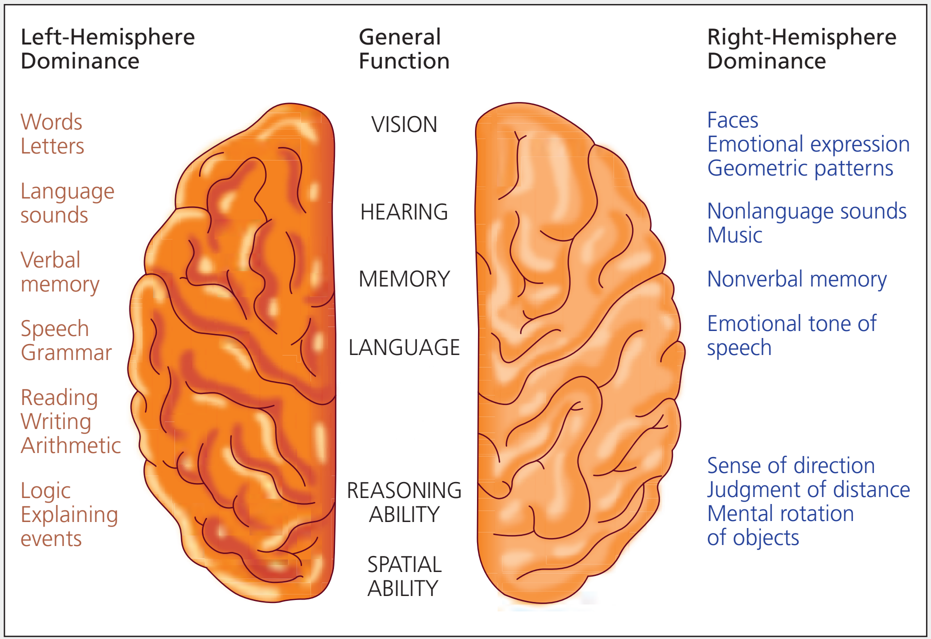
The brain is wider than the sky.

—Emily Dickinson, U.S. poet, 1830–1886

FIGURE 2-12

Specialized Abilities of the Two Hemispheres

The left and right cerebral hemispheres exhibit different abilities, but they also share general functions.



and some language deficits (Curtiss et al., 2001). In fact, brain scans indicate that the remaining healthy hemisphere takes over many of the functions of the removed hemisphere (Swerdlow, 1995).

This transferring of neural function is probably due to the accelerated growth of dendrites that provide the connections between neurons. Just like other children with normal brains, these children's production of dendrites is at a peak level from about age 4 to age 10. Besides neural connections being caused by inherited growth patterns, they are also fostered by environmental challenges, which is exactly why children who undergo this procedure are pushed so hard during their weekly speech and language therapy sessions. As more connections are made among the billions of neurons in their remaining brain regions, the end result is a better-functioning brain. Indeed, children who have had one of their brain hemispheres removed have later earned college degrees and are currently leading successful and productive lives as adults (Battro, 2001; Vining et al., 1997).

Plasticity
The ability of the brain to alter its neural connections

The extraordinary recovery of these children from such a dramatic loss of brain tissue demonstrates what neuroscientists call **plasticity**—the remarkable flexibility of the brain to alter its neural connections (Bryck & Fisher, 2012). Through such *collateral growth* (Figure 2-13), branches from the axons of nearby healthy neurons grow into the pathways previously occupied by the axons of damaged neurons. The ability to transfer brain functions from one part of the brain to the other is highest in childhood, during the peak years of dendrite growth (Liegeois & Morgan, 2012). Yet, it is also true that limited transfer of function can occur in older adults when certain brain areas are destroyed by strokes or accidents. (See Self-Discovery Questionnaire 2.2.)

Journey of Discovery

After limbs have been amputated, amputees often feel excruciating pain in the area of their lost limb. How might the brain's plasticity play a role in this pain?

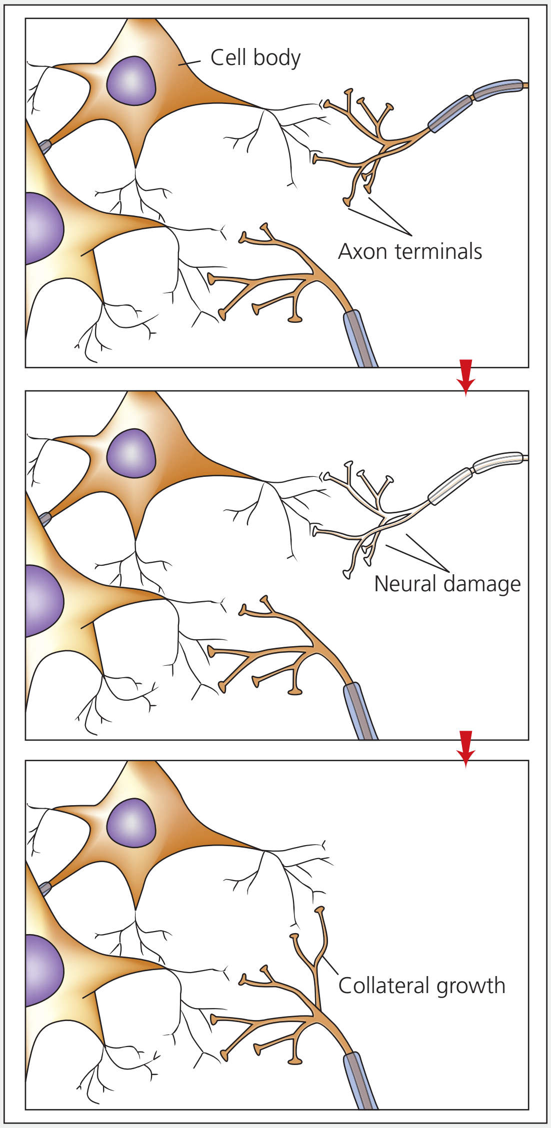


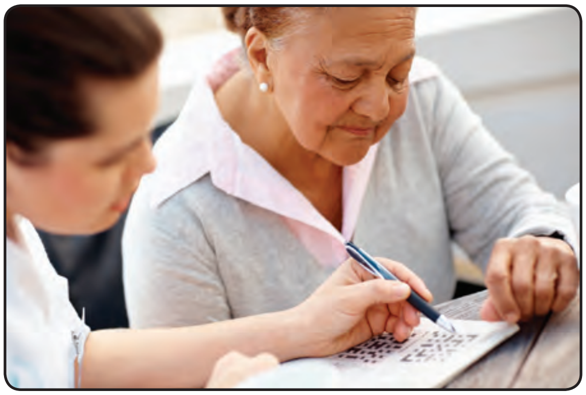
FIGURE 2-13

Collateral Growth

The brain's plasticity is demonstrated by the way in which neural connections are altered when neurons are damaged. This collateral growth is highest in childhood, when dendrite growth is at its peak.

SELF-DISCOVERY 2.2 Questionnaire

How Can You Keep Your Brain Healthy as You Age?



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"Use it or lose it!" Staying mentally active by reading regularly or doing crossword puzzles keeps the brain strong.

Scientists once believed that brain structures ceased any positive physical development by early adulthood. Yet, this thinking changed following a series of studies that suggested a very different developmental pattern. In this research, rats with an age equivalent to that of 75 human years were moved from the impoverished physical environment in which they had lived all their lives (bare cage, simple food containers) to an enriched environment (spacious home, interesting playthings). By the time they reached the equivalent of 90 human years, these rats showed significant increases in brain growth and synaptic interconnections (Diamond, 1988). These findings, which mirror the results of studies with baby rats, adult monkeys, and other species, suggest that environmental enrichment significantly enhances brain functioning, even among the elderly (Gould, Reeves, Graziano, & Gross, 1999).

Today we know that the more you engage in certain activities, the more neural growth occurs in the brain areas controlling those activities. For example, when researchers have compared professional musicians with nonmusicians, they have found greater neural connectivity among the musicians in areas within the motor cortex associated with muscles used in musical performance (Rosenkranz et al., 2007). When it comes to maintaining and enhancing cognitive functioning, there is considerable evidence that an important factor in promoting neural growth in brain areas associated with memory is cardiovascular exercise (Erickson et al., 2012). Such physical activity not only fosters the growth of new blood vessels that feed the brain but also stimulates the growth of new neurons that then become integrated into the brain's neural network (Bherer et al., 2013). The lesson here is simple, yet profound: Exercising the brain at all stages of life increases its ability to adapt to and overcome life's challenges and hard knocks.

Neuroscientific research suggests the following lifelong strategies to maintain a healthy brain at any age:

1. *Avoid harmful substances.* Drug abuse and alcohol abuse damage brain cells.
2. *Exercise on a regular basis.* People who engage in strenuous physical activity throughout their lives are not only more likely to stay physically healthy but also more likely to maintain high cognitive functioning. Further, elderly adults who do not exercise can enhance their cognitive vitality by engaging in some form of aerobic fitness training. The type of exercise that has the greatest benefit for brain longevity is that requiring complex motor skills and focused attention, rather than the repetition of simple motor skills. Thus, playing tennis or soccer might be better for your brain than simply doing jumping jacks or running on a treadmill.
3. *Eat sensibly.* Dietary factors are associated with the incidence of stroke, which is the largest single cause of brain disabilities. Decrease the intake of saturated fat, and eat more fruits and vegetables. Overeating also harms the brain. Elderly adults who overeat—consume 2,100 to 6,000 calories a day—are twice as likely to have mild cognitive impairment as those who eat fewer than 1,500 calories daily.
4. *Get adequate sleep.* Sleep deprivation and interrupted sleep harms the brain and the body. The average length of sleep for North American and European adults today is less than 7.5 hours, about 20% lower than what it was 100 years ago. Middle-aged and elderly adults who don't sleep well—waking up more than five times each hour—are more likely to have deposits of protein in their brain related to Alzheimer's disease.
5. *Challenge yourself mentally*. When it comes to the brain, the old adage "Use it or lose it" really does apply. Staying mentally active by reading regularly and learning new skills strengthens neural connections much like regular physical exercise strengthens the heart.
6. *Wear your seat belt and bike helmet*. Motor vehicle accidents account for up to half of all brain injuries. Head injury is the most common cause of death in bicycle crashes, accounting for 62% of all bicycle-related deaths.

- Some of the more commonly used technological devices to examine the brain's electrical activity, structure, blood flow, and chemistry are the electroencephalograph (EEG), computerized axial tomography (CAT), magnetic resonance imaging (MRI), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI).
- There are three major brain regions: the hindbrain, located above the spinal cord and consisting of the medulla, pons, and cerebellum; the midbrain, which contains the reticular formation and is located above the hindbrain; and the forebrain, which consists of the thalamus, hypothalamus, limbic system, and cerebral cortex and is located above the midbrain.
- The cerebral cortex, which is divided into two rounded halves called the cerebral hemispheres, coordinates and integrates all other brain areas and is mostly responsible for our ability to plan, reason, remember, speak, and analyze ourselves.
- The left and right cerebral hemispheres are both divided into four major sections: frontal lobe, parietal lobe, temporal lobe, and occipital lobe.
- The right hemisphere is superior to the left in completing visual and spatial tasks, recognizing nonlinguistic sounds, identifying faces, and perceiving and expressing emotions.
- The left hemisphere excels at using language, employing logic, and providing explanations for events.
- Women's brains may be less lateralized—less likely to have various brain functions located in only one of the hemispheres—than men's brains.
- The brain can alter its neural connections to compensate for damage.

2.4 Genetic Influences on Behavior

Having examined the neural basis of human functioning, let us now turn our attention to the influence of genetics on human functioning. The primary question I want to address in this section of the chapter is how the visible and measurable traits (**phenotype**) of an organism reflect its underlying genetic makeup (**genotype**).

Phenotype
The visible and measurable traits of an organism

Genotype
The underlying genetic makeup of an organism

2.4a *The Basic Biochemical Unit of Inheritance Is the Gene.*

In 2003, geneticists completed the Human Genome Project, which identified 99.99% of the genetic material in humans. Because every person has a unique genetic pattern, researchers do not expect to ever reach 100%. *Genome* is the term used to describe the total genetic information in the cells of a particular species. The focus of the Human Genome Project was the **gene**, the biochemical unit of inheritance that provides instructions for how every activity in every cell of our body should be carried out.

Gene
The basic biochemical unit of inheritance that is located on and transmitted by chromosomes

What sort of instructions do genes provide to the body's cells? Gene instructions concern the production of *proteins,* which regulate the body's physiological processes and the expression of phenotypic traits (for example, body build, intelligence, athletic ability). Proteins are the building blocks of life. As an example, consider how a gene instructs a liver cell to remove excess cholesterol from the bloodstream. The gene instructs the cell to make a particular protein (a receptor protein), and it is this protein that removes the cholesterol from the blood. The cholesterol molecules are then transported into the cell and processed by other proteins.

Chromosomes
Thread-like structures carrying genetic information that are found in every cell of the body

Deoxyribonucleic acid (DNA)
The complex molecular strands of a chromosome that contain thousands of different genes, located at fixed positions

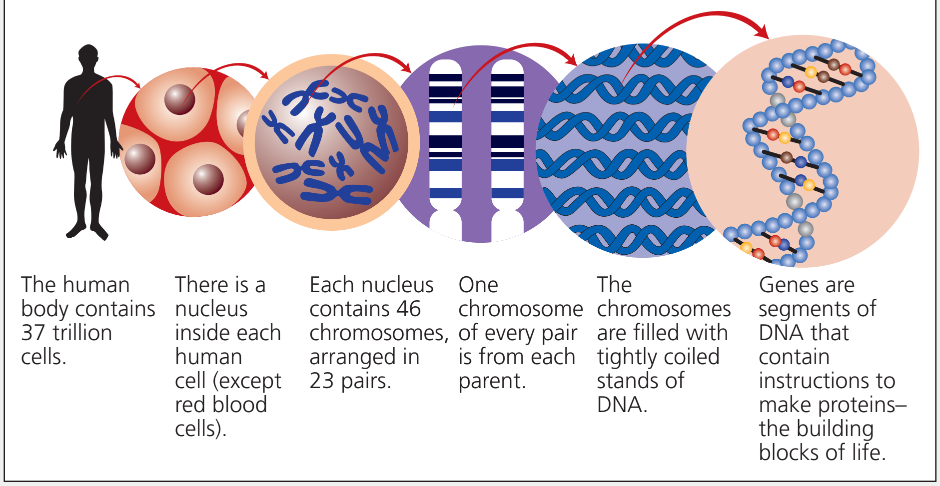
Genes are located on and transmitted by **chromosomes**, which are thread-like structures found in every cell of the body, with the exception of red blood cells. All chromosomes contain strands of the molecule **deoxyribonucleic acid**, commonly known as DNA, which in turn contains thousands of different genes, located at fixed positions. Figure 2-14 depicts our genetic building blocks, breaking down the human body from its 37 trillion cells to the genes that provide them with instructions on protein production.

One of the most surprising early findings of the Human Genome Project is that humans have only about 30,000 genes, not many more than a worm (18,000) and less than a rice plant (40,000). This discovery highlights the fact that human complexity is not solely due to the number of genes we possess but is largely determined by the many different ways that genes interact with one another (Drayna, 2006; Johnston & Edwards, 2002). By understanding how genes function and interact with one another, scientists may soon be able to identify genes that cause cancer, diabetes, and heart disease.

When comparing the genes of different species, counting the sheer number of total genes is less important than determining how many genes the species share. This is because the structural similarity of DNA between species provides scientists with important clues concerning how closely related the species are on the evolutionary tree. For example, humans and chimpanzees share 98% of the same DNA structure, humans and gorillas share a bit less than 98%, and humans' and monkeys' DNA similarity is only about 90%. Coupled with the fossil record studies of these species, the DNA evidence indicates that monkeys diverged from humans much earlier in their evolutionary past than did chimps and gorillas.

Humans are unusual among primates because we have much less genetic variability within our species than do chimpanzees, gorillas, and other apes (Gagneux et al., 1999). These findings strongly suggest that not long ago in human evolution our ancestors experienced a severe reduction in their population due to disease, famine, or some other disaster. The best estimates are that this brush

FIGURE 2-14
Genetic Building Blocks
Chromosomes are contained in the nucleus of each of the cells in our bodies. Each chromosome contains tightly coiled strands of DNA. Genes are DNA segments that are the biochemical units of inheritance.



with extinction occurred about 70,000 years ago, with the number of early humans shrinking to as low as 2,000 (Schmid, 2008). The effective result of this massive population loss was that a large part of our within-species genetic variability was lost. Genetic testing of humans around the world indicates that the great majority of the existing overall genetic variation in humans is represented by individual diversity within populations, not across populations (Fish, 2002). This finding has important implications in understanding the concept of "race" as a distinguishing feature in the human population, a topic that we will examine in Section 2.4d.

All humans possess 99.9% of the same genes. This is why we have the capacity to do many of the same things, such as walking, talking, and engaging in abstract thought (Plomin & Crabbe, 2000). Despite this genetic similarity, there also is a great deal of genetic variation across individuals in that final 0.1% of genetic material. As you have already discovered in the Chapter 1, Section 1.2e discussion of the evolutionary process, the genetic makeup of organisms not only determines their ability to survive in their environment but also influences their ability to reproduce and pass their genes on to the next generation.

How did you inherit your particular genotype? Well, let's return to our discussion of chromosomes. Chromosomes come in pairs. Each sperm cell of a human male and egg cell of a human female contains 23 chromosomes. Upon the union of your father's sperm and your mother's egg at conception, all body cells that developed from this new cell (called the *zygote*) contained 46 chromosomes, or 23 pairs. Each of these body cells contained your genetic blueprint, or genotype, with half the genetic material coming from each parent. However, the selection of which of each pair was given to you was random. Among the 23 chromosomal pairs, one pair, known as the **sex chromosomes**, determined your sex. You inherited an X chromosome from your mother and either an X or a Y chromosome from your father. XX pairings result in the embryo developing female physical characteristics, whereas XY pairings lead to male physical characteristics. Because it is only the father's sex chromosome that varies, it is your father's genetic contribution that determined your sex.

Sex chromosomes
One of the 23 pairs of chromosomes, specifically the pair that determines whether an individual is male or female

Just as you share 50% of the same genes with each of your parents, you also share that same percentage with your brothers and sisters. This is true even for **fraternal twins** (also known as *dizygotic twins*), who develop in the womb from the union of two separate sperms and eggs. The exception to this rule, of course, is **identical twins** (also called *monozygotic twins*), who develop from the union of the same egg and sperm. Identical twins share exactly the same genotype. Although identical twins are identical genetically, they may not express these identical genes in identical ways. That is, their phenotype may not be identical. Environmental factors, such as stress and nutrition, can actually cause certain genes to become activated or deactivated, resulting in even identical twins not having the same *active* genetic makeup (Lytton & Gallagher, 2002). Thus, the interaction of genotype (our underlying genetic composition) with the environment can produce changes in our phenotype (our visible and measurable traits).

Fraternal twins
Twins who develop from the union of two separate sperm and eggs; also known as *dizygotic twins*

Identical twins
Twins who develop from the union of the same egg and sperm, and thus share exactly the same genotype; also known as *monozygotic twins*

2.4b Both Heredity and Environment Can Influence Physical and Behavioral Traits.

The field of **behavior genetics** studies how the genotype and the environment of an organism influence its behavior (Vukasovic & Bratko, 2015). One example of how heredity and environment can influence phenotype is obesity, a condition afflicting many adults (Thorpe & Day, 2008). In understanding obesity, overeating is certainly an important cause of weight gain, but some people can consume many calories without gaining a pound (Rodin, 1986). Research suggests that obesity is partly related to

Behavior genetics
The study of how the genotype and the environment of an organism influence its behavior

the number and size of fat cells in the body, with the number being determined by our genes and the size being determined by our eating habits (Grinker, 1982). When people overeat beyond their bodily needs, the number of fat cells does not increase, but the size of the fat cells does.

Adoption and twin studies indicate that heredity is an important factor in determining both how many fat cells you have and how efficiently you utilize your intake of calories (Bouchard et al., 1990; Stunkard et al., 1990). Some people are born with an overabundance of fat cells, while others are born with a tendency to burn excess calories by turning them into muscle tissue rather than fat. Thus, regardless of whether they are raised together or apart, identical twins—whose genes are the same—have virtually the same weight. In contrast, the weights of fraternal twins—whose genes are different—can differ greatly. In addition, the body size of children adopted from birth more closely resembles the body size of their biological parents, who each provide 50% of the children's genes, than that of their adoptive parents. This example illustrates that both heredity and environment can influence a specific phenotypic characteristic, namely, body size. The nature of the gene-environment interaction is still not clearly understood. What is clear, however, is that neither genes nor environment alone can account for how we live our lives.

2.4c *Molecular Genetics Seeks to Identify Specific Genes That Influence Behavior.*

Molecular genetics
The subdiscipline in biology that studies the molecular structure and function of genes to determine how they influence behavior

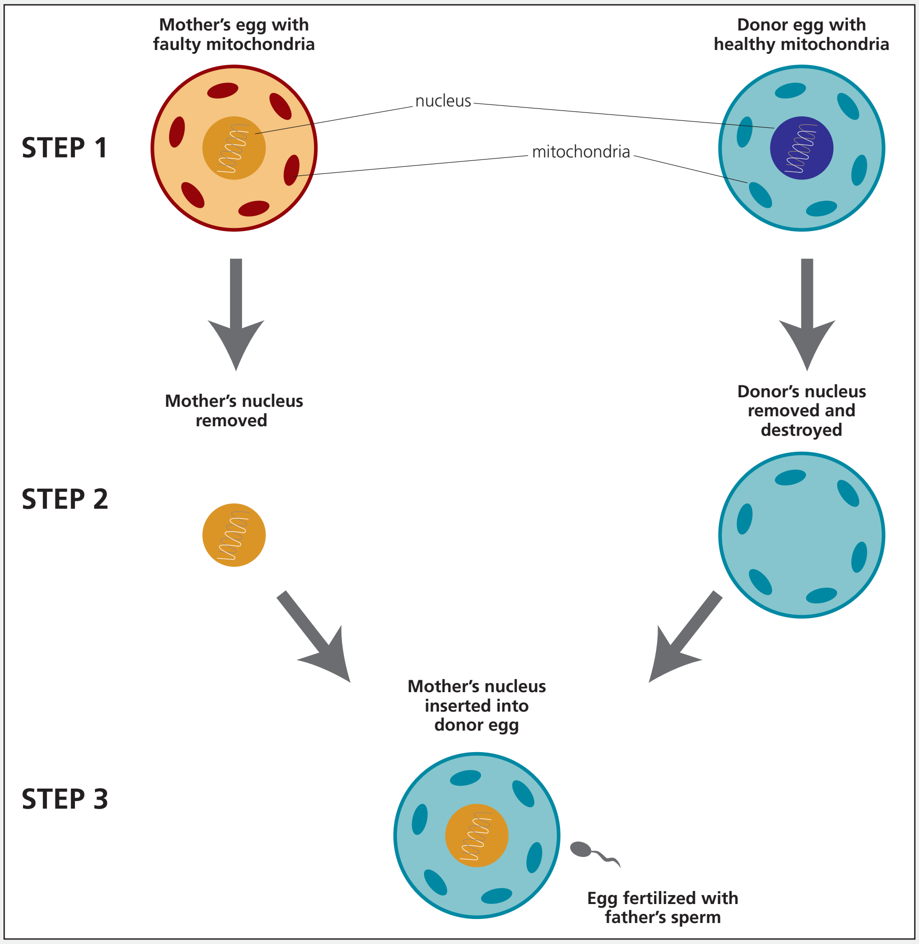
While behavior genetics has focused on determining the degree to which genes influence behavior, a relatively new area in the biological sciences is **molecular genetics**, which seeks to identify the *specific genes* that influence behavior. One hope is that discoveries in molecular genetics will provide cures for genetically influenced disorders. Many diseases are caused by *mutations,* which are chemical changes in the DNA sequence of a gene (Benet-Pagès et al., 2005; Perry & Faraone, 2015).

Most research in molecular genetics has been conducted using nonhuman genomes, such as those of the fruit fly, the roundworm, and the laboratory mouse (Meikle et al., 2005). These animals, with simpler genetic construction, provide useful models for developing and testing the procedures needed for studying the much more complex human genome. The results of this work have already yielded valuable knowledge that has helped geneticists identify single genes associated with a number of diseases and age-related disorders, such as cystic fibrosis, colon cancer, and hearing loss. Research is also under way to discover the mechanisms for diseases caused by several genes or by single genes interacting with environmental factors. By identifying the genes and their proteins associated with disease susceptibility and the aging process, scientists will be better able to design more effective therapies and preventive measures. For example, researchers have identified a gene that prevents the regeneration of inner ear cells critical to hearing (Sage et al., 2005). If geneticists discover how to "turn off" this gene, they can potentially reverse hearing loss among the elderly. Investigators are also attempting to identify genes that play a role in various psychological disorders, learning disabilities, and other health problems such as diabetes and alcoholism.

Ethical Concerns Raised by Genetic Testing

Genetic tests can now determine the risk that people might have for specific diseases. In some cases, a medical procedure might even be able to prevent the transfer of genetic mutations from a mother to a child. For example, mitochondrial diseases, which are inherited solely from the mother's genes, affect at least 1 in 3,000 children (Mitalipov & Wolf, 2015). (Mitochondria are small structures within almost every cell of the body that use nutrients and oxygen to produce about 90% of the body's chemical energy; if the mitochondria aren't functioning properly, bodily organs that need a lot of energy to function—such as those in the brain, heart, and skeletal muscle—are severely impaired.) In Great Britain, a woman carrying a gene for this kind of mitochondrial condition can take steps when planning her pregnancy to avoid passing those genes on to her child. The promising new treatment involves replacing the defective mitochondria in a woman's unfertilized egg cell with a donor woman's healthy mitochondria; then, that newly repaired egg is fertilized with male sperm (see Figure 2-15). Although such mitochondrial replacement surgery is now being conducted in Great Britain, it is not available in the United States primarily due to ethical concerns. One of the issues is that the resulting children have a genetic connection to three people: mother, father and donor. However, the 0.1% genetic contribution from the donor is extremely small compared to the roughly 50% contribution by both the mother and the father.

FIGURE 2-15 **Mitochondrial Replacement Surgery**



Beyond pre-pregnancy testing, the most common test is conducted on newborn infants to screen them for abnormal or missing gene products (Patenaude, 2005). Four million newborns undergo such testing each year in the United States. Genetic testing of fetuses in the mother's womb is also increasingly common, especially when there is a risk of bearing a child with genes associated with intellectual disability or severe birth defects. Do you perceive any dangers that might result from such prenatal screening?

One danger is that these tests can easily determine the sex of a fetus. Parents in such countries as China and India—which place a much higher value on male babies than female babies—have used prenatal genetic testing to abort pregnancies involving undesirable female fetuses. Estimates are that millions of such sex-selective abortions have already been carried out, which will probably lead to future male-female population imbalances in these countries (Das Gupta & Mari Bhat, 1997).

Adult genetic testing also raises serious ethical issues. For example, if testing reveals that an individual has an inherited risk for colon cancer, early-onset Alzheimer's disease, or a specific psychological disorder, should family members be informed that they might be at risk? This question has generated concerns within the medical community regarding the conflict between the physician's ethical obligations to respect the privacy of genetic information versus the potential liabilities resulting from the physician's failure to notify at-risk relatives.

Another related concern involves the dangers in releasing genetic information to people and organizations outside the family of those tested. For example, if a family has an inherited gene that makes them highly likely to develop a specific disease, this information could affect their future employability and insurability if it became public knowledge. That is, such results could be misused by employers and insurers, discriminating between those identified as low risk and high risk (Raithatha & Smith, 2004). To prevent such possibilities, in 2008, the United States Congress passed the Genetic Information Nondiscrimination Act to protect people from discrimination by health insurance companies and employers.

The Ethics of Cloning

Cloning
The process of making a genetically identical organism through nonsexual means

Ethical concerns have also been raised about **cloning**, which is the process of making a genetically identical organism through nonsexual means. Actually, cloning refers to three very different procedures that have very different goals.

Embryo cloning is a medical technique that duplicates the process that nature uses to produce twins or triplets. One or more cells are removed from a fertilized embryo and encouraged to develop into duplicate embryos. This procedure has been performed for many years on different animal species, but only very limited experimentation has been done on humans.

Adult DNA cloning, or *reproductive cloning,* is a technique used to produce a duplicate of an existing animal. To date, this technique has been used to clone such mammals as mice, sheep, cats, cows, and horses. In reproductive cloning, the DNA from a female egg is removed and replaced with the DNA from a cell removed from an adult animal. Then the fertilized egg is implanted in a womb and allowed to develop into a new animal. Animal studies reveal that such cloning can produce severe genetic defects. For this reason alone, there are very serious ethical concerns about human cloning. Many countries have specifically outlawed this procedure.

Finally, *therapeutic cloning,* or *biomedical cloning,* is a procedure in which *stem cells*—which are immature cells from which all mature cells develop—are removed from a pre-embryo so that tissue or a whole organ can be produced. The goal of therapeutic cloning is to produce a healthy copy of a sick person's tissue or organ, and it is vastly superior to relying on organ transplants from other people (Civin et al., 2005). Although the ethical issues surrounding the use of stem cells are not as readily apparent as those involving human cloning, some people argue that embryonic stem cells represent a human life and that this life is destroyed in therapeutic cloning (Tsai, 2005). This is an ongoing debate that brings up the question of when life begins.

As you see, unlocking the mysteries of the human genome carries both great rewards and risks, as well as mind-boggling ethical concerns. In the coming years, the advances in molecular genetics and the controversies surrounding how to use this new knowledge will undoubtedly have a significant impact on our lives. Stay tuned.

2.4d *Controversies Surround Genetic Explanations of Certain Sex and Race Differences.*

For more than a century, there has been an ongoing debate in psychology and other sciences concerning whether certain cognitive and behavioral differences found between women and men, as well as those between different racial groups (see Chapter 8, Section 8.4c), are caused by genetic factors or life experiences (the old *nature-nurture debate*). In this text, we will examine the research surrounding these group-based comparisons (for example, see Section 2.3f in this chapter). To help you better understand the complexities in the various debates concerning genetic determinants of group differences in thought and action, I want to introduce you to a few important concepts and issues.

What Is the Difference Between Sex and Gender?

The terms *sex* and *gender* are often used interchangeably. However, to better understand what it means to be female and male, a growing number of psychologists believe that distinctions should be made between these two concepts (Lippa, 2005). In this text, **sex** refers to the biological status of being female or male, and **gender** refers to the meanings that societies and individuals attach to being female and male. Put simply, sex is a matter of genetic construction, and gender is a matter of cultural construction (Yoder, 1999). Sex is something we *are,* whereas gender is something we *do* with the help and encouragement of others.

Sex
The biological state of being female or male

Gender
The meanings that societies and individuals attach to being female and male

People are often confused about the distinction between sex and gender because the two concepts are generally thought of as going together—that is, female equals feminine, and male equals masculine. Yet behaviors or interests considered masculine in one culture may be defined as feminine in others (Zinn et al., 2000). For instance, in certain North African societies, decorating and beautifying the face and body is a sign of masculinity, not femininity. Similarly, within cultures, beliefs about gender transform over time. For instance, in contemporary North American culture, it is now acceptable—even encouraged—for girls to participate in sports that were previously designated only for boys. Among adults, women are now much more actively involved in careers outside the household (a traditionally masculine domain), and men are more involved in child care (a traditionally feminine domain) than in previous generations. Gender is not fixed—it is constantly changing and being redefined.

Because sex is biologically based and gender is culturally based, when research finds that men and women actually behave differently, we often ask whether this difference is due to sex (biology) or to gender (culture). This is not an idle question. If someone labels the behavior in question a *sex difference,* the implication is that the cause of the difference is rooted in human biology rather than in social or cultural factors. In contrast, when people talk about *gender differences,* the implication is that these differences do not stem from biology but develop, instead, in the course of socialization as boys and girls learn about appropriate gender-based attitudes, roles, and behaviors.

As discussed in Section 2.4a, men and women differ biologically in a number of ways. The most basic sex difference is that males carry the chromosomal pattern XY, and females carry the pattern XX. This important difference at the chromosomal level produces differences in female and male anatomy and physical appearance. For instance, a newborn male has a penis and testicles, whereas a newborn female has a vagina and ovaries. At puberty, a male develops a prominent Adam's apple, while a female's breasts enlarge. Although the changes associated with puberty occur well after birth, no one would seriously argue that boys have been taught how to grow an Adam's apple or that girls learn how to grow breasts. These particular differences are due to biological factors—that is, they are sex differences and are not due to cultural experience.

Beyond these identifiable biological differences in chromosome pattern and anatomy, it is extremely difficult, if not impossible, to currently conclude that differences in the way women and men think, feel, and act are clearly due to sex or gender. As already discussed, psychologists with a biological or evolutionary orientation emphasize biological factors in explaining such differences, whereas psychologists with a sociocultural orientation weigh in with cultural explanations. Yet the point that many psychologists often make when the issue of genetics is discussed is that even in those instances when genetics influences behavioral differences between men and women, these biologically based differences can be greatly increased or decreased due to social forces.

How great are the differences between women and men in their psychological functioning? This is an issue we will address throughout this text. As a preliminary answer, I can tell you that research conducted over the past 30 years indicates there are many more similarities than differences. Across a wide variety of cognitive skills, psychological motives, and social behaviors, men and women do not differ from one another. Thus, despite cultural stereotypes to the contrary, women and men are remarkably alike in much of their psychological functioning. Reflecting these scientific findings, in this text I do not use the misleading term *opposite sex* when comparing one sex with the other but instead use the more appropriate term *other sex.*

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These three individuals identify themselves as Asian, black, and Caucasian, respectively. Genetic studies reveal that these three people may be more similar to one another genetically than to many members of their own "races."

Does Race Tell Us Anything Useful about How People Differ Genetically?

The *Oxford English Dictionary* defines race as "a group of persons connected by a common descent; a subdivision of species." Consistent with this definition, many people believe that Caucasians, Africans, Asians, and Hispanics make up biologically distinct races. Often underlying this common belief in race categorization is the assumption that greater genetic similarity exists among the members of each race than between the races. However, are two people categorized as black more genetically similar than a black person and an Asian person, or a Caucasian person and a Hispanic person?

Analysis of fossilized skull fragments found in Ethiopia, a country in eastern Africa, has led scientists to estimate that the very first modern-looking human beings emerged about 195,000 years ago (McDougall et al., 2005). This research, coupled with fossil evidence from other scientists and genetic analysis of contemporary human populations throughout the world, strongly suggests that it was these first modern *Homo sapiens* in eastern Africa who eventually populated the rest of the planet (Stringer, 2003). Thus, all humans are related, and our common ancestors came from Africa. What then is the biological significance of race?

When early humans migrated to different areas of the planet, they often encountered physical environments vastly different from those in eastern Africa. Over the course of thousands of generations, human populations that were geographically separated from one another gradually began to differ in their physical appearance due to the effects of natural selection. For example, the dark skin of early humans in Africa offered protection against the intense ultraviolet light in the region. Too much ultraviolet light penetrating the skin not only causes skin cancer but also, more importantly, breaks down folic acid in the body, which can cause anemia and deadly birth defects. Thus, in this region of the world—and in other areas close to the equator—darker-skinned humans were better adapted to their surroundings and more likely to produce healthy offspring than those with light skin. However, those humans who had migrated to northern Europe and northern North America lived in parts of the world with much less sunlight. In these new surroundings, they needed much lighter skin in order to take in more ultraviolet light for the production of vitamin D, which is essential for absorbing calcium to build strong bones and teeth. Here, light skin provided an advantage over dark skin (Jablonski, 1998). Lighter-skinned humans produced more vitamin D than those with darker skin, and they were ultimately more successful in surviving and reproducing.

Also due to natural selection, humans who migrated to very cold climates gradually became shorter and more round because this body type lost less heat and thus was better adapted to the frigid environment. In very hot climates, taller, thinner body frames were advantageous because they dispersed heat more effectively so that the body stayed cooler. Large, circular nostrils and broad noses also helped disperse extra heat among people living in hot climates, while smaller, noncircular nostrils and more projecting noses helped warm the incoming air for people living in cold climates.

The superficial physical differences resulting from this migration of early humans to different world regions are what many of us now rely on when designating a person's race. Yet almost all anthropologists and many geneticists agree that the concept of race is purely a social construct and has very little to do with who is actually genetically similar to whom (A. Smedley & B. Smedley, 2005). For example, DNA research demonstrates that genetically, all humans—regardless of skin color, facial features, and other surface distinctions—are basically identical. Any person's race accounts for 0.25% of her or his genetic makeup (Ossorio & Duster, 2005). The genetic differences that account for these evolutionary-based adaptations in physical appearance probably involve only a few hundred of the billions of nucleotides in a person's DNA.

Would it surprise you to learn that greater genetic diversity exists among the different human populations in Africa than among the different populations in Asia, Europe, and North and South America? Would you also be surprised to learn that non-African populations are more genetically similar to many African populations than the African populations are to each other? This means that if you identify yourself as African American, it is entirely possible that you are genetically more similar to a randomly chosen person who is white, Hispanic, or Asian than you are to another African American who is not a direct blood relative. This is because the human species has spent most of its 195,000-year existence in Africa, and as mentioned in Chapter 8, Section 8.1a, many human populations in Africa have been physically separated from each other longer than they have been separated from the human populations in other parts of the world. Thus, more genetic differences exist between the indigenous peoples of Africa than between them and non-Africans.

Given this scientific fact, what exactly does the race of a person tell us about his or her genetic makeup? As previously mentioned, it tells us very little: 99.76% of our genetic makeup has nothing to do with race. However, does the less than 0.25% genetic difference account for any differences other than the superficial physical characteristics we use in making racial classifications in the first place? This question is currently being studied and intensely discussed in the scientific community. In the meantime, we can cast aside the *Oxford English Dictionary* definition of race. What we call "races" are not biologically distinct from one another; thus, they are definitely not subspecies in the human population. Biologically, there is only one race: the human race.

- Genes are the biochemical units of inheritance located on and transmitted by chromosomes, which are thread-like structures found in human body cells containing strands of DNA.
- The field of behavior genetics studies how an organism's genetic makeup and environment influence its behavior.
- The field of molecular genetics studies how specific genes influence behavior, and the application of this knowledge has raised many ethical concerns.
- When differences in thinking and action are found between women and men or between people from different racial groups, genetically based researchers and socioculturally based researchers offer very different explanations of these differences.

PSYCHOLOGICAL applications

If You Are Left-Handed, Is Your Brain Organized Differently from That of a Right-Hander?

Are you a "lefty" or a "righty?" Actually, people rarely use the same hand for all manual activities. Instead, one hand tends to be preferred for more tasks than the other. One of the most commonly employed questionnaires to assess a person's direction and degree of handedness is the Edinburgh Handedness Inventory (Oldfield, 1971), reproduced in Table 2-4. Before reading further, complete this questionnaire to determine your laterality quotient.

If you are predominantly left-handed, you are among the 7%–8% minority of people who live in a right-handed world. Put simply, our world is designed for right-handers. Indeed, powerful cultural pressures are often brought to bear on many natural left-handers to use their right hands. For example, many tools, materials, and equipment—such as power saws, can openers, fishing reels, bowling balls, scissors, and school desks—are designed for right-handed people.

TABLE 2-4 What Is Your Direction and Degree of Handedness?

Instructions: Consider each of the 10 activities listed below and indicate which hand you prefer using when engaged in each of these different tasks by placing an "x" in either the "left" or the "right" box.

	Left	Right
1. Writing	☐	☐
2. Drawing	☐	☐
3. Throwing	☐	☐
4. Using scissors	☐	☐
5. Using a toothbrush (brushing your teeth)	☐	☐
6. Using a knife (without a fork)	☐	☐
7. Using a spoon	☐	☐
8. Using a broom (upper hand)	☐	☐
9. Striking a match (hand holding the match)	☐	☐
10. Opening a box (lid)	☐	☐

Scoring: Once hand preferences for all 10 activities have been identified, your laterality quotient is found by subtracting the number of left x's from right x's and then multiplying by 10. The quotient's range extends from +100 for extreme right-handedness to –100 for extreme left-handedness, with 0 representing ambidextrous activity (that is, equal use of both hands). About 50% of right-handers who completed this questionnaire had laterality quotients greater than 80, while 50% of left-handers had quotients less than –76. What these findings indicate is that (1) people tend to exhibit a preference for one hand over the other rather than being ambidextrous, and (2) right-handers are more strongly hand dominant than left-handers.

Source: Reprinted from Neuropsychologia, 9, R. C. Oldfield, "The assessment and analysis of handedness: The Edinburgh Inventory", pp. 97–114, Copyright 1971, with permission from Elsevier.

continues

PSYCHOLOGICAL applications

If You Are Left-Handed, Is Your Brain Organized Differently from That of a Right-Hander? *(Continued)*

Shutterstock

Most tools in our culture are designed for right-handed people, often forcing left-handers to adapt and use their nondominant hand for most tasks. Many left-handers initially learn a new activity, such as golf, with right-handed tools.

There is a great deal of evidence that handedness is substantially determined by our biology. For example, when the human figures depicted in more than 1,000 drawings, paintings, and engravings spanning thousands of years are analyzed regarding their handedness, 90% are right-handers (Coren, 1989). Likewise, ultrasound studies of fetal thumb-sucking indicate the same percentage of left-right hand preferences, further suggesting that handedness may be an inherited trait (Hepper et al., 1990). Yet, one problem with a simple genetic explanation of handedness is that 54% of the children of two left-handed parents are right-handed. What we know about genetics would lead us to expect more left-handed children in this case. Even more troublesome is the fact that identical twins are no more likely to prefer the same hand than are fraternal twins (Sicotte et al., 1999).

Faced with these problems, some genetic theorists have proposed that handedness is related to the lateralization of the brain. They argue that although there may be no specific gene for left- or right-handedness, there is a dominant gene responsible for the development of speech in the left hemisphere, and it is this gene that also predisposes people toward right-handedness (Annett, 1985). Support for this view comes from studies indicating that although over 95% of right-handers have speech localized to the left hemisphere, only about 65% of left-handers show this same pattern (Loring et al., 1990; Springer & Deutsch, 1998). The remaining 35% of left-handers tend to process speech using either the right hemisphere or both hemispheres. These findings suggest that, for left-handers, the two hemispheres are less specialized than they are for right-handers. Due to this difference, left-handers experience less language loss following damage to either hemisphere and recover more quickly than right-handers because their healthy hemisphere is better equipped to assume the speech functions (Provins, 1997).

Another explanation for the development of left-handedness is that prenatal hormonal imbalances or birth stress causes neurological disturbances in the left hemisphere, which in turn causes the right hemisphere to become dominant, thus causing them to favor their left hands (Coren & Halpern, 1991). There is also evidence that left-handers are more likely to be gifted and creative individuals (Benbow & Stanley, 1981). Indeed, the incidence of left-handedness is much higher in artists than in the population as a whole (Mebert & Michel, 1980). Although the meaning of these findings is still unclear, it certainly poses problems for any hypothesis that left-handedness is caused by some sort of cognitive defect.