

BIOLOGICAL FOUNDATIONS  
OF BEHAVIOR

3

# 3

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**FIGURE 3.1** The brain damage suffered by Phineas Gage seemed to change him into a new person.

The brain is the last and grandest biological frontier, the most complex thing we have yet discovered in our universe. It contains hundreds of billions of cells interlinked through trillions of connections. The brain boggles the mind.

—James Watson

**T**he year was 1848. As the Vermont winter approached, a railroad construction crew hurried to complete its work on a new track. They could not know that they were to witness one of the most celebrated incidents in the annals of neuroscience.

As a blasting crew prepared its charges, the dynamite accidentally exploded. A spike more than 3 feet long and weighing 13 pounds was propelled through the face and head of Phineas Gage, a 25-year-old foreman. The spike entered through the left cheek, passed through the brain, and emerged through the top of the skull (Figure 3.1). Dr. J. M. Harlow, who treated Gage, described the incident:

The patient was thrown upon his back by the explosion, and gave a few convulsive motions of the extremities, but spoke in a few minutes. He . . . seemed perfectly conscious, but was becoming exhausted from the hemorrhage, . . . the blood pouring from the top of his head. . . . He bore his sufferings with firmness, and directed my attention to the hole in his cheek, saying, “the iron entered there and passed through my head.” (Harlow, 1868, pp. 330–332)

Miraculously, Gage survived. Or did he?

His physical health is good, and I am inclined to say that he has recovered. Has no pain in his head, but says it has a queer feeling that he is not able to describe. . . . His contractors, who regarded him as the most efficient and capable foreman in their employ previous to his injury, considered the change in his mind so marked that they could not give him his place again. The equilibrium or balance, so to speak, between his intellectual faculties and animal propensities, seems to have been destroyed. He is fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires . . . devising many plans of future operations, which are no sooner arranged than they are abandoned in turn for others. . . . His mind is radically changed, so decidedly that his friends and acquaintances say that he is “no longer Gage.” (Harlow, 1868, pp. 339–340)

**A** young woman appeared in the emergency room of Baltimore City Hospital three days before her 23rd birthday, pleading for help. The story she told was a strange one indeed.

She and two other girls had been delivered by the same midwife in Georgia’s Okefenokee Swamp on a Friday the 13th. The midwife, a member of a voodoo cult, had, for reasons known only to herself, placed a curse on all three babies. She proclaimed that one would die before her 16th birthday, another before her 21st birthday, and the third (the patient) before her 23rd birthday.

True to the midwife’s prediction, the girl who was to die before her 16th birthday was killed in an auto accident when she was 15 years old. The second young woman was killed by a stray bullet during a shooting in a night club where she was celebrating her 21st birthday. Now, the third woman waited in terror for her own death.

The emergency room psychiatrist reassured the terrified woman that no harm would come to her in the hospital and reluctantly admitted her for observation. Despite the doctor's reassurance, the woman remained convinced that she was doomed. The next morning, two days before her 23rd birthday, she was found dead in her hospital bed. Doctors were unable to determine a physical cause for her death (Seligman, 1975)

As the tragic accident to Phineas Gage and the young woman's sudden death show us, biological and psychological processes are intimately related. In one case, physical damage to Gage's brain changed his thinking and behavior so radically that a psychologically different person emerged. The death of the young woman suggests the possibility that her psychological belief that she was doomed brought about biological changes so profound that they killed her.

In this chapter we explore three interrelated biological systems. The nervous system is the master control network of nerve cells whose activities underlie your every thought, feeling, and behavior. The endocrine system of glands influences many behaviors through the activities of hormones. The immune system, the body's defense network, is the site of some of the most profound recent discoveries of so-called psychological-biological interactions. We also examine genetic processes that help determine who you are, how you behave, and what you are capable of becoming.

## ► THE NEURAL BASES OF BEHAVIOR

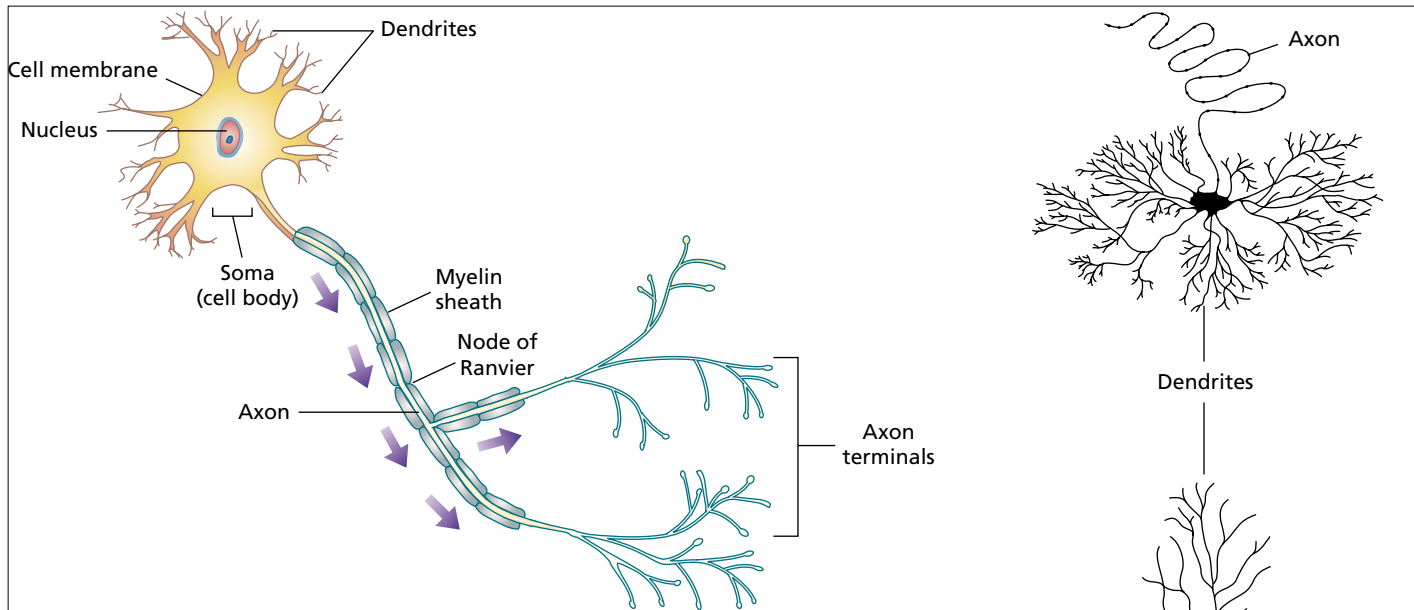
The brain is a grapefruit-size mass of tissue that feels like jelly and looks like a grayish gnarled walnut. One of the true marvels of nature, it has been termed "our three-pound universe" (Hooper & Teresi, 1986). To understand how the brain controls our experience and behavior, we must first understand how its individual cells function and how they communicate with one another.

### Neurons

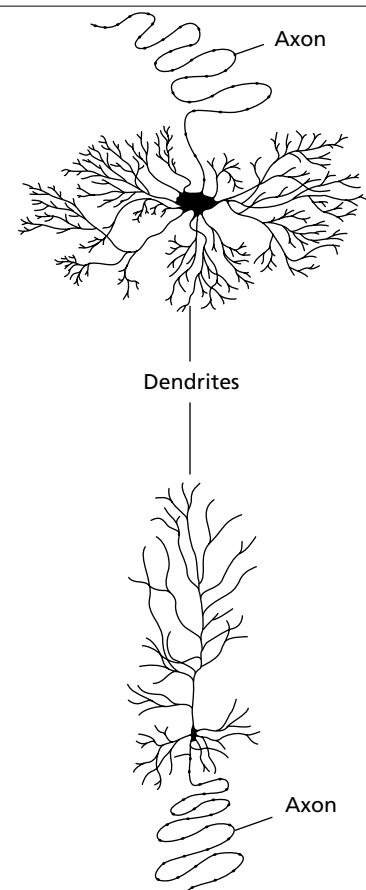
Specialized cells called **neurons** are the basic building blocks of the nervous system. These nerve cells are linked together in circuits, not unlike the electrical circuits in a computer. At birth your brain contained about 100 billion neurons (Bloom, 2000; Kolb & Whishaw, 1989). To put this number in perspective, if each neuron were an inch long and they were placed end to end, the resulting chain would circle the earth more than 63 times. It is fortunate that humans have this many neurons, for it is estimated that through the normal process of cell death that accompanies aging, about 10,000 of them are lost each day of our lives (Filogamo, 1998).

Each neuron has three main parts: a cell body, dendrites, and an axon (Figure 3.2). The **cell body** contains the biochemical structures needed to keep the neuron alive, and its nucleus carries the genetic information that determines how the cell develops and functions. Emerging from the cell body are branchlike fibers called **dendrites** (from the Greek word meaning "tree"). These specialized receiving units are like antennas that collect messages from neighboring neurons and send them on to the cell body. There the incoming information is combined and processed. The many branches of the dendrites can receive input from 1,000 or more neighboring neurons. The surface of the cell body also has receptor areas that can be directly stimulated by other neurons. Extending from one side of the cell body is a single **axon**, which conducts electrical impulses away from the cell body to other neurons, muscles, or

- 1. Name and describe the functions of the three main parts of the neuron.



**FIGURE 3.2** Structural elements of a typical neuron. Stimulation received by the dendrites or soma (cell body) may trigger a nerve impulse, which travels down the axon to stimulate other neurons, muscles, or glands. Some axons have a fatty myelin sheath interrupted at intervals by the nodes of Ranvier. The myelin sheath helps increase the speed of nerve conduction.



**FIGURE 3.3** Neurons' structural characteristics can vary widely. Despite these differences, all neurons have only one cell body and one axon.

► 2. Which structural characteristics permit the many possible interconnections among neurons?

glands. The axon branches out at its end to form a number of *axon terminals*—as many as several hundred in some cases. Each axon terminal may connect with dendritic branches from numerous neurons, making it possible for a single neuron to pass messages to as many as 50,000 other neurons (Fain, 1999; Shepherd, 1997). Given the structure of the dendrites and axons, it is easy to see how there can be trillions of interconnections in the brain, making it capable of performing the complex psychological activities that are of interest to psychologists.

Neurons can vary greatly in size and shape (Figure 3.3). More than 200 different types of neurons have been viewed through electron microscopes (Nolte, 1998). A neuron with its cell body in your spinal cord may have an axon that extends several feet to one of your fingertips, equivalent in scale to a basketball attached to a cord 4 miles long; a neuron in your brain may be no more than a thousandth of an inch long. Regardless of their shape or size, neurons have been exquisitely sculpted by nature to perform their function of receiving, processing, and sending messages.

► 3. How do glial cells differ from neurons? What three functions do they have in the nervous system?

Neurons are supported in their functions by **glial cells**, (from the Greek word for *glue*). Glial cells do not send or receive nerve impulses, but they surround neurons and hold them in place. The glial cells also manufacture nutrient

chemicals that neurons need, and they absorb toxins and waste materials that might damage neurons. During prenatal brain development, as new neurons are being formed through cell division, glial cells send out long fibers that guide newly divided neurons to their targeted place in the brain (Filogamo, 1998). Within the nervous system, glial cells outnumber neurons about ten to one.

## Nerve Conduction: An Electrochemical Process

Neurons do two important things: They generate electricity, and they release chemicals. Nerve conduction is thus an electrochemical process. The electrical properties of neurons have been known for more than a century, but we have only recently begun to understand the chemical processes involved in neural activity. An understanding of how neurons generate electricity requires a brief excursion into chemistry.

Neurons function a bit like batteries in that their own chemical substances are a source of energy. Like other cells, the neuron is surrounded by a cell membrane. This membrane not only protects the inner structures but also operates as a kind of selective filter that allows certain particles in the body fluid around the cell to pass through while refusing passage to other substances.

Neurons are surrounded by a salty liquid environment. This environment's high concentration of sodium carries a positive atomic charge, that is, it has a high concentration of positively charged particles, or ions. Although the inside of the neuron has some positively charged potassium ions, it contains many other ions that carry a negative charge. As a result, the inside of the neuron is electrically negative in relation to the outside, producing an electrical *resting potential* of about  $-70$  millivolts, or  $-70/1,000$  of a volt, across the membrane. When in this resting state, the neuron is said to be *polarized*.

All cells in the body have a similar resting voltage. In some animals, specialized organs can combine this tiny voltage to generate very high voltages. For example, electric eels can generate 600 to 700 volts because their muscle tissue cell membranes are arranged so that the small individual cell voltages can be combined to produce one big jolt.

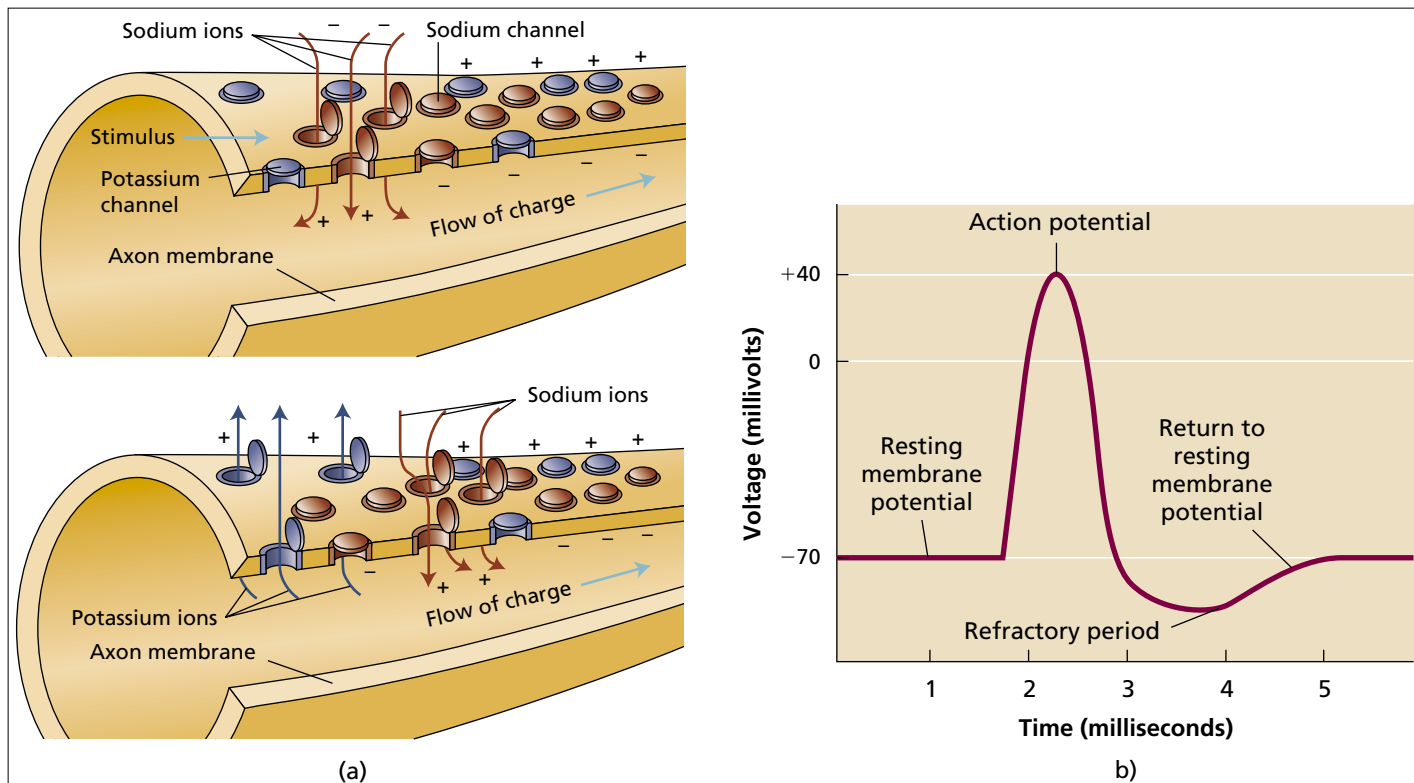
### The Action Potential

Neurons, like muscle cells, have a unique property among body cells: Sudden and extreme changes can occur in their resting potential voltage. An **action potential**, or nerve impulse, is a sudden reversal in the neuron's membrane voltage, during which the membrane voltage momentarily moves from  $-70$  millivolts (inside) to  $+40$  millivolts (Figure 3.4). This shift from negative toward positive voltage is called **depolarization**.

To understand how this depolarization process occurs, we might liken the release of an action potential to the firing of a gun. When the dendrites or the cell body of neurons are stimulated by axons from other neurons cells, small shifts occur in the cell membrane's electrical potential. These changes, called **graded potentials**, are proportional to the amount of incoming stimulation. If the graded potential is not strong enough, the neuron will be partially depolarized, but not enough to fire off an action potential. In this sense, graded potentials are like light pressure on the trigger of a gun that is not sufficient to activate its hammer. But if the graded potential is large enough to reach the **action potential threshold**, the required level of intensity needed to fire the neuron, the neuron discharges with an action potential. Unlike the graded potential, which varies in proportion to the intensity of stimulation, the action potential obeys the **all-or-none law**; it either occurs with maximum intensity or it does not occur at all. It is in this sense that triggering an action potential is like firing a gun. Unless enough energy is

► 4. What causes the resting potential of neurons? Under what condition is a neuron said to be in a state of polarization?

► 5. What chemical changes cause the process of depolarization that creates graded and action potentials? How do the latter differ from one another?



**FIGURE 3.4** The nerve impulse is a change in electrical potential resulting from depolarization of the cell membrane. The movement of a nerve impulse along an axon involves the opening of sodium ion channels that allow many positively charged sodium ions to flow into the cell (a) while a smaller number of potassium ions are pumped out (b). The net effect is a reversal of the membrane polarity from about  $-70$  millivolts (resting potential) to about  $+40$  millivolts (action potential). An instant later the sodium ion channels close and the sodium ions are pumped back out of the cell and the potassium ions flow back in, restoring the negative resting potential. After a brief refractory period, another impulse can follow.

applied to the trigger, the gun will not fire. But once it does fire, the velocity of the bullet bears no relation to how hard the trigger was pulled.

What causes the depolarization of the neuron membrane that may result in an action potential? Through a series of sophisticated experiments that won them the 1963 Nobel Prize, British scientists Alan Hodgkin and Andrew Huxley provided the answer. Recall that when the cell is resting, positively charged sodium ions in the salty liquid environment are kept outside the cell. When a neuron is stimulated, however, tiny protein structures on the cell membrane called **ion channels** are activated. Each channel can pump specific ions back and forth across the cell membrane. Sodium ion channels in the axon membrane open for an instant, and positively charged sodium ions flow into the interior of the cell, attracted by the negative electrical force inside the neuron. The influx of sodium ions causes the interior of the cell to become less negative than it was, creating a state of partial depolarization that may reach the action potential threshold (which is at about  $-.65$  millivolts in most neurons—a decrease of only  $.05$  millivolts from the resting potential). If that occurs, the inside of the neuron responds by becoming more positively charged than the outside for an instant, producing the state of complete depolarization that constitutes the action potential. In a reflex action to restore the resting polarity, the cell quickly closes the sodium ion channels and opens potassium channels through which positive potassium ions are pumped out of the cell. In this way, the cell's negatively charged resting potential is restored (Fain, 1999). In less than  $1/1,000$  of a second, the process is over at any

given point on the membrane, but the action potential has started a chain reaction “wave” that flows down the membrane as succeeding sodium gates open and the process is repeated. After a brief instant, the sodium ions inside the membrane are pumped back outside and the potassium ions flow back inside the membrane, restoring the normal ion distribution. Figure 3.4 shows this sequence of events.

The wavelike quality of the action potential as it moves down the length of the axon is not unlike the human “wave” that occurs in sports stadiums as fans in adjacent seats successively stand up, cheer, and raise their arms, then sit back down. Nobody actually changes position, but the visual (and auditory) effect is of a “wave” that moves around the stadium.

Immediately after an impulse passes any given point along the axon, there occurs a **refractory period**, a time period during which the membrane is not excitable and cannot discharge another action potential. This refractory period, lasting one or two thousandths of a second, limits the rate at which action potentials can be triggered in a neuron. In humans the limit seems to be about 300 nerve impulses per second (Roland, 1997).

If action potentials are always identical to one another, how does the nervous system tell the difference between, for example, a dim light and a bright light, or between a light touch and a hard rub? Such information is communicated in a number of ways. For example, a strong stimulus may increase the *rate* of firing of the individual neuron. Or it may increase the *number* of neurons that fire by stimulating additional neurons that fire only in response to high-intensity stimulation. In such ways, information is provided concerning the nature of the stimulus.

### *The Myelin Sheath*

Many axons that transmit information throughout the brain and spinal cord are covered by a tubelike **myelin sheath**, a fatty whitish insulation layer derived from glial cells during development. The myelin sheath is interrupted at regular intervals by the *nodes of Ranvier*, where the myelin is either extremely thin or absent). The nodes make the myelin sheath look a bit like sausages placed end to end (see Figure 3.2). In unmyelinated axons, the action potential travels down the axon length like a burning fuse. But in myelinated axons, electrical conduction can skip from node to node, and these “great leaps” from one gap to another account for high conduction speeds of more than 200 miles per hour. But even these high-speed fibers are 3 million times slower than the speed at which electricity courses through an electric wire. This is why your brain, though vastly more complex than any computer, cannot begin to match it in speed of operation.

The myelin sheath is most commonly found in the nervous systems of higher animals. In many nerve fibers, the myelin sheath is not completely formed until some time after birth. The increased efficiency of neural transmission that results is partly responsible for the gains that infants exhibit in muscular coordination as they grow older (Weyhenmeyer et al., 2000).

The tragic effects of damage to the myelin coating can be seen in people who suffer from *multiple sclerosis*. This progressive disease occurs when the person’s own immune system attacks the myelin sheath. Damage to the myelin sheath disrupts the delicate timing of nerve impulses, resulting in jerky, uncoordinated movements and, in the final stages, paralysis.

## Now Neurons Communicate: Synaptic Transmission

The nervous system operates as a giant communications network, and its action requires the transmission of nerve impulses from one neuron to another. Early in the history of brain research, scientists thought that the tip of the axon made physical contact with the dendrites or cell bodies of other neurons, passing electricity

- ▶ 6. What is the nature and importance of the myelin sheath? Which disorder results from inadequate myelination?

directly from one neuron to the next. With the advent of the electron microscope, however, researchers discovered that there is actually a **synapse**, a tiny gap between the axon terminal and the next neuron. This discovery raised new and perplexing questions: If neurons do not physically touch the other neurons to which they send signals, how does communication occur? If the action potential does not cross the synapse, what does? What carries the message?

### *Neurotransmitters*

We now know that in addition to generating electricity, neurons produce **neurotransmitters**, chemical substances that carry messages across the synapse to either excite other neurons or inhibit their firing. This process of chemical communication involves five steps: synthesis, storage, release, binding, and deactivation. In the *synthesis* stage, the chemical molecules are formed inside the neuron. The molecules are then *stored* in chambers called **synaptic vesicles** within the axon terminals. When an action potential comes down the axon, these vesicles move to the surface of the axon terminal and the molecules are *released* into the fluid-filled space between the axon of the sending (presynaptic) neuron and the membrane of the receiving (postsynaptic) neuron. The molecules cross the synaptic space and *bind* (attach themselves) to **receptor sites**—large protein molecules embedded in the receiving neuron's cell membrane. These receptor sites, which look a bit like lily pads when viewed through an electron microscope, have a specially shaped surface that fits a specific transmitter molecule much like a lock accommodates a single key (Figure 3.5).

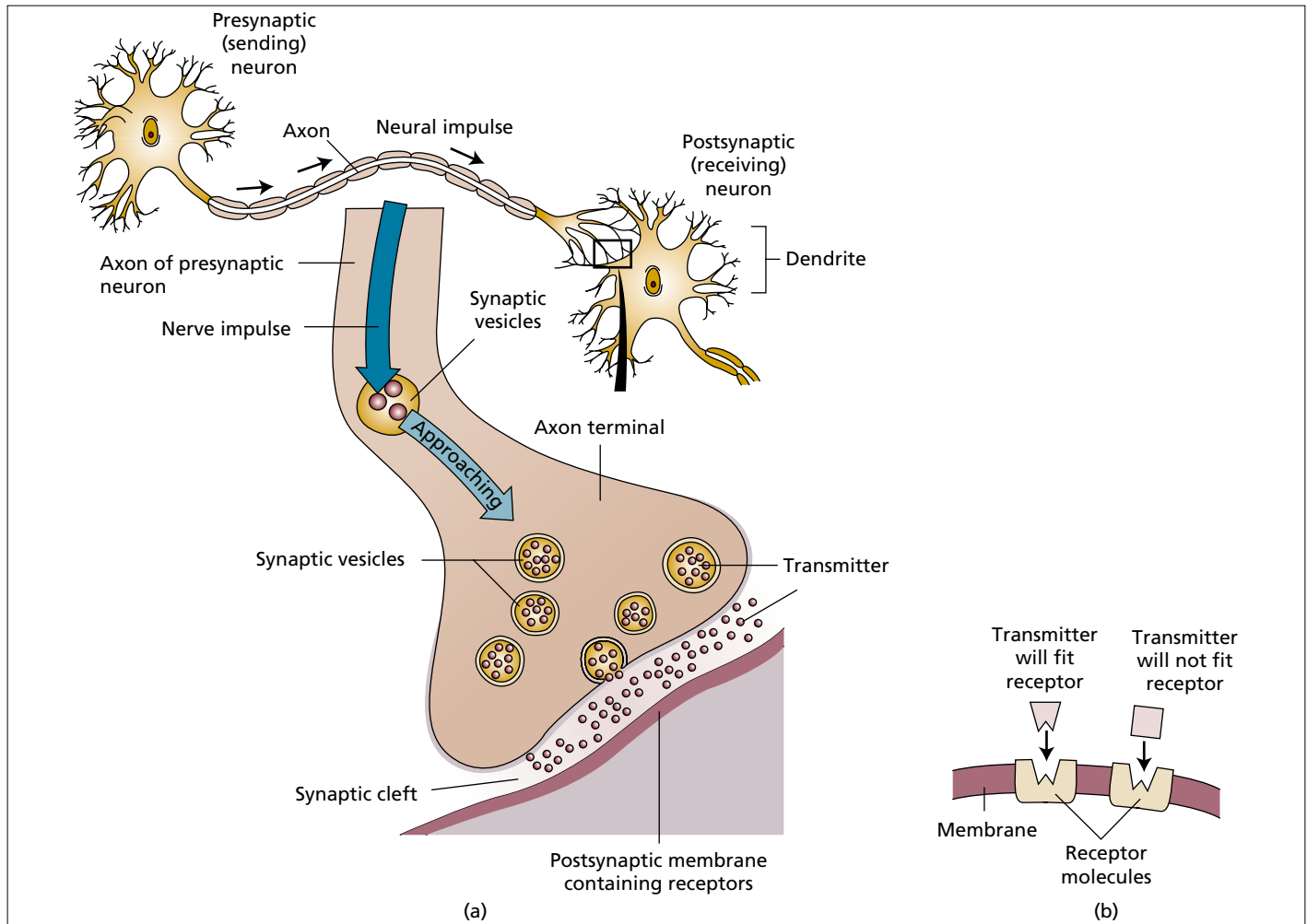
### *Excitation, Inhibition, and Deactivation*

The binding of transmitter molecule to the receptor site produces a chemical reaction that can have one of two effects on the postsynaptic neuron. In some cases, the reaction will depolarize (excite) the postsynaptic cell membrane by stimulating the inflow of sodium ions. Neurotransmitters that create depolarization are called *excitatory* transmitters. This stimulation, alone or in combination with activity at other excitatory synapses on the dendrites or cell body, may exceed the action potential threshold and cause the postsynaptic neuron to fire an action potential.

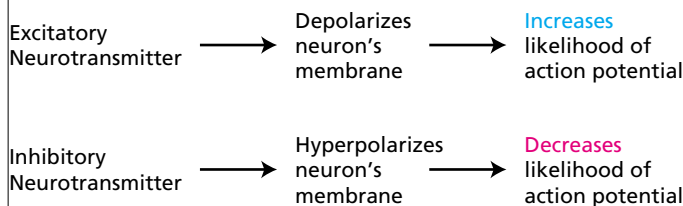
In other cases, the chemical reaction created by the docking of a neurotransmitter at its receptor site will *hyperpolarize* the postsynaptic membrane by stimulating ion channels that allow positively charged potassium ions to flow out of the neuron and thereby make its resting potential even more negative (e.g., increasing it from  $-70$  millivolts to  $-72$  millivolts). Hyperpolarization makes it more difficult for excitatory transmitters at other receptor sites to depolarize the neuron down to its action potential threshold of  $-.65$ , and transmitters that create hyperpolarization are thus *inhibitory* in their function (Figure 3.6). A given neurotransmitter can have an excitatory effect on some neurons and an inhibitory influence on others.

Every neuron is constantly bombarded with excitatory and inhibitory neurotransmitters from other neurons, and the interplay of these influences determines whether or not the cell fires an action potential. The action of an inhibitory transmitter from one presynaptic neuron may prevent the postsynaptic neuron from reaching the action potential threshold even if it is receiving excitatory stimulation from several other neurons at the same time. An exquisite balance between excitatory and inhibitory processes must be maintained if the nervous system is to function properly. The process of inhibition allows a fine-tuning of neural activity and prevents an uncoordinated discharge of the nervous system, as occurs in a seizure, when large numbers of neurons fire off action potentials in a runaway fashion.

► 7. How do neurotransmitters achieve the processes of excitation and inhibition of postsynaptic neurons?



**FIGURE 3.5** A synapse between two neurons. The action potential travels to the axon terminals, where it stimulates the secretion of transmitter molecules from the synaptic vesicles. These molecules travel across the synapse and bind to specially keyed receptor sites on the dendrite of the postsynaptic neuron (a). If the neurotransmitter has an excitatory effect on the neuron, the opening of sodium channels depolarizes the neuron and creates a graded or action potential. If the transmitter substance is inhibitory, it hyperpolarizes the neuron by causing potassium channels to open, releasing potassium ions from the interior. This makes it more difficult to depolarize the neuron. The lock-and key nature of neurotransmitters and receptor sites is shown in (b). Only transmitters that fit the receptor will influence membrane potentials.



**FIGURE 3.6** Neurotransmitters have either excitatory or inhibitory effects on postsynaptic neurons. Excitatory transmitters depolarize the postsynaptic neuron's cell membrane, making it less negative and thereby moving it toward the action potential threshold. Inhibitory neurons hyperpolarize the membrane, making it more negative and therefore more difficult to excite to an action potential.

Once a neurotransmitter molecule binds to its receptor, it continues to activate or inhibit the neuron until it is shut off, or *deactivated*. This occurs in two major ways (Fain, 1999). Some transmitter molecules are deactivated by other chemicals located in the synaptic space that break them down into their chemical components. In other instances, the deactivation mechanism is **reuptake**, in which the transmitter molecules are taken back into the presynaptic axon terminal. When the receptor molecule is vacant, the postsynaptic neuron returns to its former inactive state, awaiting the next chemical stimulation.

- 8. Describe two methods by which neurotransmitter molecules are deactivated at the synapse.

**TABLE 3.1** SOME NEUROTRANSMITTER SUBSTANCES AND THEIR EFFECTS

Neurotransmitter	Major Function	Disorders Associated with Malfunctioning
Acetylcholine (ACh)	Excitatory at synapses involved in muscular movement and memory	Undersupply produces memory loss in Alzheimer's disease.
Norepinephrine	Excitatory and inhibitory functions at various sites. Involved in neural circuits controlling learning, memory, wakefulness, and eating.	Depression (undersupply)
Serotonin	Inhibitory at most sites. Involved in mood, sleep, eating, and arousal, and may be an important transmitter underlying pleasure and pain.	Depression, sleeping, and eating disorders (undersupply)
Dopamine	Inhibitory. Involved in voluntary movement, emotional arousal, learning, memory, and experiencing of pleasure or pain.	Parkinson's disease and depression (undersupply) Schizophrenia (oversupply)
GABA	Inhibitory transmitter in motor system	Destruction of GABA-producing neurons in Huntington's disease produces tremors and loss of motor control, as well as personality changes.

### Specialized Transmitter Systems

Through the use of chemical transmitters, nature has found an ingenious way of dividing up the brain into systems that are uniquely sensitive to certain messages. There is only one kind of electricity, but there are many shapes that can be assumed by transmitter molecules. Because the various systems in the brain recognize only certain chemical messengers, they are immune to “cross talk” from other systems. At present, 100 to 150 different substances are known or suspected transmitters in the brain, but there may be hundreds more (Fain, 1999; Wayne & Morris, 1999). Each substance has a specific excitatory or inhibitory effect on certain neurons. Table 3.1 lists several of the more important neurotransmitters that have been linked to psychological phenomena.

Perhaps the best understood neurotransmitter is **acetylcholine (ACh)**, which is involved in memory and in muscle activity. Underproduction of acetylcholine is thought to be an important factor in *Alzheimer's disease*, a degenerative brain disorder involving profound memory impairments that afflicts between 5 and 10 percent of all people over 65 years of age (Ron & David, 1997). Reductions in ACh weaken or deactivate neural circuitry that stores memories.

Acetylcholine is also an excitatory transmitter at the synapses where neurons activate muscle cells (Sherwood, 1991). Drugs that block the action of ACh can therefore prevent muscle activation, resulting in muscular paralysis. One example occurs in *botulism*, a serious type of food poisoning that can result from improperly canned food. The toxin formed by the botulinum bacteria blocks the release of ACh from the axon terminal, resulting in a potentially fatal paralysis of the muscles, including those of the respiratory system. The opposite effect on ACh occurs with the bite of the black widow spider. The spider's venom releases a torrent of ACh, resulting in violent muscle contractions, convulsions, and possible death. Thus although botulism and black widow venom affect ACh synapses in different ways, they can have equally fatal effects.

The treatment of emotionally disturbed people has been revolutionized by the development of psychoactive drugs that affect experience and behavior. Like the poisons described above, these drugs operate by either enhancing

- 9. Describe the roles of (a) acetylcholine, (b) dopamine, (c) serotonin, and (d) endorphins in psychological functions.

or inhibiting the actions of certain transmitters at the synapse. For example, abnormally high concentrations of **dopamine**, an excitatory transmitter, have been found in the brains of patients suffering from schizophrenia, a severe disorder of thought, emotion, and behavior (Depue, 1991). Researchers speculate that one factor in schizophrenia may be overactivity in the brain's dopamine transmitter system, producing disordered thinking, hallucinations, and other psychotic symptoms. Certain *antipsychotic drugs* fit like keys into the receptor "locks" meant for dopamine, thus preventing dopamine from overstimulating neurons and producing the symptoms (LeMoal, 1999; Robinson, 1997).

Quite a different mechanism occurs in the treatment of depression. Depression involves an underactivity of **serotonin**, a neurotransmitter that enhances mood, eating, sleep, and sexual behavior. Antidepressant drugs increase serotonin activity in several ways. The drug Prozac blocks the reuptake of serotonin from the synaptic space, allowing serotonin molecules remain active and exert their mood-elevating effects on depressed patients. Other antidepressant drugs work on a different deactivating mechanism. They inhibit the activity of enzymes in the synaptic space that deactivate serotonin by breaking it down into simpler chemicals. In so doing, they prolong serotonin activity at the synapse.

Endorphins are another important family of neurotransmitters. **Endorphins** reduce pain and increase feelings of well-being. They bind to the same receptors as the ones activated by opiate drugs, such as opium and morphine, which produce similar psychological effects. We discuss the endorphins and their discovery in greater detail in Chapter 4.

Most neurotransmitters have their excitatory or inhibitory effects only on specific neurons that have receptors for them. Others, called **neuromodulators**, have a more widespread and generalized influence on synaptic transmission. These substances circulate through the brain and either increase or decrease (i.e., modulate) the sensitivity of thousands, perhaps millions, of neurons to their specific transmitters. The best-known neuromodulator is the endorphins, which travel through the brain's circulatory system and inhibit pain transmission while enhancing neural activity that produces pleasurable feelings. Other neuromodulators play important roles in functions such as eating, sleep, and stress. Thus some neurotransmitters have very specific effects, whereas others have more general effects on neural activity.

## ▶ THE NERVOUS SYSTEM

The nervous system is the body's master control center. Three major types of neurons carry out the system's input, output, and integration functions. **Sensory neurons** carry input messages from the sense organs to the spinal cord and brain. **Motor neurons** transmit output impulses from the brain and spinal cord to the body's muscles and organs. Finally, there are neurons that link the input and output functions. **Interneurons**, which far outnumber sensory and motor neurons, perform connective or associative functions within the nervous system. For example, interneurons would allow us to remember a tune by linking the sensory input from the song we're hearing with the memory of that song stored elsewhere in the brain. The activity of interneurons makes possible the complexity of our higher mental functions, emotions, and behavioral capabilities.

The nervous system can be broken down into several interrelated subsystems (Figure 3.7). The two major divisions are the **central nervous system**, consisting of all the neurons in the brain and spinal cord, and the **peripheral nervous system**, comprising all the neurons that connect the central nervous system with the muscles, glands, and sensory receptors.

▶ 10. What are the three major types of neurons in the nervous system? What are their functions?

▶ 11. Differentiate between the central nervous system and the peripheral nervous system. What are the two divisions of the peripheral nervous system?

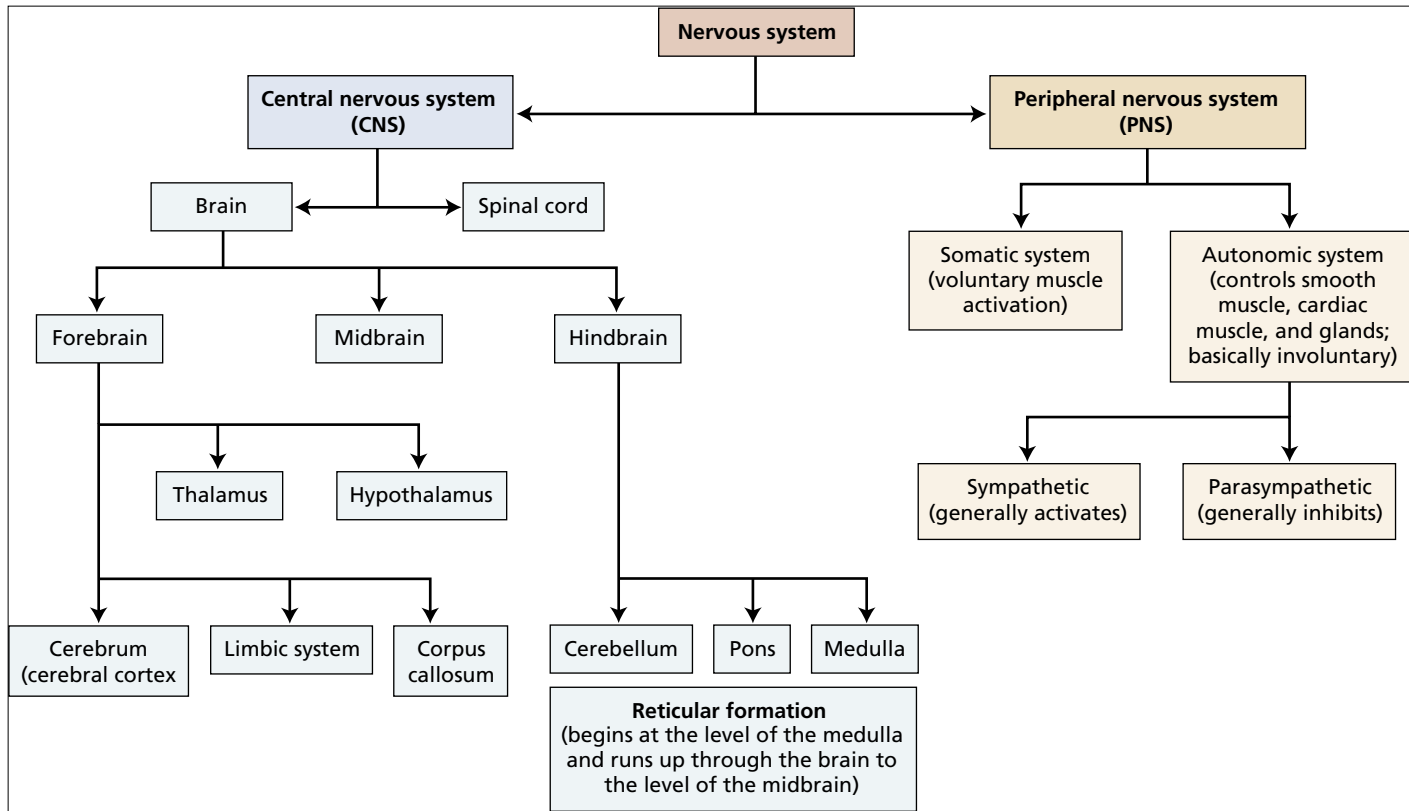


FIGURE 3.7 Structural organization of the nervous system.

## The Peripheral Nervous System

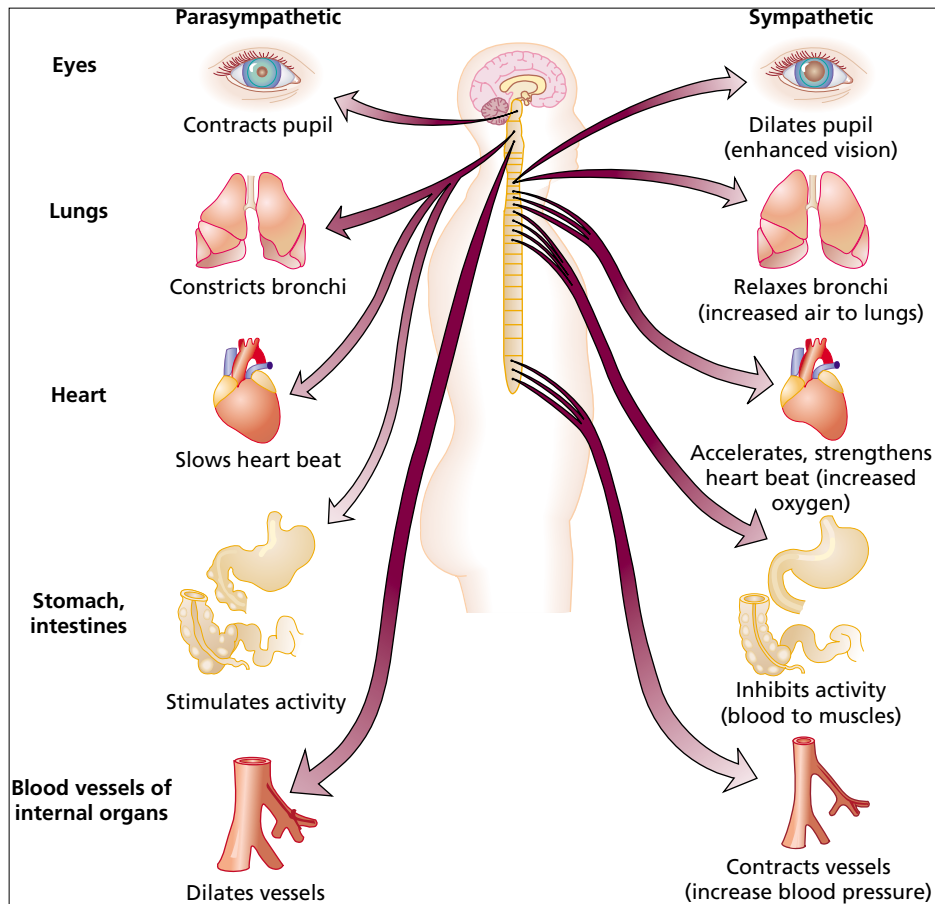
The peripheral nervous system contains all the neural structures that lie outside of the brain and spinal cord. Its specialized neurons help carry out the input and output functions that are necessary for us to sense what is going on inside and outside our bodies and to respond with our muscles and glands. The peripheral nervous system has two major divisions, the somatic nervous system and the autonomic nervous system.

### *The Somatic Nervous System*

The **somatic nervous system** consists of the *sensory neurons* that are specialized to transmit messages from the eyes, ears, and other sensory receptors, and the *motor neurons* that send messages from the brain and spinal cord to the muscles that control our voluntary movements. The axons of sensory neurons group together like the many strands of a rope to form *sensory nerves*, and motor neuron axons combine to form *motor nerves*. (Inside the brain and spinal cord, nerves are called *tracts*.) As you read this page, sensory neurons located in your eyes are sending impulses into a complex network of specialized visual tracts that course into your brain. At the same time, motor neurons are stimulating the eye movements that allow you to scan the lines of type and turn the pages. The somatic system thus allows you to sense and respond to your environment.

### *The Autonomic Nervous System*

The body's internal environment is regulated largely through the activities of the **autonomic nervous system**, which controls the glands and the smooth



**FIGURE 3.8** The sympathetic branch of the autonomic nervous system arouses the body and speeds up its vital processes, whereas the parasympathetic division slows down body processes. The two divisions work together to maintain an equilibrium within the body.

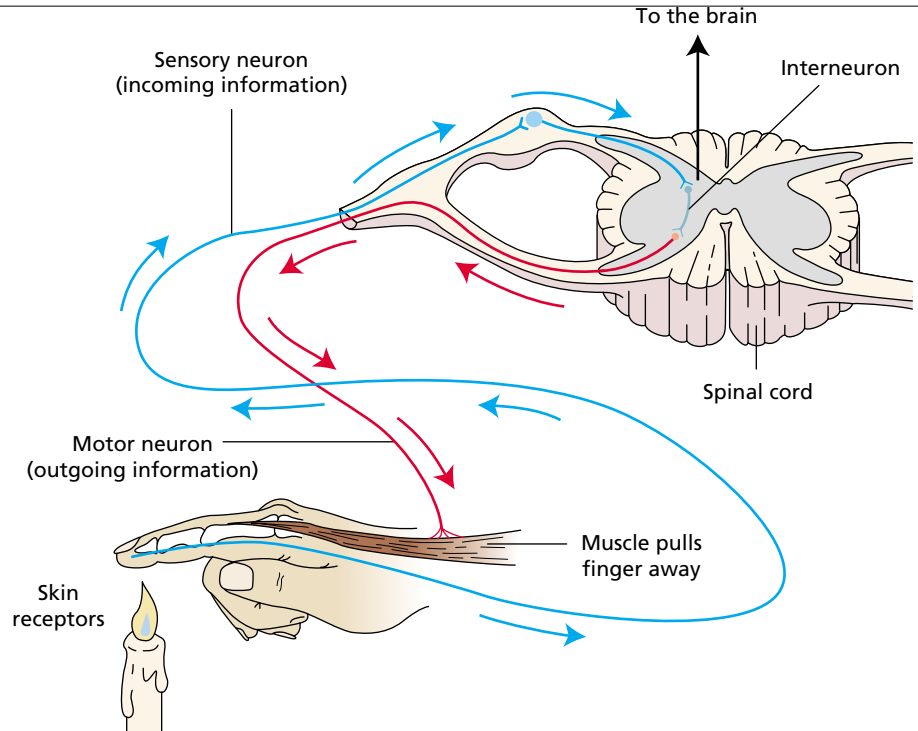
(involuntary) muscles that form the heart, the blood vessels, and the lining of the stomach and intestines. The autonomic system is largely concerned with involuntary functions, such as respiration, circulation, and digestion, and it is also involved in many aspects of motivation, emotional behavior, and stress responses. It consists of two subdivisions, the sympathetic nervous system and the parasympathetic nervous system (Figure 3.8). Typically, these two divisions affect the same organ or gland in opposing ways.

The **sympathetic nervous system** has an activation or arousal function, and it tends to act as a total unit. For example, when you encounter a stressful situation, your sympathetic nervous system simultaneously speeds your heart rate so it can pump more blood to your muscles, dilates your pupils so more light can enter the eye and improve your vision, slows down your digestive system so that blood can be transferred to the muscles, increases your rate of respiration so your body can get more oxygen, and, in general, mobilizes your body to confront the stressor. This is sometimes called the *fight-or-flight response*.

Compared with the sympathetic branch, which tends to act as a unit, the parasympathetic system is far more specific in its opposing actions, affecting one or a few organs at a time. The **parasympathetic nervous system** slows down body processes and maintains a state of tranquility. Thus your sympathetic system speeds up your heart rate; your parasympathetic system slows it down. By working together to maintain equilibrium in our internal organs, the two divisions can maintain **homeostasis**, a delicately balanced or constant internal state. Some acts also require a coordinated sequence of sympathetic and parasympathetic activities. For example, sexual activity in the male involves erection of the penis (a primarily parasympathetic function) followed by ejaculation (a primarily sympathetic function) (Masters et al., 1988).

- 12. Describe the two divisions of the autonomic nervous system, as well as their roles in maintaining homeostasis.

**FIGURE 3.9** A cross section of the spinal cord shows the organization of sensory and motor nerves. Sensory and motor nerves enter and exit the spinal cord on both sides of the spinal column. Interneurons within the H-shaped spinal gray matter can serve a connective function, as shown here, but in many cases, sensory neurons can also synapse directly with motor neurons. At this level of the nervous system, reflex activity is possible without involving the brain.



## The Central Nervous System

More than any other system in our body, the central nervous system distinguishes us from other creatures. This system contains the spinal cord, which connects most parts of the peripheral nervous system with the brain, and the brain itself.

### The Spinal Cord

Most nerves enter and leave the central nervous system by way of the spinal cord, a structure that in a human adult is 12 to 15 inches long and about a half-inch in diameter. The spinal cord's neurons are protected by the vertebrae (bones of the spine). When the spinal cord is viewed in cross section (Figure 3.9), its central portion resembles an H, or a butterfly. The H-shaped portion consists largely of gray-colored neuron cell bodies and their interconnections. Surrounding the gray matter are white-colored myelinated axons that connect various levels of the spinal cord with each other and with the higher centers of the brain. Entering the back side of the spinal cord along its length are sensory nerves. Motor nerves exit the spinal cord's front side.

Some simple stimulus-response sequences, known as **spinal reflexes**, can be triggered at the level of the spinal cord without any involvement of the brain. For example, if you touch something hot, sensory receptors in your skin trigger nerve impulses in sensory nerves that flash into your spinal cord and synapse inside with interneurons. The interneurons then excite motor neurons that send impulses to your hand, so that it pulls away. Other interneurons simultaneously carry the "Hot!" message up the spinal cord to your brain, but it is a good thing that you don't have to wait for the brain to tell you what to do in such emergencies. Getting messages to and from the brain takes slightly longer, so the spinal cord reflex system significantly reduces reaction time, and, in this case, potential tissue damage.

► 13. How do the structural characteristics of the spinal cord permit spinal reflexes?

## The Brain

The three pounds of protein, fat, and fluid that you carry around inside your skull is the real “you.” It is also the most complex structure in the known universe and the only one that can wonder about itself. As befits this biological marvel, your brain is the most active energy consumer of all your body organs. Although the brain accounts for only about 2 percent of your total body weight, your brain consumes about 20 percent of the oxygen you use in a resting state (Robinson, 1997). Moreover, the brain never rests; its rate of energy metabolism is relatively constant day and night. In fact, when you dream, the brain’s metabolic rate actually increases slightly (Hobson, 1996).

How can this rather nondescript blob of grayish tissue discover the principle of relativity, build the Hubble Telescope, and produce great works of art, music, and literature? Answering such questions requires the ability to study the brain and how it functions. To do so, neuroscientists use a diverse set of tools and procedures.

### Unlocking the Secrets of the Brain

More has been learned in the past three decades about the brain and its role in behavior than was known in all the preceding ages. This knowledge explosion is due in large part to revolutionary technical advances that have provided scientists with new research tools, as well as to the contributions of psychological research on brain-behavior relations. Investigators can use a variety of methods to study the brain’s structures and activities.

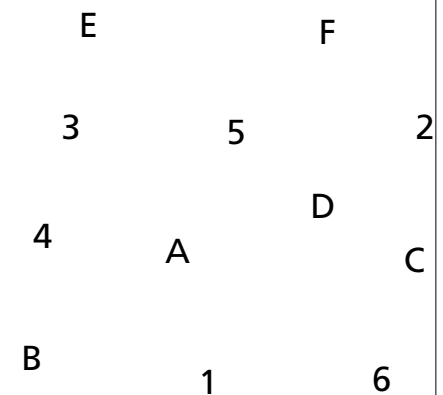
**Neuropsychological tests.** Psychologists have developed a variety of **neuropsychological tests** to measure verbal and nonverbal behaviors that are known to be affected by particular types of brain damage (Lezak, 1995). These tests are used in clinical evaluations of people who may have suffered brain damage through accident or disease. They are also important research tools. For example, Figure 3.10 shows a portion of a Trail Making Test, used to test memory and planning. Scores on the test give an indication of the type and severity of damage the person may have. Neuropsychological tests of this kind have provided much information about brain-behavior relations.

**Destruction and stimulation techniques.** Experimental studies are another useful method of learning about the brain. Researchers can produce brain damage (destroy neurons) under carefully controlled conditions in which specific nervous tissue is destroyed with electricity, with cold or heat, or with chemicals. They can also surgically remove some portion of the brain and study the consequences. Most experiments of this kind are performed on animals, but humans can also be studied when accident or disease produces a specific lesion or when abnormal brain tissue must be surgically removed.

An alternative to destroying neurons is stimulating them, which typically produces opposite effects. A specific region of the brain can be stimulated by a mild electric current or by chemicals that excite neurons. Electrodes can be permanently implanted so that the region of interest can be stimulated repeatedly. Some of these electrodes are so tiny that they can stimulate individual neurons. In chemical stimulation studies, a tiny tube is inserted into the brain so that a small amount of the chemical can be delivered directly to the area to be studied. Again, most of these techniques are used with animals, but in many respects, animal and human brains are similar enough in structure and functions that results with animals can often be generalized to humans.

**Electrical recording.** Because electrodes can record brain activity as well as stimulate it, it is also possible to “eavesdrop” on the electrical conversations occurring within the brain. Neurons’ electrical activity can be measured by inserting small electrodes in particular areas of the brain or even in individual neurons.

► 14. Describe four methods used to study brain-behavior relations.



**FIGURE 3.10** The Trail Making Test consists of a randomly scattered set of numbers and letters. On this timed test, the patient must connect the numbers and letters consecutively with a continuous line, or “trail” (i.e., A to 1 to B to 2 to C to 3, and so on). People with certain kinds of brain damage have trouble alternating between the numbers and letters because they cannot retain a plan in memory long enough, and poor test performance picks up this deficit.



**FIGURE 3.11** The electroencephalogram (EEG), shown in (a) permits the electrical recording of the activity of large groups of neurons in the brain by means of electrodes attached to the scalp. An EEG readout is shown in (b). Various brain scanning machines, such as the one shown in (c), produce a number of different images. The CT scan uses narrow beams of X-rays to construct a composite picture of brain structures (d). PET scans (e) record the amount of radioactive substance that collects in various brain regions to assess brain activity. MRI scanners produce vivid pictures of brain structures (f). Functional MRI procedures take images in rapid succession, showing neural activity as it occurs.

In addition to measuring individual voices, scientists can tune in to “crowd noise” by placing larger electrodes on the scalp to measure the activity of large groups of neurons with the **electroencephalogram (EEG)** (Figure 3.11). Although the EEG is a rather gross measure that taps the electrical activity of thousands of neurons in many parts of the brain, specific EEG patterns correspond to certain states of consciousness, such as wakefulness and sleep. Clinicians also use the EEG to detect abnormal electrical patterns that signal the presence of brain disorders.

**Brain imaging.** The newest tools of discovery are imaging techniques that permit neuroscientists to peer into the living brain (Figure 3.11c). The most important of these technological “windows” are CT scans, PET scans, and magnetic resonance imaging (MRI) (Duncan, 1997; Leondes, 1997).

Developed in the 1970s, **computerized axial tomography (CT)** scans use X-ray technology to study brain structures (Peyster, 2000). A highly focused beam of X rays takes pictures of narrow slices of the brain. A computer analyzes

► 15. How are CT scans, PET scans, and MRIs produced, and how is each used in brain research?

the X-rayed slices and creates pictures of the brain's interior from many different angles (Figure 3.11d). Pinpointing where injuries or deterioration have occurred helps clarify relations between brain damage and psychological functioning. CT scans are 100 times more sensitive than standard X-ray procedures, and the technological advance was so dramatic that its developers, Allan Cormack and Godfrey Hounsfield, were awarded the 1979 Nobel Prize for Medicine.

Whereas CT scans provide pictures of brain structures, **positron emission tomography (PET)** scans measure brain activity, including metabolism, blood flow, and neurotransmitter activity (Hornak, 2000; Ron & David, 1997). PET is based on the fact that glucose, a natural sugar, is the major nutrient of neurons. Thus when neurons are active, they consume more glucose. To prepare a patient for a PET scan, a harmless form of radioactive glucose is injected into the bloodstream and travels to the brain, where it circulates in the blood supply. The energy emitted by the radioactive substance is measured by the PET scan, and the data are fed into a computer that uses the readings to produce a color picture of the brain on a display screen (Figure 3.11c). Researchers can tell how active particular neurons are by using the PET scan to measure the amount of radioactive glucose that accumulates in them. If a person is performing a mental reasoning task, for example, a researcher can tell by the glucose concentration pattern which parts of the brain were activated by the task (Raichle, 1994). Using the PET scan, brain activity can be studied in relation to cognitive processes, behavior, and even forms of mental illness.

**Magnetic resonance imaging (MRI)** combines features of CT and PET scans and can be used to study both brain structures and brain activity (Chakeres, 2000). MRI creates images based on how atoms in living tissue respond to a magnetic pulse delivered by the device. MRI can make out details one-tenth the size that can be detected by CT scans, and it distinguishes much better among different types of brain tissue (Leondes, 1997). To obtain an MRI, the part of the body to be studied is placed in the hollow core of a long magnetic cylinder and the atoms in the subject's body are exposed to a uniform magnetic field. The field is then altered, and when the magnetic field is shut off, the magnetic energy absorbed by the atoms in the tissue emits a small electrical voltage. The voltage is picked up by detectors and relayed to a computer for analysis. In addition to providing color images of the tissue, MRI can also tell researchers which chemicals (such as neurotransmitters) are active in the tissue (Figure 3.11f).

The conventional MRI yields pictures taken several minutes apart. A recent advance in MRI technology is *functional MRI (fMRI)*, which can produce pictures of blood flow in the brain taken less than a second apart (Baert et al., 1999). Researchers can now, quite literally, watch "live" presentations as different regions of the brain "light up" when subjects are given various types of tasks to perform. Researchers can thereby identify brain regions involved in specific psychological functions. In this chapter's *Research Close-up*, we will see fMRI's value in providing new information about differences between men and women in language-related brain activity.

Advances in brain research have made this area one of the most exciting frontiers of psychology. Driven by its intense desire to "know thyself," the brain is beginning to yield its many secrets. Yet many important questions remain. This should not surprise us for, as one observer noted, "If the brain were so simple that we could understand it, we would be so simple that we couldn't" (Pugh, 1977).

## The Hierarchical Brain: Structures and Behavioral Functions

In an evolutionary sense, your human brain is far older than you are, for it represents perhaps 500 million years of evolutionary development and fine tuning (Roth, 2000). The human brain can be likened to a living archaeological site, with

► 16. In what sense might the structure of the human brain mirror evolutionary development?

the more recently developed structures built atop structures from the distant evolutionary past. The structures at the brain's core govern the basic physiological functions, such as breathing and heart rate, that keep us alive. These we share with all other vertebrates (animals having backbones). Built upon these basic structures are newer systems that involve progressively more complex functions—sensing, emoting, wanting, thinking, reasoning. Evolutionary theorists believe that as genetic variation and recombination sculpted these newer structures over time, natural selection favored their retention because animals who had them were more likely to survive in changing environments. The crowning feature of brain development is the cerebrum, the biological seat of Einstein's scientific genius, Mozart's creativity, Mother Teresa's compassion, and that which makes you a unique human being.

The major structures of the human brain, together with their psychological functions, are shown in Figure 3.12. The brain has traditionally been divided into three major subdivisions: the hindbrain, which is the lowest and most primitive level of the brain; the midbrain, which lies above the hindbrain; and the forebrain.

### *The Hindbrain*

► 17. Which behavioral functions are controlled by the hindbrain structures, namely, the medulla, the pons, and the cerebellum? What occurs with damage to these structures?

As the spinal cord enters the brain, it enlarges to form the structures that compose the stalklike **brain stem**. Attached to the brain stem is the other major portion of the hindbrain, the cerebellum.

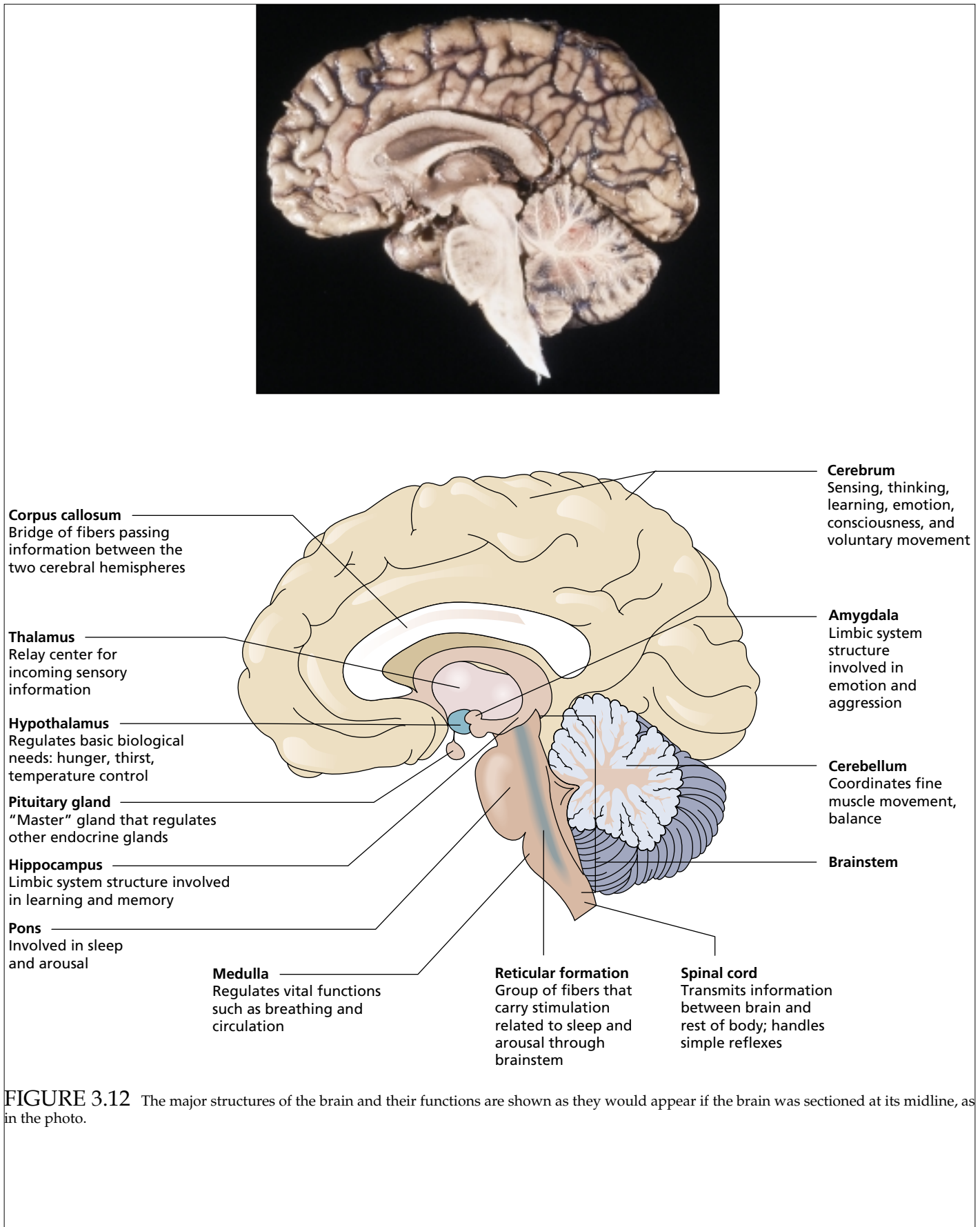
**The brain stem: life support systems.** The medulla is the first structure encountered after leaving the spinal cord. A 1 1/2-inch-long structure that is well developed at birth, the **medulla** plays an important role in vital body functions such as heart rate and respiration. Because of your medulla, these functions occur automatically. Damage to the medulla usually results in death or, at best, the need to be maintained on life support systems. Suppression of medulla activity can occur at high levels of alcohol intoxication, resulting in death by heart or respiratory failure (Blessing, 1997).

The medulla is also a two-way thoroughfare for all the sensory and motor nerve tracts coming up from the spinal cord and descending from the brain. Most of these tracts cross over within the medulla, so the left side of the brain receives sensory input from and exerts motor control over the right side of the body, and the right side of the brain serves the left side of the body. Why this crossover occurs is one of the unsolved mysteries of brain function.

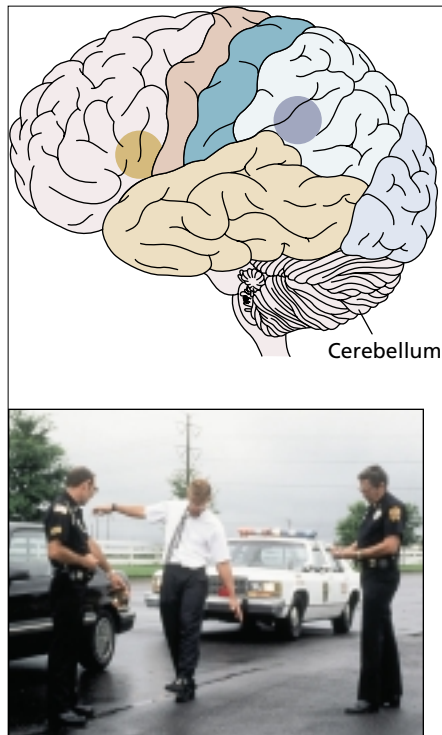
The **pons** (meaning *bridge* in Latin) lies just above the medulla, and it indeed serves as a bridge carrying nerve impulses between higher and lower levels of the nervous system. The pons also has clusters of neurons that help regulate sleep and are involved in dreaming, and it contains motor neurons that control the muscles and glands of the face and neck. Like the medulla, the pons helps to control vital functions, especially respiration, and damage to it can produce death.

**The cerebellum: motor coordination center.** The cerebellum ("little brain" in Latin) does indeed look like a miniature brain attached to the rear of the brain stem directly above the pons. Its wrinkled cortex, or covering, consists mainly of gray cell bodies (gray matter). The **cerebellum** is concerned primarily with muscular movement coordination, but it also plays a role in certain types of learning and memory.

Specific motor movements are initiated in higher brain centers, but their timing and coordination depend on the cerebellum (Thatch et al., 1992). The cerebellum regulates complex, rapidly changing movements that require exquisite timing, such as those of a ballet dancer or a competitive diver. Within the animal kingdom, cats have an especially well-developed cerebellum, helping to account for their graceful movement abilities (Altman & Bayer, 1996).



**FIGURE 3.12** The major structures of the brain and their functions are shown as they would appear if the brain was sectioned at its midline, as in the photo.



**FIGURE 3.13** The cerebellum's movement-control functions are easily disrupted by alcohol, providing the neural basis for the sobriety tests administered by police.

► 18. Describe the roles played by the ascending and descending reticular formation. Why is it called the "brain's gatekeeper"?

The motor control functions of the cerebellum are easily disrupted by alcohol, producing the coordination difficulties that police look for in their roadside tests of sobriety (Ito, 1984). Intoxicated people may be unable to walk a straight line or touch their nose with their index finger (Figure 3.13). Physical damage to the cerebellum results in severe motor disturbances characterized by jerky, uncoordinated movements, as well as an inability to perform habitual movements such as walking. The behavioral effects of a rapidly developing cerebellar tumor are apparent in the following clinical case:

Ed could no longer walk a straight line. His gait involved wide separation of his legs. The timing of his steps was jerky and irregular, causing him to lurch from side to side. . . . By the fifth day he could no longer stand without assistance, and he began to display rapid and jerky eye movements. Ed was admitted to a hospital, where imaging techniques revealed a cerebellar tumor. Surgical removal of the tumor resulted in a marked improvement in his motor coordination. (Gazzaniga et al., 1979)

### The Midbrain

Lying just above the hindbrain, the **midbrain** contains clusters of sensory and motor neurons, as well as many sensory and motor fiber tracts that connect higher and lower portions of the nervous system. The sensory portion of the midbrain contains important relay centers for the visual and auditory systems. Here, nerve impulses from the eyes and ears are organized and sent to forebrain structures involved in visual and auditory perception (Nolte, 1998). The midbrain also contains motor neurons that control eye movements. For example, if you see movement out of the corner of your eye, midbrain activity causes your eyes to swing toward the source of the movement in order to identify it.

**The reticular formation: the brain's gatekeeper.** Buried within the midbrain is a finger-shaped structure that extends from the hindbrain up into the lower portions of the forebrain. This structure receives its name from its resemblance under a microscope to a *reticulum*, or net. The **reticular formation** is heavily involved in brain arousal, sleep, and attention. It acts as a kind of sentry, both alerting higher centers of the brain that messages are coming and then either blocking those messages or allowing them to go forward. The reticular formation has an *ascending* part, which sends input to higher regions of the brain to alert it, and a *descending* portion, through which higher brain centers can either admit or block out sensory input.

The reticular formation has attracted a great deal of interest from psychologists because of its central role in consciousness, sleep, and attention. The ascending reticular formation rouses higher centers in the brain and prepares them to receive input from our sense organs. Without reticular stimulation of higher brain regions, sensory messages do not register in conscious awareness even though the nerve impulses may reach the appropriate higher areas of the brain. It is as if the brain is not "awake" enough to notice them. In fact, some general anesthetics work by deactivating neurons of the ascending reticular formation, producing a state of unconsciousness in which the sensory impulses that ordinarily would be experienced as pain never "register" in the sensory areas of the brain involved in pain perception (Derogatis, 1986).

Sleep, wakefulness, and attention are also affected by the reticular formation. In a classic series of experiments in the late 1940s, researchers discovered that electrical stimulation of different portions of the reticular formation can produce instant sleep in a wakeful cat and sudden wakefulness in a sleeping animal (Moruzzi & Magoun, 1949; Marshall & Magoun, 1997). As you might expect, severe damage to the reticular formation can produce a permanent coma (Roland, 1997).

Attention is an active process in which only important or meaningful sensory inputs get through to our consciousness. Other inputs have to be toned

down or completely blocked out or we'd be overwhelmed by stimulation. The descending reticular formation plays an important part in this process, serving as a kind of "gate" through which some inputs are admitted while others are blocked out by signals coming down from higher brain centers (Van Zomeren & Brouwer, 1994). We hope it is operating for you right now, as you focus on these words and "block out" other sights, sounds, and body sensations that could distract you from our messages.

### *The Forebrain*

The most profound biological difference between your brain and that of a lower animal is the size and complexity of your forebrain, or *cerebrum*. The **forebrain** consists of two large cerebral hemispheres, a left side and a right side, that wrap around the brain stem like the two halves of a cut grapefruit might wrap around a spoon. The outer portion of the forebrain has a thin covering, or cortex, and there are a number of important structures buried in the central regions of the hemispheres.

**The thalamus: the brain's sensory switchboard.** The thalamus is located above the midbrain. It resembles two small footballs, one within each cerebral hemisphere. The **thalamus** is an important sensory relay station and has sometimes been likened to a switchboard that organizes input from sense organs and routes them to the appropriate areas of the brain. The visual, auditory, and body senses (balance and equilibrium) all have major relay stations in the thalamus. In each case, nerve tracts from the sensory receptors (e.g., the eyes or the ears) are sent to specific areas of the thalamus. There they synapse with neurons that send the messages on their way to the higher brain regions that create our perceptions of the sensory inputs (Jones et al., 1997).

Because the thalamus plays such a key role in routing sensory information to higher brain regions, disrupted thalamic functioning can produce a highly confusing world for its victims. In research at the National Institute of Mental Health (NIMH) carried out by Nancy Andreasen and her coworkers (1994), MRIs from 39 schizophrenic men were compared with those of 47 normal male volunteers. The brain images showed specific abnormalities in the thalamus of the "schizophrenic" brains. The researchers suggested that malfunctioning in this region of the brain could help account for the confused thinking and disordered attention that characterize schizophrenic behavior. Perhaps the thalamus is sending garbled sensory information to the higher regions of the brain. If substantiated by future research, the NIMH discovery may provide increased understanding of this baffling mental disorder.

**The hypothalamus: motivation and emotion.** The hypothalamus (literally, "under the thalamus") consists of tiny groups of neuron cell bodies that lie at the base of the brain, above the roof of the mouth. The **hypothalamus** plays a major role in many aspects of motivational and emotional behavior, including sexual behavior, temperature regulation, sleeping, eating, drinking, aggression, and the expression of emotion. Damage to the hypothalamus can disrupt all of these behaviors. For example, destruction of one area of a male's hypothalamus results in a complete loss of sex drive; damage to another portion produces an overwhelming urge to eat that results in extreme obesity. Recently, neuroscientists at the University of Texas Southwestern Medical School found that certain neurons in the hypothalamus manufacture a substance which they called *orexins* (after the Greek word for hunger) that stimulates eating. When they gave orexin to laboratory rats, they ate 8 to 10 times more food than they ordinarily would over a period of hours (Yanagisawa et al., 1998). This discovery holds out the hope that it might be possible to control both undereating (as occurs in some cancer patients) and obesity by producing medicines that either enhance or inhibit orexin activity at the synapses where eating is controlled.

➤ 19. What is the role of the thalamus in sensory input, and, possibly, in thought and perceptual disorders?

➤ 20. What role does the hypothalamus have in motivated behavior, hunger, pleasure-pain, and hormonal functions?

The hypothalamus has important connections with the endocrine system, the body's collection of hormone-producing glands. Through its connection with the pituitary gland (the master gland that exerts control over the other glands of the endocrine system), the hypothalamus directly controls many hormonal secretions that regulate sexual development and behavior, metabolism, and reactions to stress.

The hypothalamus is also involved in our experiences of pleasure and displeasure. The discovery of this fact occurred quite by accident. In 1953, psychologist James Olds was conducting an experiment to study the effects of electrical stimulation in the rat's midbrain reticular formation. One of the electrodes missed the target and was mistakenly implanted in the hypothalamus. The investigators noticed that whenever this rat was stimulated, it repeated whatever it had just done, as if it had been rewarded for that behavior. In a variety of learning situations, other animals with similarly implanted electrodes also learned and performed behaviors in order to receive what was clearly an electrical reward. Some of the rats pressed a pedal up to 5,000 times in an hour in order to receive their electrical reward until they dropped from exhaustion. Stimulation of other nearby areas produced just the opposite effect—a tendency to stop performing any behavior that was followed by stimulation, as if the animal had been punished. The investigators concluded that they had discovered what they called “reward and punishment centers” in the brain, some of which were in the hypothalamus (Olds, 1958; White & Milner, 1992; Wise & Rompre, 1989).

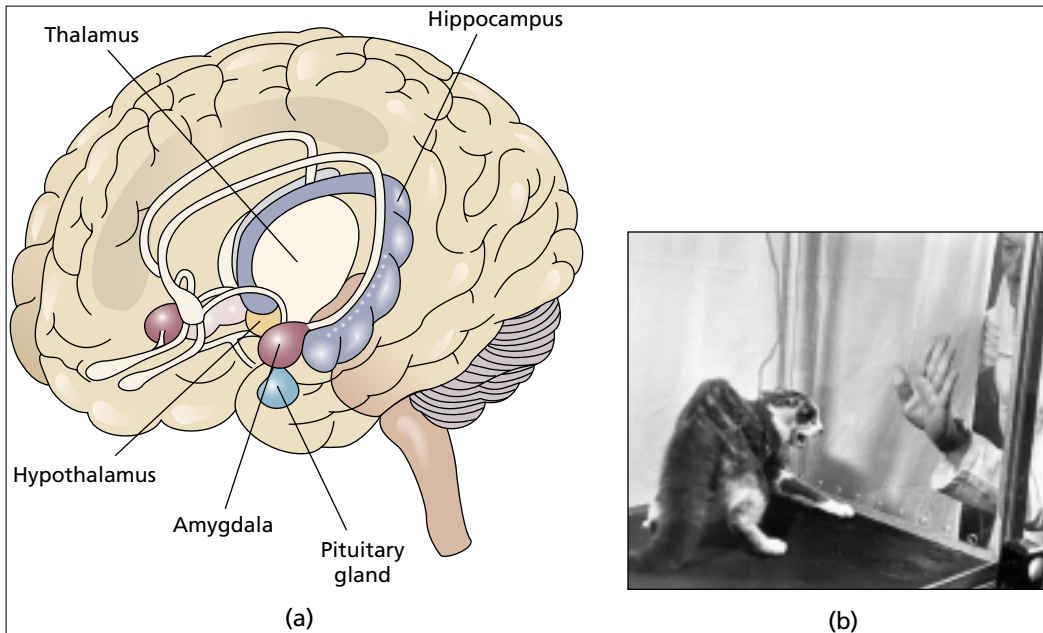
Humans who have had electrodes implanted in their brains to search for abnormal brain tissue have reported experiencing pleasure when electrically stimulated in these regions of the brain (Heath, 1972). One patient reportedly proposed marriage to the experimenter while being so stimulated. Thus a misplaced electrode led to a discovery that neural events occurring in the hypothalamus and adjacent areas have important roles in motivation.

**The limbic system: memory and goal-directed behavior.** As we continue our journey up through the brain, we come to the limbic system, a set of structures lying deep within the cerebral hemispheres. These structures, which are shaped like a wishbone, encircle the brain stem and have an important partnership with the hypothalamus. The **limbic system** helps to coordinate behaviors needed to satisfy motivational and emotional urges that arise in the hypothalamus, and it is also involved in memory. Many instinctive activities in lower animals, such as mating, attacking, feeding, and fleeing from danger appear to be organized by the limbic system (Davis, 1992). Human behaviors are similarly organized into goal-directed sequences. If certain parts of your limbic system were injured, you would be unable to carry out organized sequences of actions to satisfy your needs. A small distraction would make you forget what you had set out to do.

Two key structures in the limbic system are the hippocampus and the amygdala. The **hippocampus**, is involved in the formation and storage of memories. Damage there can result in severe memory impairment for recent events (Schacter, 2000; Squire, 1992). The **amygdala** organizes emotional response patterns, particularly those linked to aggression and fear (LeDoux, 1998). Electrically stimulating certain areas of the amygdala causes animals to snarl and assume aggressive postures (Figure 3.14), whereas stimulation of other areas results in a fearful inability to respond aggressively, even in self-defense. For example, a normally aggressive and hungry cat will cower in fear from a tiny mouse placed in its cage. The amygdala is a key part of a larger control system for anger and fear that also involves other brain regions (Borod, 2000).

An interesting feature of the amygdala is that it can produce emotional responses without the higher centers of the brain “knowing” that we are emotionally aroused. This may provide a possible explanation of clinicians' observations of “unconscious” emotional responses (LeDoux, 1998).

► 21. What is the possible relation between the hypothalamus and the limbic system in relation to emotion and motivation? What roles do the hippocampus and amygdala play in psychological functions?



**FIGURE 3.14** The limbic system structures are shown in (a). Electrical stimulation of the amygdala, as in (b) can produce an immediate aggressive response.

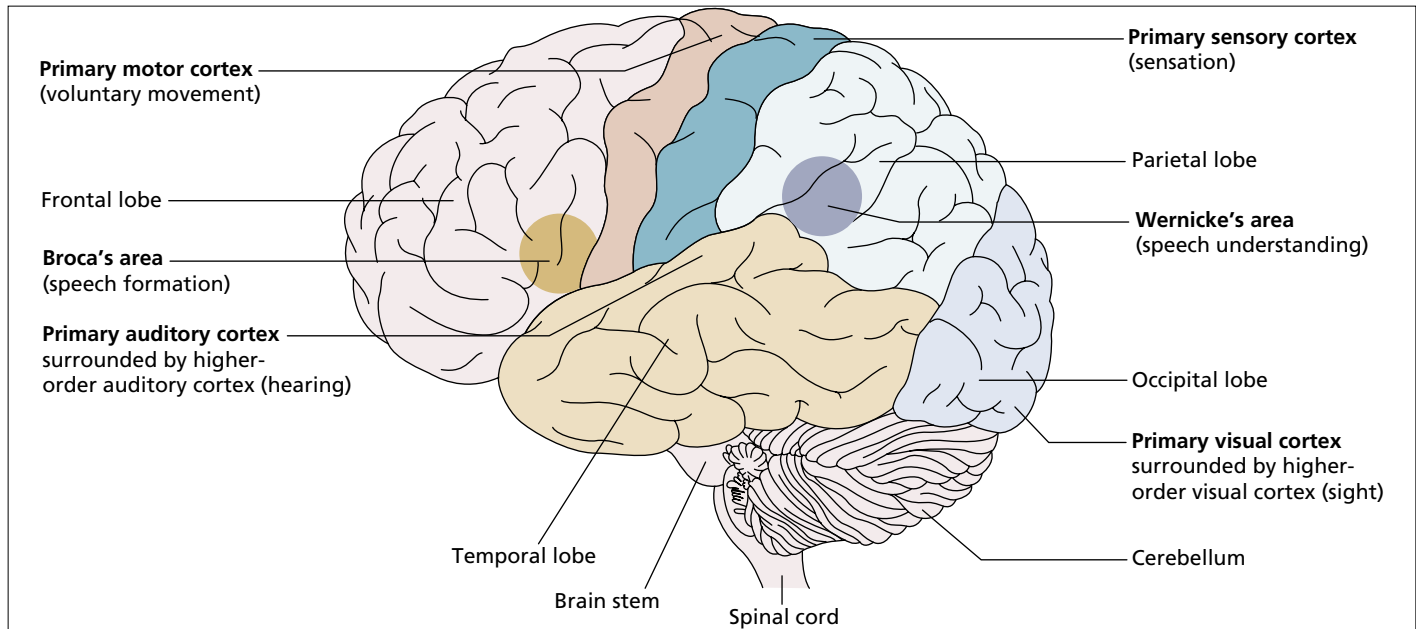
Finally, like the hypothalamus, the limbic system contains “reward” and “punishment” areas that have important motivational functions. Certain drugs, such as cocaine and marijuana, seem to induce pleasure by stimulating limbic reward areas that use dopamine as their neurotransmitter (Holloway, 1991; LeMoal, 1999). As noted earlier, lowered dopamine activity is found in people who are depressed (Depue & Iacono, 1989). These observations may provide important clues to understanding how the amygdala is involved in the creation of pleasure and pain.

### *The Cerebral Cortex: Crown of the Brain*

The **cerebral cortex**, a 1/4-inch-thick sheet of gray (unmyelinated) cells that form the outermost layer of the human brain, is the crowning achievement of brain evolution. Fish and amphibians have no cerebral cortex, and the progression from more primitive to more advanced mammals is marked by a dramatic increase in the proportion of cortical tissue. In humans, the cortex constitutes fully 80 percent of brain tissue (Nolte, 1998).

The cerebral cortex is not essential for physical survival in the way that the brain stem structures are, but it is essential for a human quality of living. How much so is evident in this description of patients who, as a result of an accident during prenatal development, were born without a cerebral cortex:

Some of these individuals may survive for years, in one case of mine for twenty years. From these cases, it appears that the human [lacking a cortex] sleeps and wakes; . . . reacts to hunger, loud sounds, and crude visual stimuli by movement of eyes, eyelids, and facial muscles; . . . may see and hear, . . . may be able to taste and smell, to reject the unpalatable and accept such food as it likes. . . . [They can] utter crude sounds, can cry and smile, showing displeasure when hungry and pleasure, in a babyish way, when being sung to; [they] may be able to perform spontaneously crude [limb] movements. (Cairns, 1952, p. 109)



**FIGURE 3.15** Division of the brain into frontal, parietal, occipital, and temporal lobes, and localization of sensory and motor functions in the cortex. The remainder is primarily association cortex, consisting of interneurons involved in complex psychological functions, such as perception and reasoning.

► 22. What are the four lobes of the brain, and where are they located?

► 23. Differentiate between sensory, motor, and association cortex.

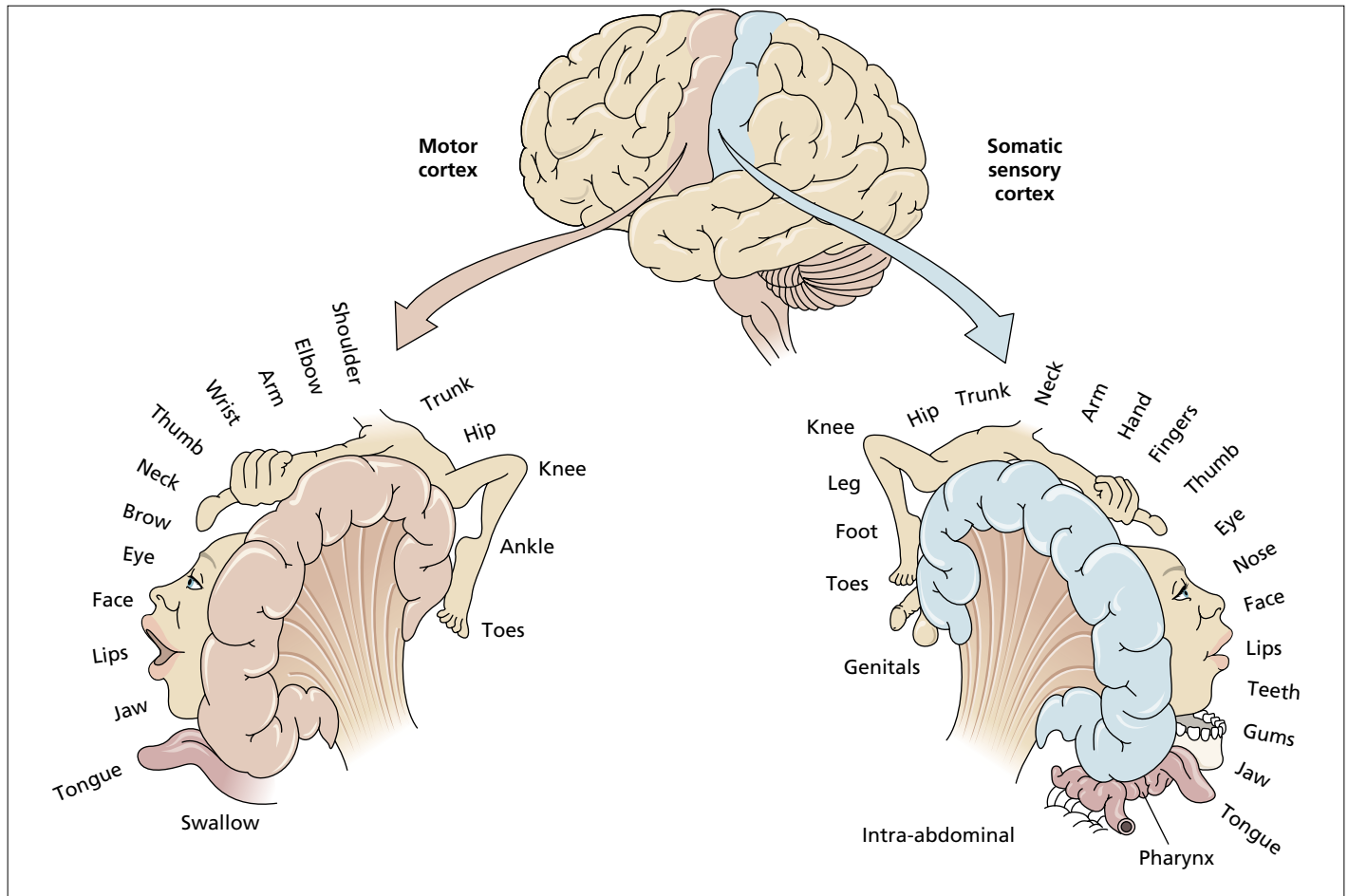
► 24. How are the somatic sensory and motor cortices organized?

Because the cortex is wrinkled and convoluted, like a wadded-up piece of paper, a great amount of cortical tissue is compressed into a relatively small space inside the skull. Perhaps 75 percent of the cortex's total surface area lies within its *fissures*, or canyonlike folds. Three of these fissures are important landmarks. One large fissure runs up the front and along the top of the brain, dividing it into right and left hemispheres. Another major fissure within each hemisphere divides the cerebrum into front and rear halves, and the third fissure runs from front to rear along the side of the brain. On the basis of these landmarks, neurologists have divided each hemisphere into four lobes: **frontal**, **parietal**, **occipital**, and **temporal** (Figure 3.15).

Each of the four cerebral lobes is associated with particular sensory and motor functions (also shown in Figure 3.15). Speech and skeletal motor functions are localized in the frontal lobe. The area governing body sensations is located in the parietal lobe immediately behind the *central fissure*, which separates the frontal and parietal lobes. The brain's visual area is located in the occipital lobe at the back of the brain. Finally, messages from the auditory system are sent to a region in the top of the temporal lobe (Robinson, 1997). The large areas in Figure 3.16 that are not associated with sensory or motor functions (about three-fourths of the cortex) are *association cortex* involved in mental processes such as thought, memory, and perception.

Most sensory systems send information to specific regions of the cerebral cortex. Motor systems that control the activity of skeletal muscles are situated in other cortical regions. The basic organization of the cortex's sensory and motor areas is quite similar from rats to humans. Let us explore these regions more closely.

**The motor cortex.** The **motor cortex**, which controls the 600 or more muscles involved in voluntary body movements, lies at the rear of the frontal lobe adjacent to the central fissure. Each hemisphere governs movement on the opposite side of the body. Thus severe damage to the right motor cortex would produce paralysis in the left side of the body. The left side of Figure 3.16 shows the relative organization of function within the motor cortex. As you can see, specific body areas are represented in different parts of the motor cortex, and the amount of cortex



**FIGURE 3.16** Both the somatic sensory and the motor cortex are highly specialized so that every site is associated with a particular part of the body. The amount of cortex devoted to each body part is proportional to the sensitivity of that area's motor or sensory functions. Both the sensory and motor cortex are arranged in an upside-down fashion and serve the opposite side of the body.

devoted to each area depends on the complexity of the movements that are carried out by the body part. Note, for example, that the amount of cortical tissue devoted to your fingers is far greater than that devoted to your torso, even though your torso is much larger. If we electrically stimulate a particular point on the motor cortex, movements occur in the muscles governed by that part of the cortex.

**The sensory cortex.** Specific areas of the cortex receive input from our sensory receptors. With the exception of taste and smell, at least one specific area in the cortex has been identified for each of the senses.

The **somatic sensory cortex** receives sensory input that gives rise to our sensations of heat, touch, cold, and our senses of balance and body movement (kinesthesia). It lies in the parietal lobe just behind the motor cortex, separated from it by the large fissure that divides the frontal lobe from the parietal lobe. As in the case of the motor system, each side of the body sends sensory input to the opposite hemisphere. Like the motor area next to it, the somatic sensory area is basically organized in an upside-down fashion, with the feet being represented near the top of the brain. Likewise, the amount of cortex devoted to each body area is directly proportional to that region's sensory sensitivity. The organization of the sensory cortex is shown on the right side of Figure 3.16, as is the proportion of cortex devoted to each body area. As far as your sensory cortex is concerned, you are mainly fingers, lips, and tongue. Notice also that the organization of the sensory cortex is such that the

body structures it serves lie side by side with those in the motor cortex, an arrangement that enhances sensory-motor interactions in the same body area.

The senses of hearing and sight are well represented in the cortex. The auditory area lies on the surface of the temporal lobe at the side of each hemisphere. Each ear sends messages to the auditory areas of both hemispheres, so the loss of one temporal lobe has little effect on hearing. The major sensory area for vision lies at the rear of the occipital lobe. Here messages from the visual receptors are analyzed, integrated, and translated into sight. As in the auditory system, each eye sends input to both hemispheres.

Within each sensory area, neurons respond to particular aspects of the sensory stimulus; they are tuned in to specific aspects of the environment. Thus certain cells in the visual cortex fire only when we look at a particular kind of stimulus, such as a vertical line or a corner (Hubel & Wiesel, 1979). In the auditory cortex, some neurons fire only in response to high tones, whereas others respond only to tones having some other specific frequency. Many of these single-cell responses are present at birth, suggesting that we are “prewired” to perceive many aspects of our sensory environment (Shair et al., 1991). Nonetheless, the sensory cortex, like other parts of the brain, is also sensitive to experiences. For example, when people learn to read Braille, the area in the sensory cortex that receives input from the fingertips increases in size, making the person more sensitive to the tiny sets of raised dots (Pool, 1994).

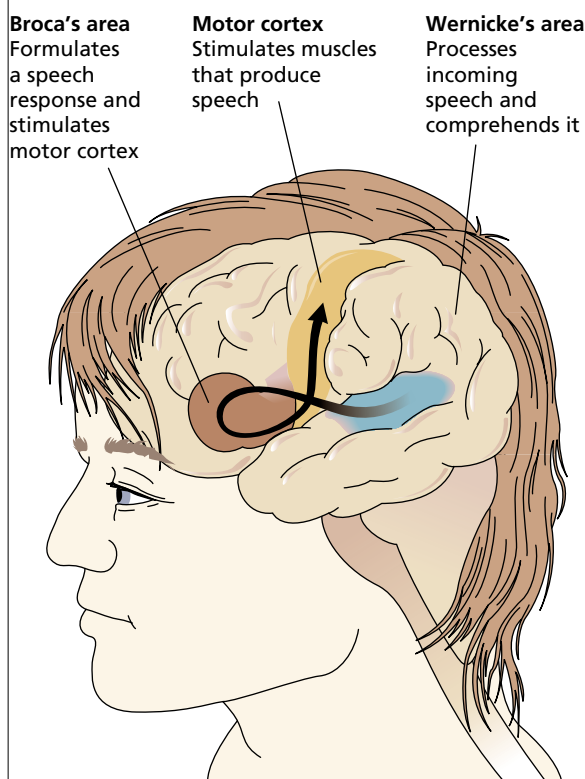
**Speech comprehension and production.** Two specific areas that govern the understanding and production of speech are also located in the cortex (Figure 3.17).

**Wernicke’s area** in the temporal lobe is involved in speech comprehension. The area is named for Carl Wernicke, who in 1874 discovered that damage to this cortical region left patients unable to understand written or spoken speech. Additionally, these patients often spoke in meaningless gibberish. **Broca’s area** in the frontal lobe is involved in the production of speech through its connections with the motor cortex region that controls the muscles used in speech. Its discoverer, Paul Broca, found that damage to this frontal area left patients with the ability to comprehend speech but not to express themselves in words or sentences. These two speech areas normally work in concert when you are conversing with another person. They allow you to comprehend what the other person is saying and to express your own thoughts (Werker & Tees, 1992). In this example, input is sent from the ears to the auditory cortex and is routed to Wernicke’s area for comprehension. When you decide to reply, nerve impulses are sent from Wernicke’s area to Broca’s area, and impulses passed on from Broca’s area to the motor cortex result in the mouthing of a verbal response. This sequence illustrates a key action principle of brain functioning: even relatively simple acts usually involve the coordinated action of several brain regions.

**Association cortex.** The **association cortex** is critically involved in the highest level of mental functions, including perception, language, and thought. These areas are sometimes referred to as “silent areas” because electrical stimulation of them does not give rise to either sensory experiences or to motor responses. This fact has probably helped promote the widely cited myth that most humans use only 10 percent of their brain power. Nothing could be farther from the truth.

Damage to specific parts of the association cortex causes disruption or loss of functions such as speech, understanding, thinking, and problem solving. As we might expect if the association cortex is involved in higher mental processes, the amount of association cortex increases

► 25. Where are Wernicke’s and Broca’s areas? How are they involved in speech?



**FIGURE 3.17** Cortical areas involved in language. Wernicke’s area is important in the comprehension of spoken or written speech. Broca’s area is involved in the production of speech, and the motor cortex stimulates the speech production muscles.

► 26. What is the role of association cortex, the “silent areas”?

dramatically as we move up the brain ladder from lower animals to human beings. It constitutes about 75 percent of the human cerebral cortex and accounts for people's superior cognitive abilities. Our mass of association cortex has been described by one scientist as "evolution's missing link" (Skoyles, 1997). He suggests that the mental flexibility and learning capacity it provides has allowed us to upgrade our cognitive skills and to acquire new mental skills specific to our human way of life, such as reading, mathematics, and chess, more quickly than could have occurred through natural selection alone.

The importance of association cortex is demonstrated in people who suffer from **agnosia**, the inability to identify familiar objects. One such case is described by the neurologist Oliver Sacks (1985).

Dr. P. was a talented and accomplished musician whose behavior was quite normal except for one glaring exception: Although his vision was perfect, he often had difficulty recognizing familiar people and objects. Thus, he would chat with pieces of furniture and wonder why they did not reply, or pat the tops of fire hydrants, thinking they were children. One day, while visiting Sack's office for an examination, Dr. P. looked for his hat as he was ready to depart. He suddenly reached out and grabbed his wife's head, trying to lift it. He had mistaken his wife for his hat! His wife smiled tolerantly; she had become accustomed to such actions on his part.

Dr. P. had suffered brain damage that left him unable to relate the information sent by his eyes to the visual cortex with information stored in other cortical areas that concerned the nature of objects. The associative neurons responsible for linking the two types of information no longer served him.

**The frontal lobes: the human difference.** Some neuroscientists have suggested that the entire period of human evolutionary existence could well be termed the "age of the frontal lobe" (Krasnegor et al., 1997). This mass of cortex residing behind our eyes and forehead hardly exists in mammals such as mice and rats. The frontal lobes comprise about 3.5 percent of the cerebral cortex in the cat, 7 percent in the dog, and 17 percent in the chimpanzee. In a human, the frontal lobes constitute 29 percent of the cortex. The site of such human qualities as self-awareness, planning, initiative, and responsibility, the frontal lobes are in some respects the most mysterious and least understood part of the brain.

Much of what we know about the frontal lobes comes from detailed studies of patients who have experienced brain damage. Frontal lobe damage results not so much in a loss of intellectual abilities as in an inability to plan and carry out a sequence of actions, even when patients can verbalize what they should do. This can result in an inability to correct actions that are clearly erroneous and self-defeating (Shallice & Burgess, 1991).

The frontal cortex is also involved in emotional experience. In people with normal brains, PET scans show increased activity in the frontal cortex when people are experiencing feelings of happiness, sadness, or disgust (Lane et al., 1997). In contrast, patients with frontal lobe damage often exhibit attitudes of apathy and lack of concern. They literally don't seem to care about anything.

A region of the frontal lobe known as the prefrontal cortex has received increasing attention in recent years. The **prefrontal cortex**, located just behind the forehead, is the seat of the so-called executive functions. *Executive functions*, mental abilities involving goal setting, judgment, strategic planning, and impulse control, allow people to direct their behavior in an adaptive fashion. Deficits in executive functions seem to underlie a number of problem behaviors. People with prefrontal cortex disorders seem oblivious to the future consequences of their actions and seem to be governed only by immediate consequences (Bechara et al., 1994). As you may have guessed by now, Phineas Gage, the railroad foreman described in our chapter-opening case, suffered massive

► 27. Describe the role of the frontal cortex in higher mental (including "executive") functions.

frontal lobe damage when the spike tore through his brain (see Figure 3.1). Thereafter he exhibited classic symptoms of disturbed executive functions, becoming behaviorally impulsive and losing his capacity for future planning.

A more ominous manifestation of prefrontal dysfunction was discovered by Adrian Raine and his coworkers (1997). Using brain-imaging techniques, the researchers studied 41 violent murderers who had pleaded not guilty by reason of insanity. The murderers' PET scans showed clear evidence of reduced activity in the prefrontal cortex. Their murderous acts, which were often random and impulsive in nature, showed parallel evidence of failure in executive functions such as judgment, foresight, and impulse control. Raine suggested that people with similar prefrontal dysfunction may have a neural predisposition to impulsive violence.

During the 1940s and 1950s many thousands of psychiatric patients who suffered from disturbed and violently emotional behavior were subjected to **prefrontal lobotomies** (Shorter, 1998). The operation was performed by inserting an icepicklike instrument with sharp edges through the eye socket, then wiggling it back and forth to sever the nerve tracts that connected the the frontal lobes with the subcortical regions connected with emotion. The calming effect was so dramatic that Egas Moriz, the developer of the technique, was awarded a Nobel Prize. However, the devastating side effects on mental functions that occurred as the executive functions were destroyed were equally dramatic, and the development of antipsychotic drugs resulted in an abandonment of this form of "treatment."

### *Hemispheric Lateralization: The Left and Right Brains*

The left and right cerebral hemispheres are connected by a broad white band of myelinated nerve fibers. The **corpus callosum** is a neural bridge that acts as a major communication link between the two hemispheres and allows them to function as a single unit. Despite the fact that they normally act in concert, however, there are important differences between the psychological functions that are represented in the two cerebral hemispheres. **Lateralization** refers to the relatively greater localization of a function in one hemisphere or the other.

Medical studies of patients who suffered various types of brain damage provided the first clues that certain complex psychological functions were lateralized on one side of the brain or the other. The deficits observed in people with damage to one hemisphere or the other suggested that, for most people, verbal abilities and speech are localized in the left hemisphere, as are mathematical and logical abilities (Springer, 1997).

When Broca's or Wernicke's speech areas are damaged, the result is **aphasia**, the partial or total loss of the ability to communicate. Depending on the location of the damage, the problem may lie in recognizing the meaning of words, in communicating verbally with others, or in both functions. C. Scott Moss, a clinical psychologist who became aphasic in both ways for a time as a result of a left hemisphere stroke, described what it was like for him.

I recollect trying to read the headlines of the Chicago Tribune but they didn't make any sense to me at all. I didn't have any difficulty focusing; it was simply that the words, individually or in combination, didn't have meaning, and even more amazing, I was only a trifle bothered by that fact. . . . I think part of the explanation was that I had [also] lost the ability to engage in self-talk. In other words, I didn't have the ability to think about the future—to worry, or anticipate or perceive it—at least not with words. (Moss, 1972, pp. 4–5)

When the right hemisphere is damaged, the clinical picture is quite different. Language functions are not ordinarily affected, but the person has great difficulty in performing tasks that demand the ability to perceive spatial relations.

► 28. What is hemispheric lateralization and what do we know about the functions that are concentrated in the left and right hemispheres?

A patient may have a hard time recognizing faces and may even forget a well-traveled route or, as in the case of Dr. P., mistake his wife for a hat (Sacks, 1985). It appears that mental imagery, musical and artistic abilities, and the ability to perceive and understand spatial relationships are primarily right-hemisphere functions (Ornstein, 1997).

The two hemispheres differ not only in the cognitive functions that reside there, but also in their links with particular types of emotions. EEG studies have shown that the right hemisphere is relatively more active when negative emotions such as sadness and anger are being experienced. Positive emotions such as joy and happiness are accompanied by relatively greater left-hemisphere activation (Fox & Davidson, 1991; Tomarken et al., 1992).

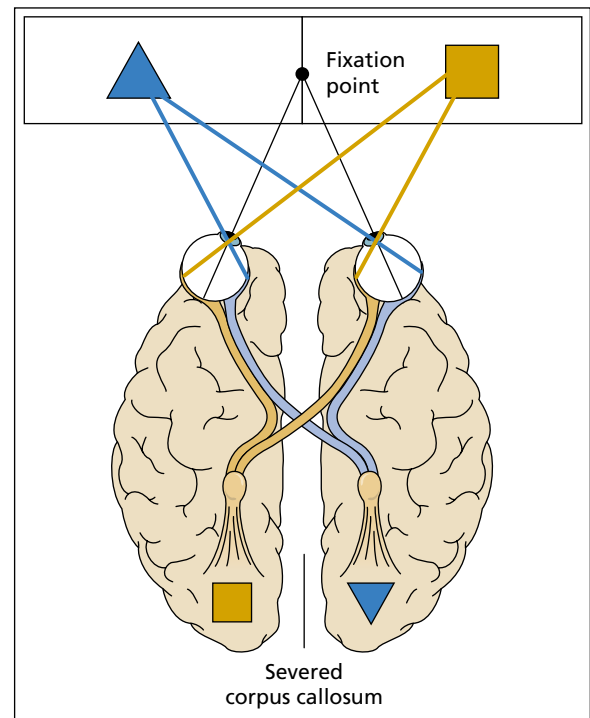
**The split brain: two minds in one body?** Despite the lateralization of specific functions in the two cerebral hemispheres, the brain normally functions as a unified whole because the two hemispheres communicate with one another through the corpus callosum. But what would happen if this communication link between the two hemispheres were cut? Would we, in effect, produce two different and largely independent minds in the same person? A series of Nobel Prize-winning studies by Roger Sperry (1970) and his associates addressed this question.

Like many scientific advances, this discovery resulted from natural human misfortune. Some patients suffer from a form of epilepsy in which a seizure that begins as an uncontrolled electrical discharge of neurons on one side of the brain spreads to the other hemisphere. Years ago, neurosurgeons found that by cutting the nerve fibers of the corpus callosum, they could prevent the seizure from spreading to the other hemisphere. Moreover, the operation did not seem to disrupt other major psychological functions. Sperry's studies of patients who had had such operations involved some ingenious ways to test the functions of the two hemispheres after the corpus callosum was cut.

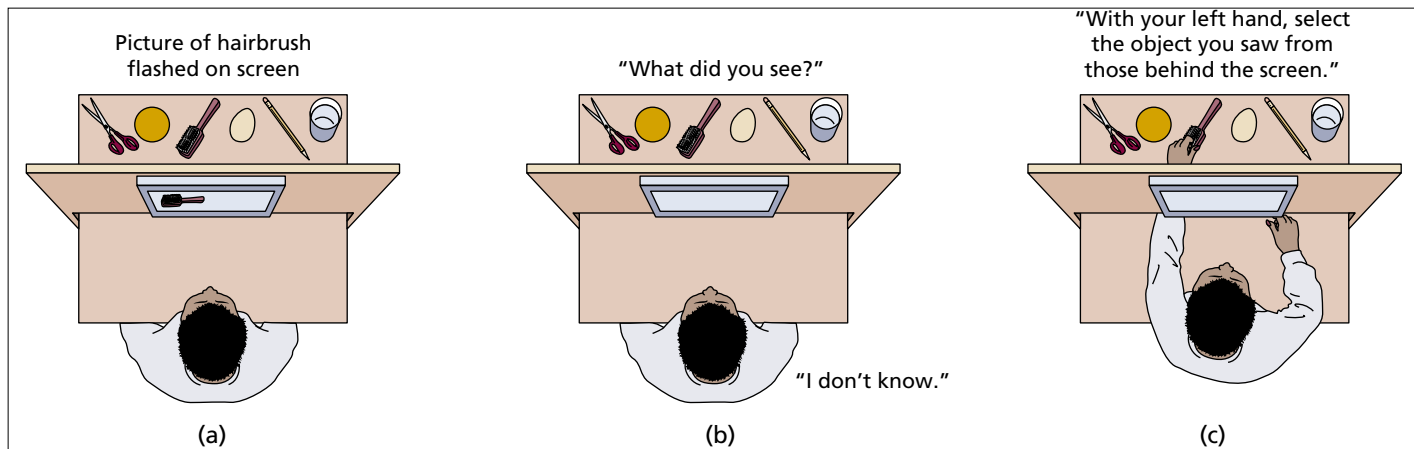
Split-brain research was made possible by the way in which our visual input to the brain is "wired." To illustrate, extend your two hands straight out in front of you, separated by about one foot. Now focus on the point between them. You'll find that you can still see both hands in your peripheral division, and that you have a unified view of the scene. It therefore might surprise you to know that your left hand is being "seen" only by your right hemisphere and your right hand only by your left hemisphere. To see how this occurs, examine Figure 3.18, which shows that some of the fibers of the optic nerve from each eye cross over at the **optic chiasma** and travel to the opposite brain hemisphere. Fibers that transmit messages from the right side of each eye's visual field project to the left hemisphere; fibers from the visual field's left half project to the right hemisphere. Despite this arrangement, we experience a unified visual world (as you did when you looked at your hands) rather than two half-worlds because the hemispheres' visual areas are normally connected by the corpus callosum. When the corpus callosum is cut, however, visual input to one hemisphere can be restricted by projecting the stimulus to either the right side of the visual field (in which case the image goes only to the left hemisphere) or to the left side of the visual field, which sends it to the right hemisphere.

In Sperry's experiments, split-brain patients basically did what you did with your hands: They focused on a fixation point, a dot on

- 29. What roles have (a) the corpus callosum and (b) the optic chiasma played in "split-brain" research? Is it reasonable to speak of separate "right" and "left" brains in normal people?



**FIGURE 3.18** The visual system's anatomy made studies of split-brain subjects possible. Images entering the eye are reversed by the lens. Optic nerve fibers from the inner portion of the retina (toward the nose) cross over at the optic chiasma, whereas the fibers from the outer portion of the retina do not. As a result, the right side of each eye's field projects to the visual cortex of the left hemisphere, whereas the left visual field projects to the right hemisphere. When the corpus callosum is cut, the two hemispheres no longer communicate with each other. By presenting stimuli to either side of the visual fixation point, researchers can control which hemisphere receives the information.



**FIGURE 3.19** A split-brain patient focuses on the fixation point in the center of the screen. In (1), a picture of a hair brush is briefly projected to the left side of the visual field, thus sending the information to the right hemisphere. In (2), the patient is asked to state verbally what she saw. She cannot name the object. In (3), she is asked to select the object she saw, and is able to find it with her left hand. If the object were transferred to her right hand or if the word were flashed to the right side of the visual field, the information would be sent to the language-rich left hemisphere, and she would be able to name the object.

the center of a screen, while slides containing visual stimuli (words, pictures, and so on) were flashed to the right or left side of the fixation point (Figure 3.19).

Sperry found that when words were flashed to the right side of the visual field, resulting in their being sent to the language-rich left hemisphere, subjects could verbally describe what they had seen. They could also write what they had seen with their right hand (which is controlled by the left hemisphere). However, if words were flashed to the left side of the visual field and sent on to the right hemisphere, the subjects could neither describe them verbally nor write what they had seen with their left hand. This pattern of findings indicated that the right hemisphere does not have well-developed language abilities.

The inability to identify objects verbally did not mean, however, that the right hemisphere was incapable of recognizing them. If a picture of an object (e.g., a hair brush) was flashed to the right hemisphere and the left hand (controlled by the right hemisphere) was allowed to feel many different objects behind the screen, the person's hand would immediately select the spoon and hold it up. As long as the person continued to hold the spoon in the left hand, sending sensory input about the object to the "nonverbal" right hemisphere, the subject was unable to name it. However, if the spoon was transferred to the right hand, the person could immediately name it. In other words, until the object was transferred to the right hand, the left hemisphere had no knowledge of what the right hemisphere was experiencing.

Later research showed the right hemisphere's definite superiority over the left in the recognition of patterns. In one study, three split-brain subjects were presented with photographs of similar-looking faces projected in either the left or right visual fields. On each trial, the subjects were asked to select the photo they had just seen from a set of 10 cards. On this task, the spatially oriented right hemisphere was far more accurate than the linguistic left hemisphere in correctly identifying the photos (Figure 3.20). Apparently, the faces were too similar to one another to be differentiated very easily by left-hemisphere verbal descriptions, but the spatial abilities of the right hemisphere could differentiate among them (Gazzaniga & Smylie, 1983).

Some psychologists have suggested that what we call the conscious self resides in the left hemisphere, because consciousness is based on our ability to verbalize about the past and present. Is the right hemisphere, then, an unconscious (nonverbal) mind? Yes, these psychologists answer, except when it communicates with the left hemisphere across the corpus callosum (Ornstein, 1997).

But when the connections between the two hemispheres are cut, each hemisphere, in a sense, can have a “mind of its own,” as this example shows.

One split-brain patient learned to use Scrabble letters to communicate from his right hemisphere using his left hand. To test the dual-mind hypothesis, researchers asked the two hemispheres the same questions—and found that the answers often disagreed. For example, when asked what occupation he would prefer, the left hemisphere responded verbally, “a draftsman.” But the right hemisphere used the Scrabble pieces to spell out, “race car driver.” (LeDoux and others, 1977)

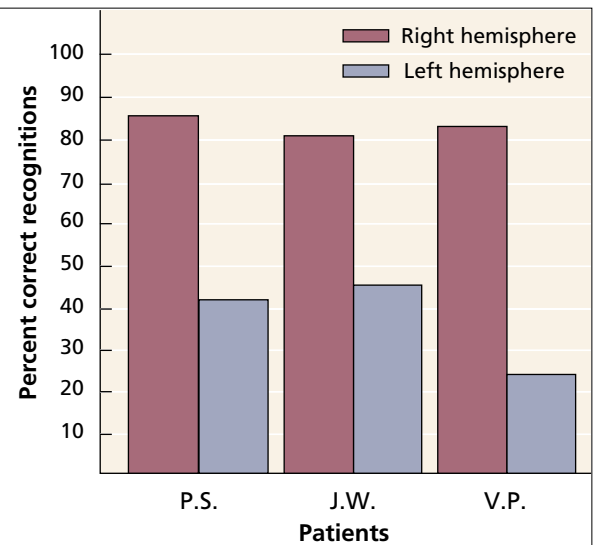
Keep in mind that in daily life, the split-brain patients could function adequately because they had learned to compensate for their disconnected hemispheres. For example, they could scan the visual environment so that visual input from both the left and right visual fields got into both hemispheres. The “split-mind” phenomena shown in the laboratory appeared because the patients were tested under experimental conditions that were specifically designed to isolate the functions of the two hemispheres. Nonetheless, the results of split-brain research were so dramatic that they led some people (and even some scientists) to promote a conception of brain functions as being highly localized and restricted to one hemisphere or the other. Even today, we hear about “right brain” education programs and the untapped potentials that they can release. Certainly, there is some degree of localization of brain functions, but a far more important principle is that in the normal brain, most functions involve many areas of the brain working together. The brain is an exquisitely integrated system, not a collection of localized functions.

**Hemispheric lateralization of language.** For many years, scientists have known that for most people, language is a left-hemisphere function. Why language tends to be localized in the left hemisphere is not known, but it may have some undiscovered evolutionary significance. The brain of the chimpanzee, our genetically closest relative in the animal kingdom, also has a larger left hemisphere in the region that corresponds with Wernicke’s speech comprehension area in the human brain (Gannon et al., 1998).

About 90 percent people are right-handed, and among this majority, 95 percent have language in the left hemisphere. Among left-handers, half have language in the left hemisphere, 25 percent have it localized in the right hemisphere, and the rest have language functions in both hemispheres. Those who use both hemispheres for language functions have a larger corpus callosum, perhaps because more interhemispheric communication is required (Springer, 1998).

Left-hemisphere lateralization is the case not only of spoken and written language, but also for nonverbal kinds of language, such as sign language. PET scans of neural activity show that just as hearing people process speech with their left hemisphere, deaf people use the left hemisphere to read sign language. Likewise, a left-hemisphere stroke affects their ability to understand or produce sign language (Corina et al., 1992).

Realize, however, that even if your left hemisphere is dominant for language, this does not mean that your right hemisphere lacks language ability. PET scan studies measuring cerebral blood flow in the brains of normal people indicate that both hemispheres are involved in speaking, reading, and listening (Leonides, 1997; Raichle, 1994). One notable finding, however, is that males and females may differ in the extent to which certain language functions are lateralized, or located, on one side of the brain. This chapter’s *Research Close-Up* describes the use of brain imaging to study possible sex differences in the brain’s language capabilities and evaluates the implications of these findings.



**FIGURE 3.20** Facial recognition accuracy by the left and right hemispheres of three split-brain patients, showing greater accuracy when information is flashed to the right hemisphere, which has stronger pattern-recognition abilities.

Data from Gazzaniga & Smylie, 1983

- ▶ 30. How is language lateralized in the brain? Are there sex differences?

## RESEARCH CLOSE-UP



## Are Language Functions Localized Differently in Men and Women?

### ► Background

There have been tantalizing hints that the brains of men and women may differ in the extent to which language is localized in the left hemisphere. For example, clinicians have observed that men who suffer left-hemisphere strokes are more likely than women to show severe aphasic symptoms. In women with left-hemisphere damage, language functions are more likely to be spared, suggesting that more of their language function is shared with the right hemisphere. What has been lacking, however, is direct comparisons of the functioning brains of men and women. This classic study, performed at Yale University, was the first to use modern brain-imaging techniques to explore the hypothesis of greater male lateralization

### ► Method

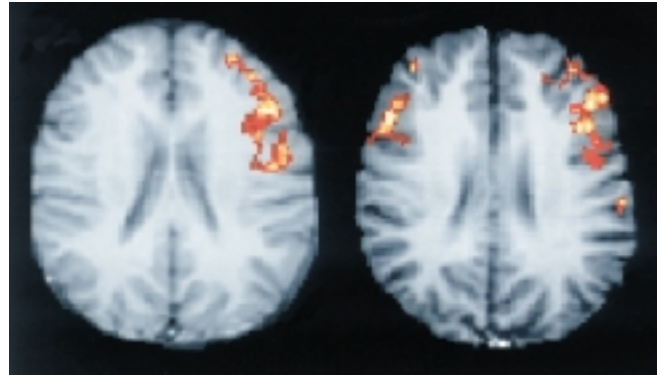
The sample consisted of 19 males and 19 females averaging 26 years of age. All participants were right-handed and neurologically normal. The participants performed several language tasks while functional magnetic resonance imaging (fMRI) recordings were made of changes in patterns of cerebral blood flow within the left and right hemispheres. This procedure allowed the researchers to identify brain regions where levels of neural activity increased in response to four different mental tasks. The critical task was a language task that required participants to view sets of randomly arranged vowels and consonants and decide whether or not the two “nonsense” words rhymed with each other. This task was chosen because it required the subjects to “sound out” the words in their minds to form a representation of the word sounds, a function that is critical in understanding language.

### ► Results

The fMRIs allowed the researchers to compare the cerebral blood flow responses of males and females as they responded to the experimental tasks. Their analyses revealed that the rhyming task produced increased cortical activity in a region of the left hemisphere that is known to be involved in language. For males, this neural activity was restricted to the left hemisphere, but for females, the activity was represented in the corresponding areas of both hemispheres (Figure 3.21).

### ► Critical Analysis

This study provided the first direct evidence through brain imaging of a gender difference in language organization within the normal brain. It also demonstrates the tremendous value of fMRI technology (Rugg, 1995). Greater left-hemisphere lateralization of language in males may help to



**FIGURE 3.21** Functional MRI recordings of brain activity in men and women as they performed a language task showed greater left hemisphere lateralization in men. Women showed activity in both hemispheres.

Shaywitz & others, 1995

account for the aphasia differences that have been observed between brain-damaged men and women, showing how clinical and experimental observations can complement one another. More importantly, the results of this landmark study add to a growing body of evidence that differences between the brains of men and women may help account for emotional, cognitive, and behavioral differences between the sexes (Halpern, 1992; Kimura & Hampson, 1994). For example, in a finding that may shed light on the results of this study, Laura Allen and Roger Gorski (1991) discovered through postmortem examinations of 100 age-matched men and women that the corpus callosum and other tracts that connect the two hemispheres were significantly larger in females than in males, suggesting the potential for greater communication between the hemispheres in women.

Before concluding that women’s brains are more “holistic” than men’s, however, we should note that several important questions remain unanswered:

- Can these findings be replicated by other researchers and with other language tasks?
- The fact that the right hemisphere of women was active during the language task was clearly evident in the data, but what we have so far is a correlation between task performance and biological activity. Does this activity play a causal role in task performance? Is it essential for task performance? We simply don’t know at this point.

—Continued

- If there is a real gender difference, what causes it—innate biological differences or differences in experience that affect thinking and brain development? Or both?

A related question is whether women have greater need than men for right-hemisphere activation. Needed are studies of women who have lesions in that right-hemisphere region. One thing we do know is that women

with right-hemisphere damage are *not* more likely than men to become aphasic (Rugg, 1995). If the right hemisphere were essential for language in women, we might expect to find more aphasia in women with damage in that hemisphere. Perhaps women utilize both hemispheres for the performance of some language functions, but can fall back on one if damage occurs to the other. Future research will provide answers to these important questions.

Source: Bennett. Shaywitz, Sally Shaywitz, Kenneth Pugh et al. (1995). Sex differences in the functional organization of the brain for language. *Nature*, 373, 607–609.

### *Plasticity in the Brain: The Role of Experience and the Recovery of Function*

Learn to walk, acquire speech, begin to read, fall in love, and your brain changes in a way that makes you a different person than you were before. Learning and practicing a mental or physical skill may change the size or number of brain areas involved and alter the neural pathways used in the skill (Posner et al., 1997). This process of brain alteration begins in the womb and continues throughout life. It is governed in important ways by genetic factors, but also is strongly influenced by the environment.

**Neural plasticity** refers to the ability of neurons to change in structure and function (Kolb & Whishaw, 1998). Two aspects of neural plasticity—the effects of early experience on brain development and recovery from brain damage—are at the forefront of current research.

**The role of early experience.** Brain development is programmed by complex commands from our genes, but how these genetic commands express themselves can be powerfully affected by the environment in which we develop, including the environment we are exposed to in the womb (Filogamo, 1998). Consider the following research findings:

- For the fetus in the womb, exposure to high levels of alcohol ingested by the pregnant mother can disrupt brain development and produce the life-long mental and behavioral damage seen in fetal alcohol syndrome (Streissguth et al., 1990).
- The brains of rat pups raised in a stimulating early environment containing lots of playmates and toys weighed more, had larger neurons and more dendritic branches, and greater concentrations of acetylcholine, the neurotransmitter involved in motor control and in memory (Rosenzweig, 1984).
- Prematurely born human infants who were caressed and massaged on a regular basis showed faster neurological development than did those given normal care and human contact (Field et al., 1986).
- MRI recordings revealed that experienced string musicians who do elaborate movements on the strings with their left hands had a larger right-hemisphere somatosensory area devoted to these fingers than did nonmusicians. The corresponding left-hemisphere (right-hand) cortical areas of the musicians and nonmusicians did not differ. The earlier in life the musicians had started playing their instruments, the more cortical change had occurred (Ebert et al., 1995).
- Cultural factors may affect brain development as well. For example, the Chinese language uses complex pictorial images (rather than words) to represent objects or concepts. Because pictorial stimuli are processed in the right hemisphere, we might expect less left-hemisphere lateralization of language among speakers of Chinese than among people who speak English or other alphabet-based languages. There is evidence to support this hypothesis in the areas of reading and writing (Tzeng et al., 1979).

►31. What is neural plasticity? How do age, environment, and behavior affect plasticity?

In a sense, your brain goes through its own personal “evolutionary” process as it adapts to and is molded by your individual environment during the course of your life. Once again we can see why the nature-nurture debate described in Chapter 1 has given way to an appreciation for the many ways in which biology and experience continually interact.

**Recovery of function after injury.** When an injury results in the destruction of brain tissue, other neurons must take over the lost functions of the dead neurons if recovery is to occur. At times the brain shows an amazing plasticity and recovery of function, as the following case illustrates:

Jimmy was a healthy and normal 5-year-old child who awoke one day unable to speak and slightly paralyzed on the right side of his body. A blood vessel in his left temporal lobe had ruptured and an area of the brain “downstream” from the site of the stroke had died when its blood supply was cut off. For Jimmy’s father, it was like reliving a nightmare. His own grandfather had also suffered a left hemisphere stroke late in life. The elderly man never recovered his speech and he remained partially paralyzed until his eventual death. But for Jimmy, the story had a happier ending. Within three months, Jimmy was again speaking normally, and his paralysis had disappeared completely. He was ready to resume the life of a normal 5-year-old. All that remained of his ordeal was a frightening memory. (Gazzaniga et al., 1979)

Neural reorganization had occurred in Jimmy’s brain, allowing other neurons to take over the functions of those that had died. The outcomes for Jimmy and his grandfather also illustrate an important general principle: Brain damage suffered early in life is less devastating than damage suffered as an adult. (Blosser, 2000).

The brain is clearly capable of greater plasticity early in life. In one study, researchers took neurons from the visual cortex of cats and then raised the neurons in a culture containing the nutrients needed for survival. They found that the neurons could survive and create new synapses with other neurons in the culture quite well if they were taken from kittens who were 2 to 4 weeks old, but not if they were obtained from older animals (Schoop et al., 1997).

Studies using the electron microscope may explain why such plasticity is possible early in life. The 1- to 2-year-old child has about 50 percent more brain synapses than mature adults do (Huttenlocher, 1979). This greater availability of synapses may help to explain why children can recover from brain damage more quickly and completely than adults. But sadly the days of synaptic riches don’t last forever. Unused or weaker synapses deteriorate with age so that the brain loses some of its plasticity (Filogamo, 1998). Moreover, cell death is programmed into every neuron by its genes, and what some neuroscientists refer to as the neuron’s “suicide apparatus” is activated by a lack of stimulation from other neurons and by many other unknown factors (Milligan & Schwartz, 1997). As a result, adults actually have fewer synapses in the brain than do children, despite their more advanced cognitive and motor capabilities.

Yet even adults can maintain or recover some functions after neuron death (Varney & Roberts, 1999). When nerve tissue is destroyed or neurons die as part of the aging process, surviving neurons can restore functioning by modifying themselves either structurally or biochemically. They can alter their structure by sprouting enlarged networks of dendrites or by extending axons from surviving neurons to form new synapses (Shepherd, 1997). Surviving neurons may also make up for the loss by increasing the volume of neurotransmitters they release (Robinson, 1997). Finally, recent research findings have begun to challenge the long-standing assumption of brain scientists that dead neurons cannot be replaced in the mature brain (McMillan et al., 1999). The development of new cells (*neurogenesis*) has been demonstrated in the brains of rodents and primates within the hippocampus, which is involved in memory. In 1998, evidence for the birth of new cells in the human adult hippocampus appeared (Eriksson et al., 1998). Then

► 32. Why do children typically show better recovery of function after brain injury?

in what could be a landmark scientific discovery, psychologist Elizabeth Gould and her Princeton coworkers (1999) provided the first evidence of neurogenesis in the cerebral cortex of a primate. Using complex chemical and microscopic analysis techniques with adult macaque monkeys, Gould's team tracked newly developed neurons from their birthplace in subcortical tissue. The immature neurons migrated upward along myelinated nerve tracts into the association areas of the cerebral cortex, where they sprouted axons and extended them toward existing neurons. The researchers speculated that these new neurons may be involved in higher-order mental functions, such as complex learning and memory. If similar results are found in humans, whose brain structures and functions are similar to those of primates, new light could be shed on brain mechanisms of information storage and plasticity. It is even possible that degenerative mental disorders such as Alzheimer's disease represent a failure or decline in a previously unknown process of neuron regeneration in the mature brain.

Behavioral and lifestyle measures can also help preserve brain functioning. In elderly people, for example, continued intellectual stimulation and activity seems to preserve synapses and their resulting cognitive functions, adding support to physiological psychologist David Krech's statement that "Those who live by their wits die with their wits" (Krech, 1978).

Basic research on naturally occurring recovery processes is leading to new ways to help the brain heal itself. These efforts are the focus of this chapter's *Applications of Psychological Science*.

►33. How are axon repair, brain grafts, and neural stem cell injections being used to improve the functioning of damaged brains? What kinds of ethical issues arise in the use of these procedures?

## APPLICATIONS OF PSYCHOLOGICAL SCIENCE



### Healing the Nervous System

Neurological disorders take a frightening psychological toll on their victims, who often lose basic cognitive, sensory, and motor functions and can suffer devastating emotional and social consequences. Although severed fingers and toes can be reattached and regain their functions, the same has not been true in the damaged spinal cord and brain. Until recently, it was thought that dead neurons were impossible to replace. Now, however, hope for victims of neurological disease or injuries has been rekindled by the discovery that damaged neurons can be repaired (Solso, 1999).

Until recently, paralyzed individuals with spinal injuries have had little hope of recovering lost motor and sensory functions. Such injuries usually involve severed axons, resulting in a loss of nerve transmission to neighboring neurons. But in several experiments involving rats, axons in the spinal cord have been severed, and the neurons from which the axons originated placed under a weak electrical current. This current stimulated regrowth of axons out of the cell bodies. The axons grew over the injury to seek their predamage positions on the other side of the cut. Other studies have used chemical methods to stimu-

late axon development, including the implantation of cells that produce *nerve growth factor*, a substance that helps stimulate and guide the growth of axons. In many cases, surviving neurons responded by sprouting axons that grew toward the the graft and repaired the damaged tract (Joosten, 1997). The positive results obtained in animal research on neural regrowth following injury gives scientists hope that they may one day be able to fix what has long been irreparable—the severed spinal cord.

*Parkinson's disease* is a progressive brain disorder that produces uncontrollable tremors, difficulties in movement, and body rigidity that can eventually border on paralysis. Psychological problems such as memory and concentration problems and depression are also commonly experienced. The disease is caused by the chemical destruction of dopamine-producing cells within a small midbrain structure. Victims of Parkinson's can obtain some relief with *L-DOPA*, a drug that helps restore missing dopamine and helps alleviate the movement problems. Unfortunately, after 5 to 10 years of using the drug, many patients must stop taking it because of serious side effects, whereupon their symptoms return

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and become progressively worse (Ron & David, 1997). Thus the long-term prognosis for Parkinson's disease patients has been rather grim.

Might it be possible to transplant healthy neural tissue into diseased areas of the brain so as to produce the missing dopamine and restore neurological function? Successes with animal implants have stimulated experiments with human patients. Scientists have taken advantage of the fact that one of the substances produced by the adrenal glands is dopamine. They have therefore taken dopamine-producing cells from patients' own adrenal glands (to avoid rejection of the transplant) and implanted them into the subcortical brain region affected by Parkinson's disease. So far the results have been variable, with dramatic improvement occurring in some cases and no improvement at all in others. In one of the successes reported by a team of Mexican scientists, a patient who had been confined to a wheelchair was out playing soccer with his son 10 months after the surgery (Madrazo et al., 1987).

Dopamine-producing human fetal tissue seems to be even better for transplants than a patient's own adrenal tissue, because fetal tissue tends to secrete more dopamine and is more likely to survive and "take hold" in the damaged area. Such tissue is sometimes available as a result of miscarriages. In one study, 6 patients who had received fetal tissue transplants were followed up for periods of up to 6 years. After 8 to 12 months, PET scans showed that the transplanted tissue had survived and was producing significant amounts of dopamine. As a result, the patients required less L-DOPA over time, and one patient was able to be taken off the drug altogether after 32 months. Significant improvement in motor function was observed in 4 of the 6 patients (Wenning et al., 1997). These results are encouraging, but before the new treatment will be ready for widespread clinical use, researchers must increase the survival and growth of the transplanted fetal tissue. Meanwhile researchers working with laboratory animals have reported success in using neural transplants to treat epilepsy and even strokes (Blank, 1999). This is an example of the important role that animal research can play in developing the knowledge and techniques needed for human interventions.

As brain grafting takes us into a new era in which we may be able to physically modify the brain, new ethical and legal questions have become topics for debate (Gold, 1997; Sauer, 1998). What do you think about the following issues?

- Is it possible that increased demand for fetal tissue may provide a profitable market for the "harvesting" of needlessly aborted fetuses? Could the prospect of financial gain encourage some women to become pregnant with the intention of aborting the fetus and selling the tissue? Is it the parents' tissue to sell? (Gold, 1998)
- Suppose the daughter of a Parkinson's patient asked to be artificially inseminated with her father's sperm so that she could later have an abortion, thereby producing a supply of fetal tissue for implantation in his brain with a reduced likelihood of tissue rejection because of genetic similarity. Aside from the moral issue concerning the premeditated abortion, would the insemination constitute incest?

- Suppose a brain graft from another person results in a genetically based change in personality and a penchant for antisocial behavior. Is the person legally responsible for his or her subsequent acts? In fact, because of the genetic change, is he or she still the same person?

Such issues are now being debated by medical ethicists. Meanwhile practical steps are being taken in anticipation of future advances in brain grafting and other interventions. For example, scientists at the National Institutes of Health in the United States, are attempting to grow tissue cultures of human fetal cells that could be used in future transplants as an alternative to actual fetal tissue. Other interventions currently being developed include the implanting of genetically altered cells into the brain, where they could directly change cellular processes, such as the production of neurotransmitters (Horellou et al., 1997; Wood, 1997).

One revolutionary technique involves the transplantation into the brain of **neural stem cells**, immature "uncommitted" cells that can mature into any type of neuron or glial cell needed by the brain (Gage & Christen, 1997). These cells, found in both the developing and adult nervous system, can be put into a liquid medium and injected directly into the brain. Once in the brain, they can travel to any of its regions, especially developing or degenerating areas. There they can detect defective or genetically impaired cells and somehow convert themselves into healthy forms of the defective cells.

Researchers at Harvard Medical School demonstrated the potential value of stem cell transplantation (Yandava et al., 1999). They worked with a strain of mice called "shiverers" who have a genetic defect that prevents their glial cells from producing the insulating myelin sheath on axons. Within 3 weeks after birth, the animals begin to develop severe tremors similar to those seen in multiple sclerosis, a human disease produced by insufficient myelin. Using a neural stem cell culture grown from cells removed 13 years ago from the brain of a newborn mouse, the researchers injected stem cells directly into the brains of randomly selected shiverers. A control group of shiverers did not receive the cells. In the injected rats, the stem cells apparently detected the defective gene and converted themselves into the myelin-producing cells. They then began to produce the missing myelin throughout the brain, and some of the mice developed myelin sheaths that could not be distinguished from those of normal mice. About 60 percent of the experimental group mice appeared to behave like normal mice, showing no signs of the motor disturbances that accompany insufficient myelination. Others showed greatly reduced motor symptoms. All of the control animals became shiverers.

The fact that transplanted stem cells can apparently go anywhere in the brain and become any kind of cell suggests the possibility of revolutionary treatments for diseases involving widespread neural degeneration and dysfunction, such as Alzheimer's, multiple sclerosis, strokes, mental disorders, and genetically based birth defects, all of which have serious psychological consequences. Much more research is needed, but, at long last, we may be on the threshold of being able to heal the damaged brain and restore lost psychological functions.

## ▶ NERVOUS SYSTEM INTERACTIONS WITH THE ENDOCRINE AND IMMUNE SYSTEMS

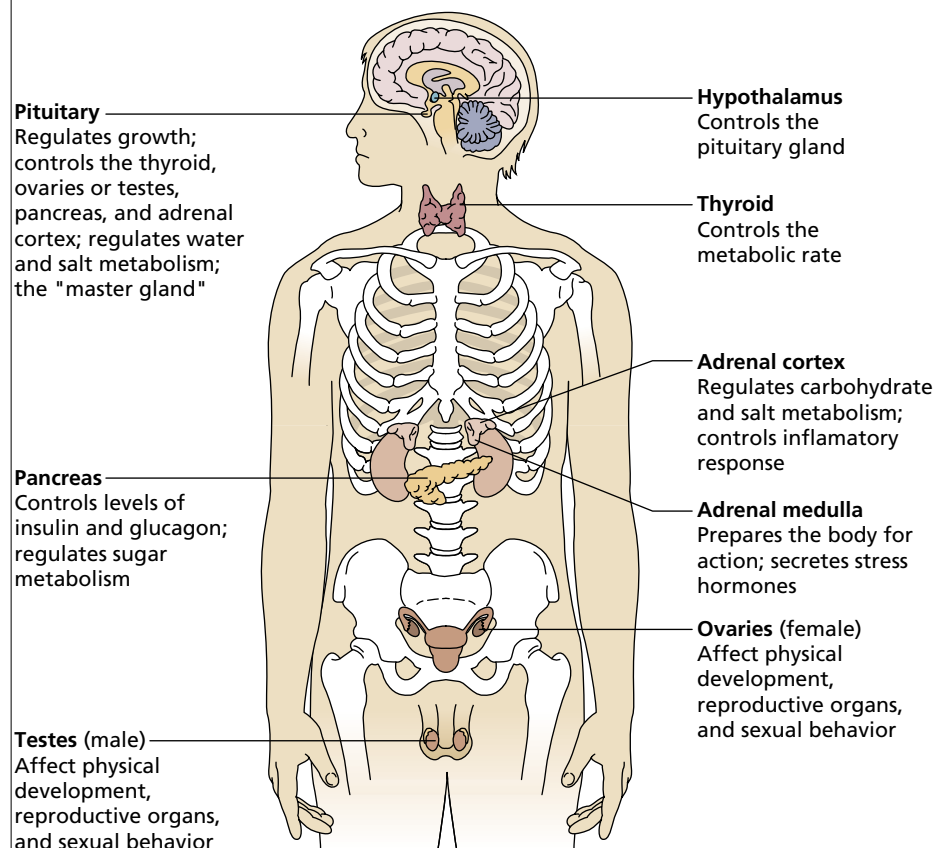
The nervous system interacts with two other communication systems within the body, namely, the endocrine and immune systems. These interactions have major influences on behavior and on psychological and physical well-being.

### Interactions with the Endocrine System

The **endocrine system** consists of numerous glands distributed throughout the body. The locations of the endocrine glands within the human body and a list of their functions are presented in Figure 3.22.

Like the nervous system, the endocrine system's function is to convey information from one area of the body to another. Rather than using nerve impulses, however, the endocrine system conveys information in the form of **hormones**, chemical messengers that are secreted from its glands into the bloodstream. Just as neurons have receptors for certain neurotransmitters, cells in the body (including neurons) have receptor molecules that respond to specific hormones from the endocrine glands. Many of the hormones secreted by these glands affect psychological development and functioning (Becker et al., 1992). For example, the genetically programmed secretion of sex hormones within the human fetus during the fourth and fifth months after conception affects not only the development of male or female sex organs, but also the development of sex differences in the brain that influence behavioral functions throughout life (Schmidt & Rubinow, 1997). One example may be the sex differences in lateralization of language described earlier.

▶34. How does the endocrine system differ from the nervous system as a communications network?



**FIGURE 3.22** The glands that comprise the endocrine system and the effects of their hormones on bodily functions.

►35. What are some ways in which the nervous and endocrine systems affect and interact with one another?

Endocrine messages can affect the nervous system, and mental processes within the brain can, in turn, affect endocrine functioning. For example, negative thoughts about a stressful situation can quickly trigger the secretion of stress hormones within the body (McEwen, 1997). Consider in this light the “voodoo death” of the young woman described at the beginning of the chapter. How are we to account for such events without invoking supernatural forces? One possibility is through the interaction of the brain and the endocrine system. Many years ago, the physiologist Walter Cannon (1942) suggested a possible mechanism, drawing upon his own research on severe stress responses in animals and quoting eyewitness reports by cultural anthropologists of deaths by “black magic.” One such account involved the practice of placing a death curse on another by pointing a sacred bone at the victim.

The man who discovers that he is being boned by any enemy is, indeed, a pitiable sight. He stands aghast, with his eyes staring at the treacherous pointer, and with his hands lifted as though to ward off the lethal medium, which he imagines is pouring into his body. . . . Unless help is forthcoming in the shape of a countercharm administered by the hands of the Nangarri, or medicine-man, his death is only a matter of a comparatively short time. (Basedow, quoted in Cannon, p. 172)

►36. What physiological explanation did Cannon offer for death by “black magic”?

Cannon noted that in cases of death by “black magic,” the victim of the curse invariably believed (as did family, friends, and enemies) that he or she was doomed, a conviction that was unquestioned within the victim’s culture. He speculated that the victim’s beliefs triggered a profound stress response that included a torrent of stress hormones released by the endocrine system, sending the victim into physiological shock. Cannon’s research had shown that one aspect of such shock is a rapid and often fatal drop in blood pressure as the stress hormones allow fluid to leak out of veins and capillaries. He noted that normal autopsy procedures would not detect this mechanism of death, making it appear, as in the case of the young woman, that there was no natural cause. Cannon’s hypothesis is a plausible alternative to supernatural explanations, and it is consistent with the results of stress research.

The nervous system transmits information rapidly, with the speed of nerve impulses. The endocrine system is much slower because delivery of its messages depends on the rate of blood flow. On the other hand, hormones travel throughout the body in the bloodstream and can reach billions of individual cells. Thus when the brain has important information to transmit, it has the choice of sending it directly in the form of nerve impulses to a relatively small number of neurons or indirectly by means of hormones to a large number of cells. Often both communication networks are used, resulting in both immediate and prolonged stimulation.

Of special interest to psychologists are the **adrenal glands**, twin structures perched atop the kidneys. The adrenal glands are, quite literally, a hormone factory, producing and secreting about 50 different hormones that regulate many metabolic processes within the brain and other parts of the body. As we have seen, dopamine is one substance produced in the adrenals. Also produced there are several stress hormones cited by Cannon. In an emergency, the adrenal gland is activated by the sympathetic branch of the autonomic nervous system, and stress hormones are secreted into the bloodstream, mobilizing the body’s emergency response system. Because hormones remain in the bloodstream for some time, the action of these adrenal hormones is especially important under conditions of prolonged stress. If not for the long-term influence of hormones, the autonomic nervous system would have to produce a constant barrage of nerve impulses to the organs involved in responding to stress.

### Interactions Involving the Immune System

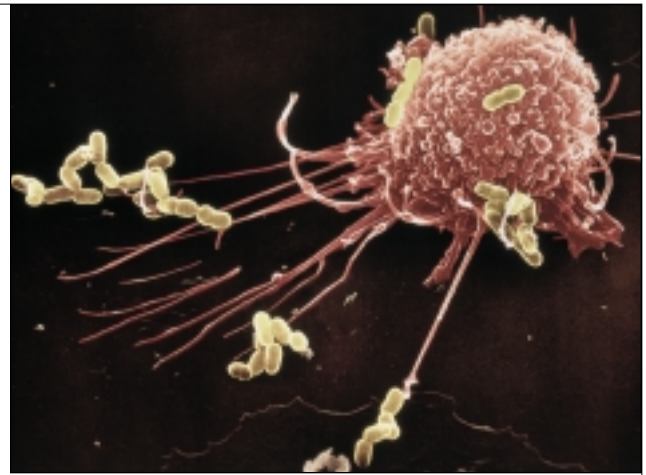
The nervous and endocrine systems interact not only with one another, but also with the immune system. A normal, healthy immune system is a wonder of nature. At this moment, microscopic soldiers patrol every part of your body, including your brain. They are on a search-and-destroy mission, seeking out biological invaders that could disable or kill you. Programmed into each member of this legion of tiny defenders is an innate ability to recognize which substances belong to the body and which are foreigners that must be destroyed. Such recognition occurs because foreign substances known as **antigens** (meaning *antibody generators*) trigger a biochemical response from the immune system. Bacteria, viruses, abnormal cells, and many chemical molecules with antigenic properties start the wars that rage inside our bodies every moment of every day (Figure 3.23).

The immune system has a remarkable memory. Once it has encountered one of the millions of different antigens that enter the body, it will recognize the antigen immediately in the future and will produce the biochemical weapons, or antibodies, needed to destroy it (Nossal & Hall, 1995). This is why we can develop vaccines to protect animals and people from some diseases, and why we normally catch diseases like mumps and chicken pox only once in our lives. Unfortunately, though the memory may be perfect, our body's defenses may not be. Some bacteria and viruses evolve so rapidly that they can change just enough over time to slip past the sentinels in our immune system and give us this year's cold or flu.

Antigens can originate externally (a flu virus or a pollen) or internally (a cancerous tumor). Problems arise when the immune system has either an underactive or an overactive response (Figure 3.24). An *underactive* immune system response to external antigens is dramatically illustrated in acquired immune deficiency syndrome (AIDS). One class of immune cells, *helper T cells*, issue "calls to action," mobilizing antigen-killing cells in the immune system. The human immunodeficiency virus (HIV) attacks the helper T cells and disables them. As a result, the individual's immune system doesn't get the order to attack and kill invaders. This leaves the body defenseless against virtually anything that can infect humans: bacteria, viruses of all kinds, fungi, and protozoa. Underreaction can also occur to an internal antigen. This is what occurs in cancer. Abnormal body cells are allowed to proliferate, resulting in the formation of tumors.

An *overactive* response to an external antigen presents problems in the form of an allergy. For example, in its violent reaction to an allergen, an asthmatic's immune system releases a torrent of histamine, a chemical that causes critical breathing muscles around the bronchial tubes to contract, leaving the asthmatic person wheezing and gasping for air.

Another type of overactive response, an **autoimmune reaction**, results when the immune system mistakenly identifies part of the body as an enemy and attacks it. For example, in rheumatoid arthritis, the immune system attacks connective tissue in the joints, causing inflammation, pain, and loss of flexibility. In diabetes, immune cells attack cells in the pancreas that produce the hormone insulin, which regulates blood sugar level. As a result the diabetic person may experience abnormally high blood sugar that can damage other organs, or drops in blood sugar that can result in a coma.



**FIGURE 3.23** An immune system cell reaches out to capture bacteria, shown here in green. The bacteria that have already been pulled to the surface of the cell will be engulfed and devoured.

►37. In what ways does the immune system have sensory, response, and memory capabilities?

►38. How do under- or overreactivity to internal or external antigens give rise to four varieties of immune dysfunction?

		Immune system	
		Underactive	Overactive
External antigen	Infections	Allergies	
Internal antigen	Cancer	Autoimmune reactions	

**FIGURE 3.24** Disorders of the immune system created by under- or overreaction to either internal or external antigens.

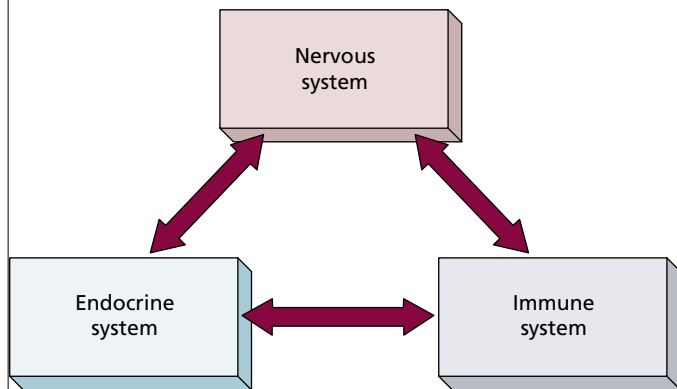
The immune system, like the nervous system, thus has an exquisite capacity to receive, interpret, and respond to specific forms of stimulation. It senses, learns, remembers, and reacts; in other words, it behaves. Despite these similarities, research on the nervous and immune systems proceeded along independent paths for many years, with only a few visionaries suggesting that the two systems might be able to communicate and influence each others' activities. They were right. We now know that the nervous, endocrine, and immune systems are all parts of a communication network that so completely underlies our every mental, emotional, and physical action that neuroscientist Candace Pert, one of the pioneers in this area of research, has dubbed this network "bodymind" (Pert, 1986).

Pieces of this communication puzzle began to fall into place with several key discoveries. The first was that selective electrical stimulation or destruction of certain areas of the hypothalamus and cerebral cortex resulted in almost instantaneous increases or decreases in immune-system activity. Conversely, activation of the immune system by injecting antigens into the body resulted in increased electrical activity in several brain regions (Saphier, 1992). Clearly, the nervous and immune systems were communicating with and influencing one another.

Later research showed that the nervous and immune systems are chemically connected as well. Immune system cells contain receptors keyed to specific neurotransmitter substances, meaning that the action of immune cells can be directly influenced by chemical messengers from the brain (Maier & Watkins, 1999). An equally startling discovery was that immune cells can actually produce hormones and neurotransmitters, allowing them to directly influence the brain and endocrine system glands. The immune system is therefore not only a response system, but also a giant sensory system. It responds to antigens by sending chemical messengers that affect neurotransmitter activity in the brain and the autonomic nervous system. The brain, in turn, responds with a cascade of chemical and neural signals

to both the immune cells and to the endocrine glands and organs of the body (Maier & Watkins, 1998). In sum, the brain, endocrine glands, and immune system form a complete communication loop, with each influencing and being influenced by one another (Figure 3.25). Implications of these linkages are discussed in our *Psychological Frontiers* feature.

►39. Cite four pieces of evidence that the immune and nervous system communicate with and affect one another.



**FIGURE 3.25** The nervous, endocrine, and immune systems are part of a complex communication system in which each can both affect and be affected by the others. This fact accounts for many of the so-called "bodymind" interactions that are the focus of current interest in psychology.

►40. Which psychosocial factors have been shown to influence immune functioning?

►41. What can be done to enhance immune functioning?

## PSYCHOLOGICAL FRONTIERS



### How Psychological Factors Affect the Immune System

In an effort to understand how psychological factors affect health and illness, psychologists have teamed with immunologists to form a new discipline known as **psychoneuroimmunology (PNI for short)**. Their research has shown that psychosocial factors such as stress, depression, social support, and personality factors have significant effects on immune

system functioning, and thereby on health and illness (Ader et al., 1995; Maier & Watkins, 1998; Marsland et al., 2000).

Stress makes many people more susceptible to illness (Dougall & Baum, 2000). Research by Ronald Glaser, Janet Kiecolt-Glaser, and their coworkers at Ohio State University has shown that one possible reason is reduced immune sys-

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tem effectiveness (Glaser & Glaser, 1995). In one study, medical students were followed closely over a one-year period. Blood samples collected during three stressful academic examination periods were used to measure immune cell activity. The researchers found that immune system effectiveness was reduced during the stressful exam periods and that this reduction was linked to the likelihood of becoming ill. Other studies showed that stress hormones released into the bloodstream by the adrenal glands as part of the stress response can suppress the activity of specific immune system cells, increasing the likelihood of illness (Cohen & Herbert, 1996; Maier & Watkins, 1999; Sapse, 1997).

School examinations are stressful, but they pale in comparison with some other life stressors, such as the death of a loved one. Within one year after the death of their spouse, about two-thirds of bereaved people decline in health (Ader, 1995; Irwin et al., 1987). An increased rate of mortality is also found, particularly in widowers. To study the impact of bereavement on immune system functioning, Michael Irwin and his associates (1987) monitored the immune cell activity of women before and after the death of their husbands. They found a decrease in immune cell activity, but only in women who reacted to the death of their husband with depressive symptoms. Depression thus appears to be an active ingredient in weakening the immune system. So is a high level of general distress. A study involving people who were followed over four months following the 1994 Northridge, California, earthquake revealed that those who reacted with the highest levels of distress showed poorer immune function than did those who reacted with less distress (Solomon et al., 1997). A reduction in immune functioning caused by distress or depression can increase the body's vulnerability to viral diseases and, possibly, to cancer cells (Lewis et al., 1995; Stein et al., 1990).

Personality and environmental factors have been implicated in other ways as well. David McClelland and his coworkers reported that people who had a strong need for power showed decreased immune system functioning when they experienced stressful situations that frustrated their power needs (Jemmott et al., 1988; McClelland, 1989). Bottling up negative feelings may also take a toll on immune functioning. In a long-term European study, people who were experiencing high levels of stress but were too emotionally restrained to express negative feelings had a significantly higher likelihood of developing cancer than did highly stressed people who were not so emotionally restrained (Eysenck, 1994). Thus persons with certain personality patterns appear to be at increased risk for illness when they are subjected to stress.

Many cancer specialists are convinced that an aggressive and determined attitude and a will to live characterize cancer survivors, whereas patients who resign themselves to their fate are less likely to survive (Greer et al., 1979; Lewis et al., 1995). High levels of social support from the environment can also increase immune system functioning (Hall & O'Grady, 1990). One review of 81 published studies revealed that level of social support available to people was reliably related to beneficial endocrine and immune system responses to stress (Uchino et al., 1996). Finally, a good sense of humor can also help. A series of studies carried out at

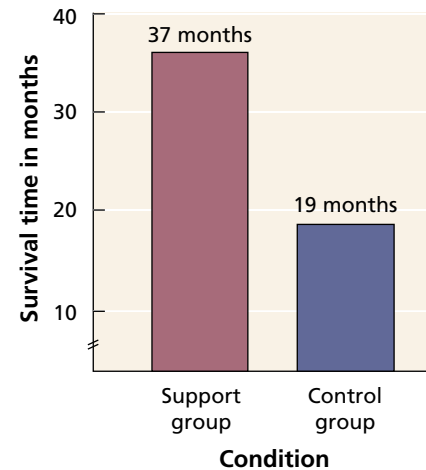


FIGURE 3.26 Mean survival time in breast cancer patients who received a coping skills and social support intervention compared with control patients who received normal cancer treatment.

Data from Spiegel et al., 1989

Boston University showed that watching a humorous movie increased immune activity, whereas a control movie did not. Moreover, people who had a good sense of humor as measured by a psychological test had stronger immune responses overall. A sense of humor may cause one to appraise some potentially stressful situations in a more benign fashion by seeing humor in them (McClelland & Cherriff, 1997).

Can psychological interventions enhance people's immune functioning? Psychological training techniques involving imagery, relaxation, and stress management training have produced promising results. In Europe, a treatment program was designed to help stress-ridden but emotionally constrained people who had not yet developed cancer, but were considered to be at risk for the disease because of their personality style. The program focused on building stress-coping skills and on helping the people learn how to express their emotions in an adaptive fashion. A control group of similar people did not receive the training. Thirteen years later, a follow-up study revealed that 90 percent of the trained people subjects were still alive, compared with only 38 percent of the untreated control group (Eysenck, 1994; Eysenck & Grossarth-Marticek, 1991). In another study involving 86 women undergoing breast cancer treatment at Stanford Medical School, women were randomly assigned to either a weekly therapy group designed to strengthen their coping skills and social support or to a no-treatment control group. As shown in Figure 3.26, those in the therapy groups survived nearly twice as long as did the controls (Spiegel et al., 1989).

Obviously, the immune system does not "know" that a feared examination is at hand, that a spouse has died, an earthquake has occurred, or that social support is available. But the brain knows, and there is increasing evidence that what the brain knows and does can affect how well the immune system protects us. The implications are attracting an increasing number of psychologists to the frontiers of psychoneuroimmunology.

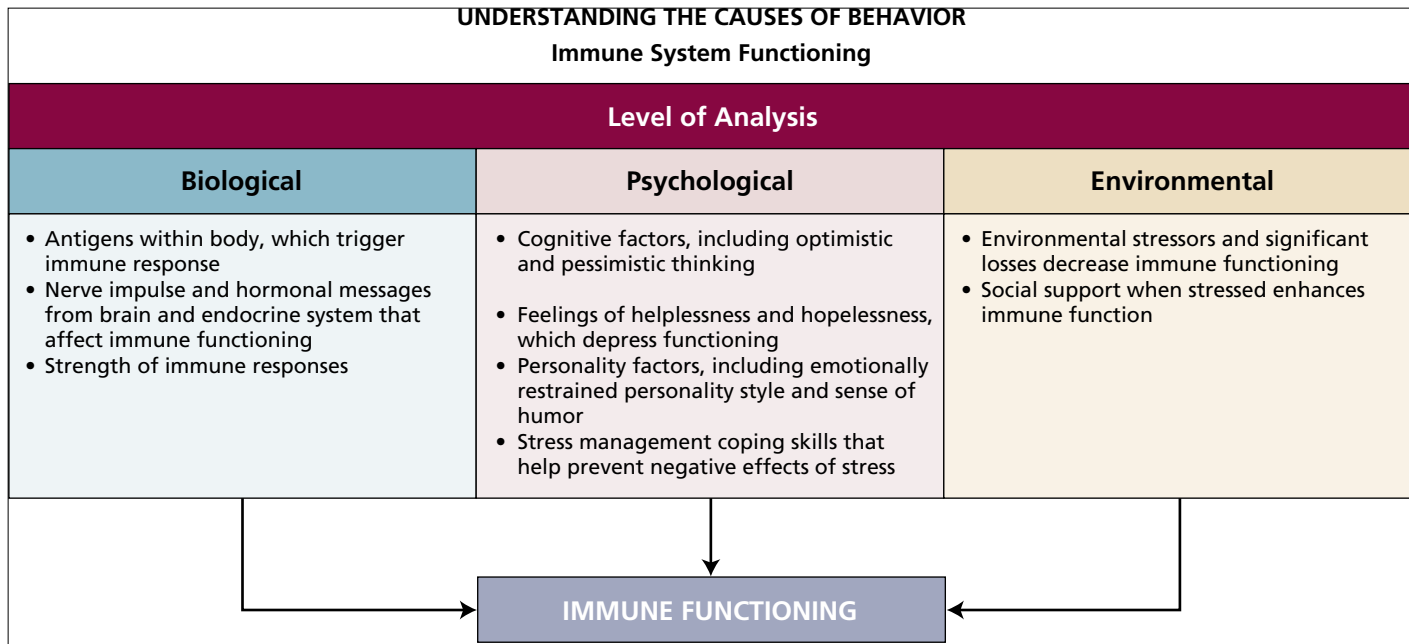


FIGURE 3.27 Understanding the Causes of Behavior: Factors Influencing Immune Functions

The immune system is clearly affected by a host of factors. As shown in Figure 3.27, these factors can be examined at biological, psychological, and environmental levels of analysis.

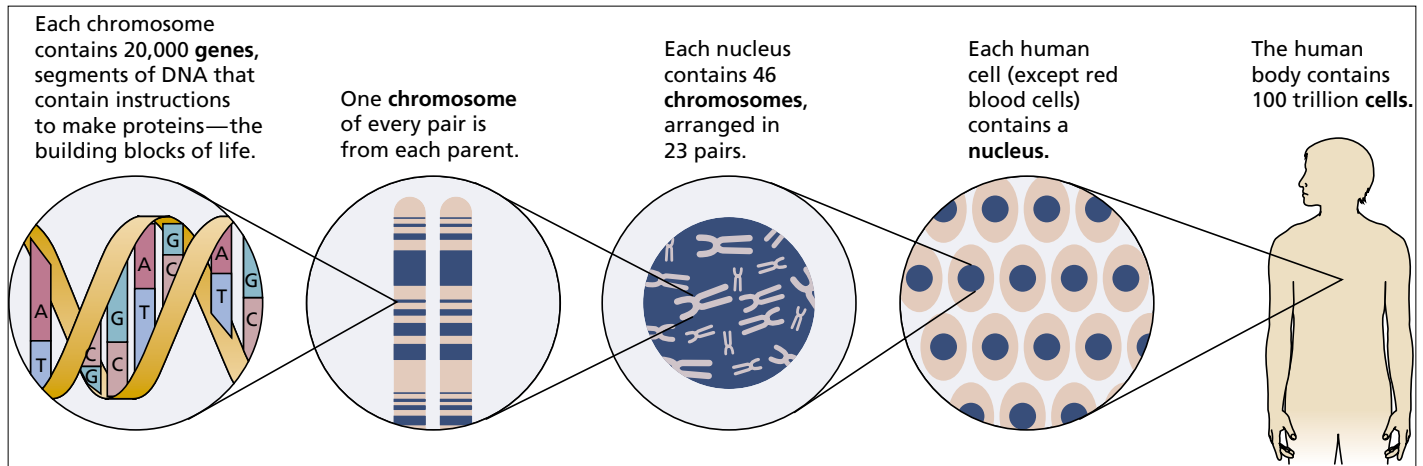
## ➤ GENETIC INFLUENCES ON BEHAVIOR

Our physical development, including the development of the nervous system, is in large part directed by an elaborate genetic blueprint passed on to us by our parents. These biological characteristics set limits on the behavioral capabilities of the organism. However, our genetic endowment combines with environmental forces to determine our behavior. Modern scientists realize that asking whether a particular behavior is caused by genetic or environmental factors makes no more sense than asking if a triangle is formed by its sides or its corners. Instead, psychologists working in the field of behavior genetics study the ways in which favorable or unfavorable environmental conditions can affect the genetically inherited potential of the organism.

### Chromosomes and Genes

How are physical characteristics passed on from parents to their offspring? This question originated in antiquity, and the ancient Greek physician Hippocrates was one of the first to provide a semi-correct answer. Hippocrates suggested that semen contains not body parts, but rather some sort of design for the formation of the offspring. It was not until 22 centuries later that the wisdom of Hippocrates's answer was confirmed by Gregor Mendel, a monk whose research with garden peas in the 1860s marked the beginning of modern genetic theory.

Mendel showed that heredity involves the passing on of specific organic factors, not a simple blending of the parents' characteristics. These specific factors might produce visible characteristics in the offspring, or they might be simply be carried for possible transmission to another generation. In any case, the offspring of one set of parents did not all inherit the same traits, as is evident in the differences we see between brothers and sisters.



**FIGURE 3.28** The ladder of life. Chromosomes consist of two long, twisted strands of DNA, the chemical that carries genetic information. Every cell in the body (with the exception of red blood cells) carries within its nucleus 23 pairs of chromosomes, each containing about 20,000 genes that regulate every aspect of cellular functioning.

Early in the 20th century, geneticists made the important distinction between **genotype**, the specific genetic makeup of the individual, and **phenotype**, the observable characteristics produced by that genetic endowment. A person's genotype is like the commands in a computer software program. Some of the directives are used on one occasion, some on another. Some are never used at all, either because they are contradicted by other genetic directives or because the environment never calls them forth. Thus genotypes are present from conception and never change, but phenotypes can be affected by other genes and by the environment. For example, geneticists have discovered that chickens have retained the genetic code for teeth (Kollar & Fischer, 1980). Yet because the code is prevented from being expressed, "hens' teeth" remains a cliché for scarcity.

The union of two cells, the egg from the mother and the sperm from the father, is the beginning of a new individual. Like all other cells in the body, the egg and sperm carry within them the material of heredity in the form of rodlike units called chromosomes. A **chromosome** is a tightly coiled molecule of *deoxyribonucleic acid* (DNA) that is partly covered by protein. The DNA portion of the chromosome carries the hereditary blueprint in units called **genes** (Figure 3.28). The 20,000 or so genes carried on each chromosome are like a giant computer file of information about your characteristics, potentials, and limitations. Every moment of every day, the strands of DNA silently transmit their detailed instructions for cellular functioning.

In humans, every cell in the body except one has 46 chromosomes. The exception is the sex cell (the egg or sperm), which has only 23. At conception, the 23 chromosomes from the egg combine with the 23 from the sperm to form a new cell containing 46 chromosomes. The genes within each chromosome also occur in pairs, so that the offspring receives one of each gene pair from each parent. It is estimated that the union of sperm and egg can result in about 70 trillion potential genotypes, accounting for the great diversity in characteristics even in siblings.

### *Dominant, Recessive, and Polygenic Effects*

Genotype and phenotype are not identical because some genes are dominant and some are recessive. If a gene in the pair received from the mother and father is **dominant**, the particular characteristic that it controls will be displayed; if the gene is **recessive**, the characteristic will not show up *unless* the partner gene inherited from the other parent is also recessive. In humans, for example, brown

►42. Differentiate between genotype and phenotype.

►43. How does genetic transmission occur from parents to offspring?

►44. Compare dominant, recessive, and polygenic influences on phenotypic characteristics.

eyes and dark hair are dominant over blue eyes and light hair; blood group types A, B, and AB are dominant over type O; and normal color vision is dominant over color blindness. Even if their traits remain hidden, however, recessive genes can be passed on to offspring.

In a great many instances, a number of gene pairs combine their influences to create a single phenotypic trait. This is known as **polygenic transmission**, and it complicates the straightforward picture that would occur if all characteristics were determined by one pair of genes. It also magnifies the number of possible variations in a trait that can occur.

### *Mapping the Genetic Code*

At present, our knowledge of phenotypes of traits and disorders greatly exceeds our understanding of the underlying genotype, but that may soon change. In 1990, geneticists around the world began the *Human Genome Project*, a coordinated effort to map all the genes of the human organism by the year 2005. The genetic structure of every one of the 23 chromosome pairs is being mapped by sophisticated methods that allow the investigators to literally disassemble the genes on each chromosome and study their sequencing, or molecular structure (Aldridge, 1998; Stoneking, 1997). We shall soon have a complete or nearly complete map of the human genetic structure, as well as the knowledge of which specific genes or gene combinations are involved in normal and abnormal characteristics. To date, the location and structure of more than 70,000 human genes, including 75 genes that contribute to hereditary diseases, have been identified through gene mapping (Rowen et al., 1997; Wahlsten, 1999).

### *Genetic Engineering: The Edge of Creation*

Advances in molecular biology enable scientists not only to map the human genome, but also to duplicate and modify the structures of genes themselves (Aldridge, 1998). In **recombinant DNA procedures**, researchers use certain enzymes to cut the long threadlike molecules of genetic DNA into pieces, combine it with DNA from another organism, and insert it into a host organism, such as a bacterium. Inside the host, the new DNA combination continues to divide and produce many copies of itself.

This procedure has been used to produce *human growth hormone*, which is very difficult to obtain naturally in large enough quantities to use for therapeutic purposes. In one study, the availability of growth hormone produced through recombinant procedures made it possible to treat 121 prepubertal children of abnormally short stature who were deficient in the hormone. As a result of their treatment, the children achieved adolescent heights that were only slightly below average, and far beyond what would have been possible without the treatment (Blethen et al., 1997). The positive social and psychological consequences that could occur for the children who received such treatments have interested many psychologists in the application of recombinant technology.

Molecular biologists have developed methods for inserting new genetic material into viruses that can infiltrate neurons and modify their genetic structure. These methods are now becoming part of the tool kit of physiological psychologists who wish to study genetic influences on behavior. Recent gene-modification research by psychologists has focused on processes such as learning, memory, emotion, and motivation (Wahlsten, 1999). One procedure done with animals (typically, mice) is to alter a specific gene in a way that prevents it from carrying out its normal function. This is called a *knockout* procedure because that particular function of the gene is eliminated. The effects on behavior are then observed. For example, psychologists can insert genetic material that will prevent neurons from responding to a particular neurotransmitter, then measure whether the animal's ability to learn or remember is affected. This can help psychologists determine the importance of

►45. Describe the methods used in recombinant DNA research.

►46. What is the knockout procedure and how is it used by psychologists to study behavior?

particular transmitter substances in relation to the behaviors of interest (Thomas & Palmiter, 1997). Gene-modification techniques may one day enable us to alter genes that contribute to psychological disorders, such as schizophrenia.

Genetic engineering gives humans potential control over the processes of heredity and evolution. But these revolutionary techniques also give birth to a host of ethical and moral issues (Reiss & Straughan, 1998; Stephenson, 1998). How and when, if ever, should these techniques be used? To prevent genetic disorders? To propagate desirable human characteristics? To duplicate or clone exceptional people? What are the social and environmental consequences of using genetic engineering to greatly extend the healthy life span of people? Questions like these are already the topic of intense discussion as scientific and technological advances carry us toward uncharted genetic frontiers.

## Behavior Genetics Techniques

Knowledge of the principles of genetic transmission tell us how genetically similar people are, depending on their degree of relatedness to one another. Recall that children get half of their genetic material from each parent. Thus the probability of sharing any particular gene with one of your parents is 50%, or .50. Brothers and sisters also have a probability of .50 of sharing the same gene with one another, since they get their genetic material from the same parents. And what about grandparents? Here, the probability of a shared gene is .25 because, for example, your maternal grandmother passed half of her genes on to your mother, who passed half of hers on to you. Thus the likelihood that you inherited one of your grandmother's genes is  $.50 \times .50$ , or .25. The probability of sharing a gene is also .25 for half siblings, who share half their genes with their biological parent, but none with the other parent. An adopted child has no genes in common with his or her adoptive parents, nor do unrelated people share genes in common.

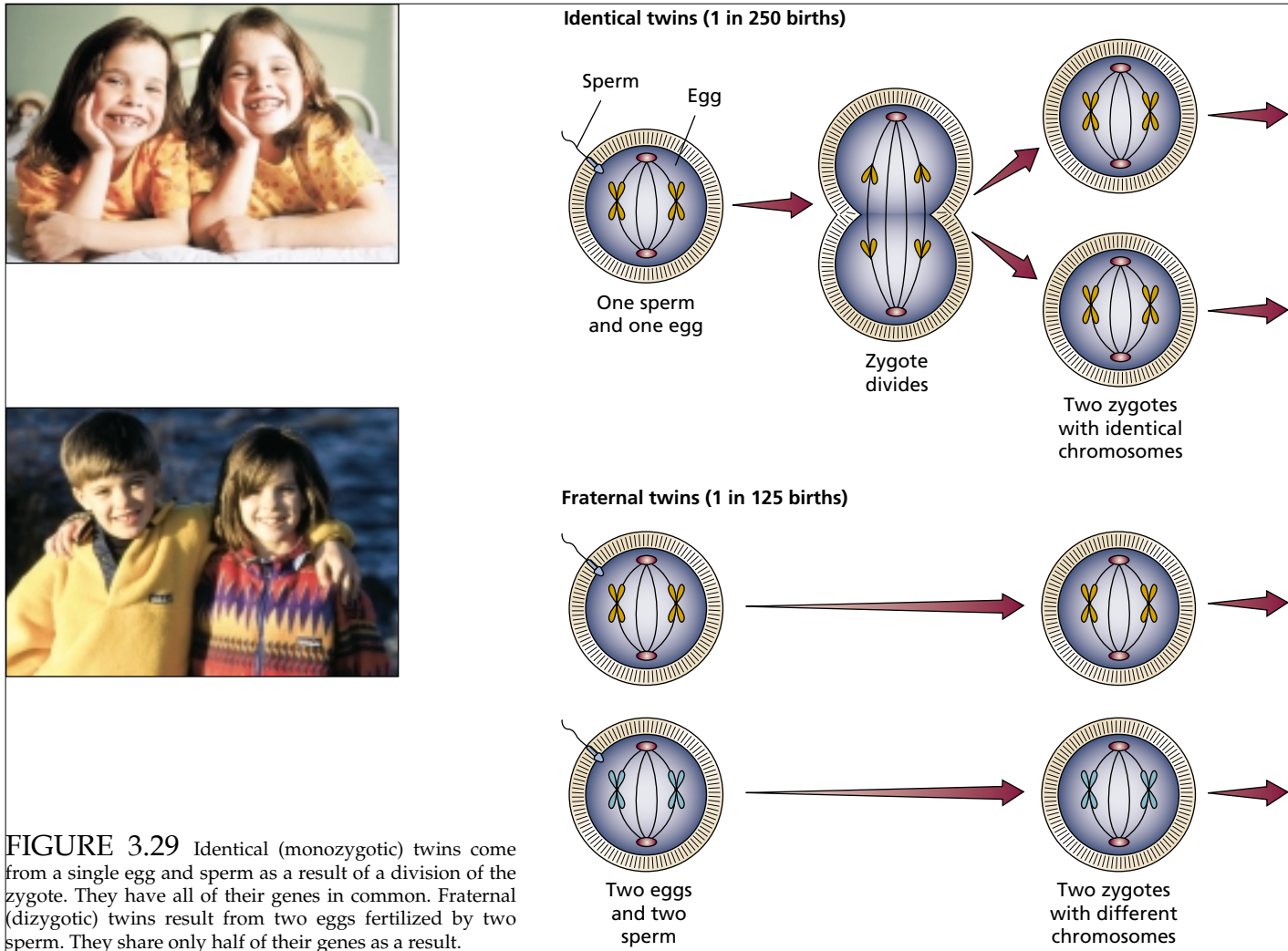
Behavior geneticists are interested in studying how hereditary and environmental factors combine to influence psychological characteristics. One important question is the potential role of genetic factors in accounting for differences among people. The extent to which the degree of variation among a group of people in a particular characteristic can be attributed to genetic factors is estimated by means of a *heritability coefficient*. For example, a heritability coefficient of .50 for intelligence indicates that half of the variation in IQ scores among the people in that group can be attributed to genetic differences. It does *not* mean that for any given individual in that group, 50 percent of the person's intelligence is due to genetic factors and the rest to the environment. Heritability applies only to differences within groups, not to the contribution of genetic factors to any individual within that group. This point is widely misunderstood and misreported in the popular media.

Knowing the level of genetic similarity in family members and relatives provides a basis for estimating the relative contributions of heredity and environment to a physical or psychological characteristic (Plomin, 1997). If a characteristic has higher **concordance**, or co-occurrence, in people who are more highly related to one another, this points to a possible genetic contribution, particularly if the people have lived in different environments.

One research method based on this principle is the **adoption study**, in which a person who was adopted early in life is compared on some characteristic with both the biological parents, with whom the person shares genetic endowment, and with the adoptive parents, with whom no genes are shared. If the adopted person is more similar to the biological parents than to the adoptive parents, a genetic influence is suggested. If greater similarity is shown with the adoptive parents, environmental factors are probably more important. In one study of genetic factors in schizophrenia, Seymour Kety and coworkers (1978) identified formerly adopted children who were diagnosed with the disorder later in life. They then examined the backgrounds of the biological and adoptive

►47. What is the percentage of genetic resemblance between parents and children, identical and fraternal twins, brothers and sisters, and grandparents and grandchildren?

►48. How are adoption and twin studies used to achieve heritability estimates? What have such studies shown?



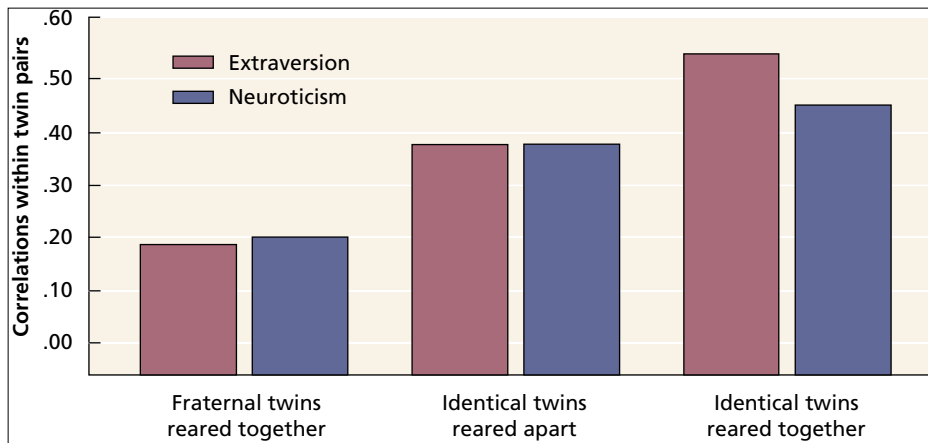
**FIGURE 3.29** Identical (monozygotic) twins come from a single egg and sperm as a result of a division of the zygote. They have all of their genes in common. Fraternal (dizygotic) twins result from two eggs fertilized by two sperm. They share only half of their genes as a result.

parents and relatives to determine the rate of schizophrenia in the two sets of families. The researchers found that 12 percent of biological family members had also been diagnosed with schizophrenia, compared with a concordance rate of only 3 percent of adoptive family members, suggesting a hereditary link.

**Twin studies** are one of the more powerful techniques used in behavior genetics. *Monozygotic*, or identical, twins develop from the same fertilized egg, so they are genetically identical (Figure 3.29). Approximately 1 in 250 births produces identical twins. *Dizygotic*, or fraternal, twins develop from two fertilized eggs, so they share 50 percent of their genetic endowment, like any other set of brothers and sisters. They occur once in 125 births.

Twins are usually raised in the same familial environment. Thus we can compare concordance rates or behavioral similarity in samples of identical and fraternal twins with the idea that if the identical twins are far more similar to one another than are the fraternal twins, a genetic factor is likely to be involved. Of course, it is always possible that because identical twins are more similar to one another in appearance than fraternal twins are, they are treated more alike and therefore share a more similar environment. This environmental factor could partially account for greater behavioral similarity in identical twins. To rule out this environmental explanation for greater psychological similarity, behavior

►49. Why are studies of twins raised together and apart especially informative? What findings have occurred in such studies?



**FIGURE 3.30** Degree of similarity on personality measures of extraversion and neuroticism of 24,000 pairs of twins who were reared together and apart. (Magnitude of correlations is in parentheses.)

Data from Loehlin, 1992.

geneticists have adopted an even more elegant research method. Sometimes they are able to find and compare sets of identical and fraternal twins who were separated very early in life and raised in *different* environments (Bouchard et al., 1990). This design permits a better basis for evaluating the respective contributions of genes and environment.

Both adoption and twin studies have led behavioral geneticists to conclude that many psychological characteristics, including intelligence, personality traits, and certain psychological disorders have a notable genetic contribution. Adoptive children are frequently found to be more similar to their biological parents than to their adoptive parents, and identical twins tend to be more similar to one another on many traits than are fraternal twins, even when they have been reared in different environments (Loehlin, 1992; Lykken et al., 1992; Plomin, 1997). Figure 3.30 shows the results of one such comparison. Three groups of twins—identical twins reared together and apart and fraternal twins reared together—completed personality tests of extraversion (sociability, liveliness, impulsiveness) and neuroticism (moodiness, anxiousness, and irritability). The higher correlation coefficients reveal that the identical twins are more similar to one another than are the fraternal twins, and that the degree of similarity in identical twins is almost as great when they are reared in different environments as when they are reared together (Loehlin, 1992).

On the other hand, heritability studies have also demonstrated that environmental factors interact with genetic endowment in important ways. For example, one adoption study compared the criminal records of men who were adopted at an early age with the criminal records of their biological fathers and their adoptive fathers. A low incidence of criminal behavior was found in the sons whose biological fathers had no criminal record, even if the adoptive fathers who reared them had criminal records. In contrast, the criminal behavior of sons whose biological fathers had criminal records was very high, even if their adoptive fathers had no criminal records. This pattern clearly points to a genetic component in criminality. But one additional finding deserves our attention: The level of criminality was highest of all for those sons whose biological and adoptive fathers *both* had criminal records, suggesting a combined impact of genetic and environmental factors (Cloninger & Gottesman, 1987). In this case, heredity and environment combined to create a double-whammy for society. This finding underscores the conclusion reached when we discussed the nature-nurture issue in Chapter 1: Genetic and environmental factors almost always interact with one another to influence behavior. In the chapters to follow, we focus in more detail on the methods and findings of behavior genetics in relation to many aspects of development and behavior.

## CHAPTER SUMMARY

### The Neural Bases of Behavior

- Each neuron has dendrites, which receive nerve impulses from other neurons; a cell body, which controls the vital processes of the cell; and an axon, which conducts nerve impulses to adjacent neurons, muscles, and glands.
- Neural transmission is an electrochemical process. The nerve impulse, or action potential, is a brief reversal in the electrical potential of the cell membrane as sodium ions from the surrounding fluid flow into the cell through sodium ion channels, depolarizing the axon's membrane. Graded potentials are proportional to the amount of stimulation being received, whereas action potentials obey the all-or-none law and occur at full intensity if the action potential threshold of stimulation is exceeded. The myelin sheath increases the speed of neural transmission.
- Passage of the impulse across the synapse is mediated by chemical transmitter substances. Neurons are selective in the neurotransmitters that can stimulate them. Some neurotransmitters excite neurons, whereas others inhibit firing of the postsynaptic neuron.

### The Nervous System

- The nervous system is comprised of sensory neurons, motor neurons, and interneurons (associative neurons). Its two major divisions are the central nervous system, consisting of the brain and spinal cord, and the peripheral nervous system. The latter is divided into the somatic system, which has sensory and motor functions, and the autonomic nervous system, which directs the activity of the body's internal organs and glands.
- The spinal cord contains sensory neurons and motor neurons. Interneurons inside the spinal cord serve a connective function between the two. Simple stimulus-response connections can occur as spinal reflexes.
- The autonomic nervous system consists of sympathetic and parasympathetic divisions. The sympathetic system has an arousal function and tends to act as a unit. The parasympathetic system slows down body processes and is more specific in its actions. Together, the two divisions maintain a state of internal balance, or homeostasis.
- Discoveries about brain-behavior relations are made using techniques such as neuropsychological tests, lesioning and surgical ablation, electrical and chemical stimulation of the brain, electrical recording techniques, and brain-imaging techniques. Recently developed methods for producing computer-generated pictures of structures and processes within the living brain include CT and PET scans and magnetic resonance imaging (MRI).

### The Hierarchical Brain: Structures and Behavioral Functions

- The human brain consists of the hindbrain, the midbrain, and the forebrain, an organization that reflects the evolution of increasingly more complex brain structures related to behavioral capabilities.
- Major structures within the hindbrain include the medulla, which monitors and controls vital body functions; the pons, which contains important groups of sensory and motor neurons; and the cerebellum, which is concerned with motor coordination.
- The midbrain contains important sensory and motor neurons, as well as many sensory and motor tracts connecting higher and lower parts of the nervous system. The reticular formation plays a vital role in consciousness, attention, and sleep. Activity of the ascending reticular formation excites higher areas of the brain and prepares them to respond to stimulation. The descending reticular formation acts as a gate, determining which stimuli get through to enter into consciousness.
- The forebrain consists of two cerebral hemispheres and a number of subcortical structures. The cerebral hemispheres are connected by the corpus callosum.
- The thalamus acts as a switchboard through which impulses originating in sense organs are routed to the appropriate sensory projection areas. The hypothalamus plays a major role in many aspects of motivational and emotional behavior. The limbic system seems to be involved in organizing the behaviors involved in motivation and emotion.
- The cerebral cortex is divided into frontal, parietal, occipital, and temporal lobes. Some areas of the cerebral cortex receive sensory input, some control motor functions, and others (the association cortex) are involved in higher mental processes in humans. The frontal lobes are particularly important in such executive functions as planning, voluntary behavior, and self-awareness.
- Although the two cerebral hemispheres ordinarily work in coordination with one another, they appear to have different functions and abilities. Studies of split-brain patients who have had the corpus callosum cut indicate that the left hemisphere commands language and mathematical abilities, whereas the right hemisphere has well-developed spatial abilities but a generally limited ability to communicate through speech. However, recent findings indicate that language functions are less lateralized in women than in men. Positive emotions are believed to be linked to relatively greater left-hemisphere activation and negative ones to relatively greater right-hemisphere involvement. Despite hemispheric localization, however, most behaviors involve interactions between both hemispheres; the brain operates as a system.

## Plasticity in the Brain

- Neural plasticity refers to the ability of neurons to change in structure and functions. Environmental factors, particularly early in life, have notable effects on brain development. There are often critical periods during which environmental factors have their greatest (or only) effects on plasticity.
- A person's ability to recover from brain damage depends on several factors. Other things being equal, recovery is greatest early in life and declines with age.
- When neurons die, surviving neurons can sprout enlarged dendritic networks and extend axons to form new synapses. Neurons can also increase the amount of neurotransmitter substance they release and the number of receptors on postsynaptic neurons so that they are more sensitive to stimulation. Recent findings suggest that the brains of mature primates and humans are capable of producing new neurons.
- Current advances in the treatment of neurological disorders include experiments on neuron regeneration, the grafting of nerve tissue that produces dopamine into the brains of Parkinson's disease patients, and the injection of neural stem cells into the brain, where they find and replace diseased or dead neurons.

## Nervous System Interactions with the Endocrine and Immune Systems

- The nervous, endocrine, and immune systems have extensive neural and chemical means of communication, and each is capable of affecting and being affected by the others.
- The endocrine system secretes hormones into the bloodstream. These chemical messengers affect many body processes, including the activities of the central and autonomic nervous systems. Hormonal effects in the womb may produce brain

differences in males and females that influence sex differences in certain psychological functions.

- The immune system is known to have extensive interactions with the central and autonomic nervous systems and with the endocrine system, and all of these systems can affect one another. As a behaving entity, it has the capacity to sense, to interpret, and to respond to specific forms of stimulation. Immune system disorders can occur because of either an underactive or an overactive immune system. Allergic reactions and autoimmune conditions are caused by overactivity; cancer and AIDS result from underactivity.
- The new field of psychoneuroimmunology studies relations between psychological factors and immune system functioning. Messages from the nervous and endocrine systems can affect the functioning of the immune system, making it susceptible to a variety of psychosocial influences. These include stress, cognitive processes, personality factors, and social support.

## Genetic Influences on Behavior

- Hereditary potential is carried within the DNA portion of the 23 pairs of chromosomes in units called genes. Genotype and phenotype are not identical because some genes are dominant while others are recessive. Many characteristics are polygenic in origin, influenced by the interactions of multiple genes.
- Genetic engineering allows scientists to duplicate and alter genetic material or, potentially, to repair dysfunctional genes.
- The field of behavior genetics studies the contributions of genetic and environmental factors in psychological traits and behaviors. The major research methods used in an attempt to disentangle hereditary and environmental factors are adoption and twin studies. The most useful research strategy in this regard is the study of identical and fraternal twins who were separated early in life and raised in different environments.

## KEY TERMS AND CONCEPTS\*

acetylcholine (ACh) 00

action potential 00

action potential threshold 00

adoption studies 00

adrenal glands 00

agnosia 00

all-or-none law 00

amygdala 00

antigens 00

aphasia 00

association cortex 00

autoimmune reactions 00

autonomic nervous system 00

axon 00

brain stem 00

Broca's area 00

central nervous system 00

cerebellum 00

cerebral cortex 00

chromosomes 00

computerized axial tomography (CT) scan 00

concordance 00

corpus callosum 00

dendrites 00

depolarization 00

dominant gene 00

dopamine 00

electroencephalogram (EEG) 00

endocrine system 00

endorphins 00	myelin sheath 00	psychoneuroimmunology (PNI) 00
forebrain 00	neural stem cells 00	receptor sites 00
frontal lobe 00	neural plasticity 00	recessive gene 00
genes 00	neuromodulators 00	recombinant DNA procedures 00
genotype 00	neurons 00	refractory period 00
glial cells 00	neuropsychological tests 00	reticular formation 00
graded potential 00	neurotransmitter 00	reuptake 00
hippocampus 00	occipital lobe 00	sensory neurons 00
homeostasis 00	optic chiasma 00	serotonin 00
hormones 00	parasympathetic nervous system 00	somatic nervous system 00
hypothalamus 00	parietal lobe 00	somatic sensory cortex 00
interneurons 00	peripheral nervous system 00	spinal reflex 00
ion channels 00	phenotype 00	sympathetic nervous system 00
lateralization 00	polygenic transmission 00	synapse 00
limbic system 00	pons 00	synaptic vesicles 00
magnetic resonance imaging (MRI) 00	positron emission tomography (PET) scan 00	temporal lobe 00
medulla 00	prefrontal cortex 00	thalamus 00
midbrain 00	prefrontal lobotomies 00	twin studies 00
motor cortex 00		Wernicke's area 00
motor neuron 00		

\* Each term has been boldfaced in the text on the page indicated in parentheses.

## APPLYING YOUR KNOWLEDGE

These questions allow you to apply your understanding of material in this chapter.

- In a class report, you wish to summarize the relationship between psychology and biology from the perspective of a neuroscientist. Which of the following statements would you choose?
  - All psychological processes result from the functioning of biological systems.
  - Mind is spiritual in nature; brain is biological. The two interact with one another.
  - Psychological process involve, but do not result from, biological processes.
  - The biological level of analysis is the only useful one for understanding behavior.
- Molly suffers from multiple sclerosis, and her movements are jerky and uncoordinated. Which part of the neuron has been damaged by this disease?
  - the dendrites
  - the axon
  - the myelin sheath
  - the synaptic vesicles
- Curare is a poisonous plant extract into which native people of South America dip their arrows. It produces paralysis of the muscles, including those involved in respiration. Based on your knowledge, which neurotransmitter is affected by this poison?
  - dopamine
  - acetylcholine
  - serotonin
  - endorphins
- Jason is suffering from schizophrenia. His doctor prescribes a drug that dramatically reduces his thought disorder and hallucinations. The drug most likely helps Jason by
  - reducing dopamine activity at synapses within the brain
  - creasing serotonin activity in the brain
  - reducing the activity of the sympathetic nervous system
  - inhibiting neurons that are activated by acetylcholine
- You are a physiological psychologist who wishes to record changes in neural activity within the brain while humans

- perform a learning task. Which brain scan method would you find most useful?
- EEG
  - PET scan
  - CT scan
  - functional magnetic resonance imaging (fMRI)
- After being knocked out and striking the back of his head on the canvas, a boxer lapses into a permanent coma. Which part of his brain has most likely been damaged?
    - the thalamus
    - the hypothalamus
    - the cerebellum
    - the reticular formation
  - After an automobile accident, Lynn is unable to form memories of recent events. The brain structure most likely damaged is the
    - amygdala
    - hypothalamus
    - hippocampus
    - medulla
  - Martin has a history of poorly planned and impulsive criminal behavior resulting from a tendency to ignore future consequences and make meaningful plans. As a neuropsychologist, which cortical area would you see as most likely being dysfunctional in him?
    - frontal
    - parietal
    - occipital
    - temporal
  - Two people, Chris A. and Chris Z., suffer similar strokes in the left hemisphere. Chris A. exhibits severe aphasia as a result, whereas Chris B.'s language functions are less severely affected. Based on current knowledge of language lateralization, Chris A. and Chris B. are likely to be, respectively, a(n) \_\_\_\_\_ and a(n) \_\_\_\_\_.
    - old woman; young woman
    - man; woman
    - child; adult
    - woman; man
  - As you enter the classroom for the course examination on this material, you find yourself experiencing anxiety in the form of increased heart rate, muscle tension, and wet underarms. These symptoms are most likely produced by your
    - central nervous system
    - immune system
    - parasympathetic nervous system
    - sympathetic nervous system

Answers

1.a) page (000) 2.c) page (000) 3.b) page (000);  
 4.a) page (000); 5.d) page (000); 6.d) page (000);  
 7.c) page (000); 8.a) page (000); 9.b) page (000);  
 10.d) page (000)