Chapter Three

The Biology Underlying Behavior

Michael J. Fox is free for the moment of the worst symptoms of Parkinson's, following an operation called a thalamotomy.

Prologue

The Fight of His Life

Michael J. Fox simply could not get out of the limousine. He and actress wife Tracy Pollan had just pulled up to the Beverly Hilton for the Golden Globe Awards last January, and the actor realized he was in serious trouble. Outside, reporters and photographers stood poised to greet the star of ABC's hit sitcom *Spin City,* but Fox, 37, was in no shape to greet them. Like so many times before, his left arm and leg were shaking uncontrollably. Behind the limo's darkened windows, Pollan began squeezing Fox's hand and massaging his foot. But she could provide only temporary relief. For the tremors to fully subside, the couple would have to wait for his medication to kick in. Fox asked the driver to circle the block once. Then a second time. And a third. "He probably thought I was nuts," says Fox with a faint smile. "But I just couldn't get out of the car and let my arm go, or mumble, or shuffle." (Schneider & Gold, 1998, p. 136)

Looking Ahead

Fox's symptoms were produced by Parkinson's disease, a disorder marked by varying degrees of muscular rigidity and shaking. Parkinson's afflicts about a million people in the United States alone (including former Attorney General Janet Reno and Muhammad Ali), strikes for no known reason, and typically progresses with age.

Happily, though, Fox is free for the moment of the worst symptoms of the disease, following a painstaking four-hour operation called a thalamotomy. In this procedure, surgeons bored a hole into Fox's brain and located and destroyed misfiring brain cells.

The ability of surgeons to identify damaged portions of the brain and carry out repairs is little short of miraculous. But the greater miracle is the brain itself. As we shall see in this chapter, the brain, an organ roughly half the size of a loaf of bread, controls our behavior through every waking and sleeping moment. The brain and the nerves that extend throughout the body constitute the human nervous system. Our movements, thoughts, hopes, aspirations, dreams—our very awareness that we are human—are all intimately related to this system.

Because of the importance of the nervous system in controlling behavior, and because humans at their most basic level are biological beings, psychologists and researchers from other fields as diverse as computer science, zoology, and medicine have paid special attention to the biological underpinnings of behavior. These experts are collectively called *neuroscientists* (Beatty, 2000).

biopsychologists (or behavioral neuroscientists): Psychologists who specialize in considering the ways in which biological structures and functions of the body affect behavior

Psychologists who specialize in considering the ways in which biological structures and functions of the body affect behavior are known as **biopsychologists** (or **behavioral neuroscientists**). These specialists seek to answer questions such as these: What are the bases for voluntary and involuntary functioning of the body? How are messages communicated to and from the brain to other parts of the body? What is the physical structure of the brain, and how does this structure affect behavior? Can the causes of psychological disorders be traced to biological factors, and how can such disorders be treated?

This chapter addresses such questions, focusing on the biological structures of the body that are of interest to biopsychologists. Initially, we discuss nerve cells, called neurons, which allow messages to travel through the brain and body; we learn that through their growing knowledge of neurons and the nervous system, psychologists are increasing their understanding of human behavior and are uncovering important clues in their efforts to cure certain kinds of diseases. Then we turn to the structure and main divisions of the nervous system, explaining how they work to control voluntary and involuntary behaviors. In the process we also examine how the various parts of the nervous system operate together in emergency situations to produce lifesaving responses to danger.

Next, we consider the brain itself, examining its major structures and how these affect behavior. We see how the brain controls movement, our senses, and our thought processes. We also consider the fascinating notion that the two halves of the brain might have different specialties and strengths. Finally, we examine the chemical messenger system of the body, the endocrine system.

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Description of neuropsychology
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As we discuss these biological processes, it is important to keep in mind the rationale for doing so: Our understanding of human behavior cannot be complete without knowledge of the fundamentals of the brain and the rest of the nervous system. As we'll see in future chapters, biological factors have an important impact on our sensory experiences, states of consciousness, motivation and emotion, development throughout the life span, and physical and psychological health. Advances in biopsychology have paved the way for the creation of drugs and other treatments for psychological and physical disorders. In short, we cannot understand behavior—the moods, motivations, goals, and desires that are central to the human condition—without an understanding of our biological makeup.

Neurons: The Elements of Behavior

If you have ever watched the precision with which a well-trained athlete or dancer executes a performance, you may have marveled at the complexity—and wondrous abilities—of the human body. But even the most everyday tasks, such as picking up a pencil, writing, and speaking, require a sophisticated sequence of events that is itself truly impressive. For instance, the difference between saying the words *dime* and *time* rests primarily on whether the vocal cords are relaxed or tense during a period lasting no more than one one-hundredth of a second. Yet it is a distinction that almost everyone can make with ease.

The nervous system provides the pathways that permit us to carry out such precise activities. To understand how it is able to exert such exacting control over our bodies, we must begin by examining neurons, the most basic parts of the nervous system, and considering how nerve impulses are transmitted throughout the brain and body.

Prepare

Why do psychologists study the brain and nervous system?

What are the basic elements of the nervous system?

How does the nervous system communicate electrical and chemical messages from one part to another?

Organize

The Structure of the Neuron

The ability to play the piano, drive a car, or hit a tennis ball depends, at one level, merely on muscle coordination. But if we consider *how* the muscles involved in such activities are activated, we see that there are more fundamental processes involved. It is necessary for the body to provide messages to the muscles and to coordinate those messages, for the muscles to be able to produce the complex movements that characterize successful physical activity.

Such messages—as well as those that enable us to think, remember, and experience emotion—are passed through specialized cells called neurons. **Neurons,** or nerve cells, are the basic elements of the nervous system. Their quantity is staggering—perhaps as many as one *trillion* neurons throughout the body are involved in the control of behavior. Although there are several types of neurons, they all have a similar basic structure, as illustrated in Figure 3-1. Like all cells in the body, neurons have a cell body, containing a nucleus. The nucleus incorporates the inherited material that establishes how the cell will function. Neurons are physically held in place by *glial cells,* which provide nourishment and insulate them (Bear, Connors, & Paradiso, 2000).

neurons: Nerve cells, the basic elements of the nervous system

In contrast to most other cells, however, neurons have a distinctive feature: the ability to communicate with other cells and transmit information, sometimes across relatively long distances. As you can see in Figure 3-1, neurons have clusters of fibers called **dendrites** at one end. These fibers, which look like the twisted branches of a tree, receive messages from other neurons. At the opposite end, neurons have a long, slim, tubelike extension called an **axon,** the part of the neuron that carries messages destined for other neurons. The axon is considerably longer than the rest of the neuron. Although most axons are several millimeters in length, some can be as long as three feet. Axons end in small bulges called **terminal buttons** that send messages to other neurons.

dendrites: A cluster of fibers at one end of a neuron that receive messages from other neurons

axon: The part of the neuron that carries messages destined for other neurons

terminal buttons: Small bulges at the end of axons that send messages to other neurons

The messages that travel through the neuron are purely electrical in nature. Although there are exceptions, these electrical messages generally move across neurons as if they were traveling on a one-way street. They follow a route that begins with the dendrites, continues into the cell body, and leads ultimately down the tubelike extension, the axon. *D*endrites, then, *d*etect messages from other neurons; *a*xons carry signals *a*way from the cell body.

To prevent messages from short-circuiting one another, axons must be insulated in some fashion (just as electrical wires must be insulated). In most axons, this is done with a **myelin sheath,** a protective coating of specialized fat and protein cells that wrap themselves around the axon.

myelin sheath: Specialized cells of fat and protein that wrap themselves around the axon, providing a protective coating

The myelin sheath also serves to increase the velocity with which the electrical impulses travel through the axons. Those axons that carry the most important and most urgently required information have the greatest concentrations of myelin. If your hand

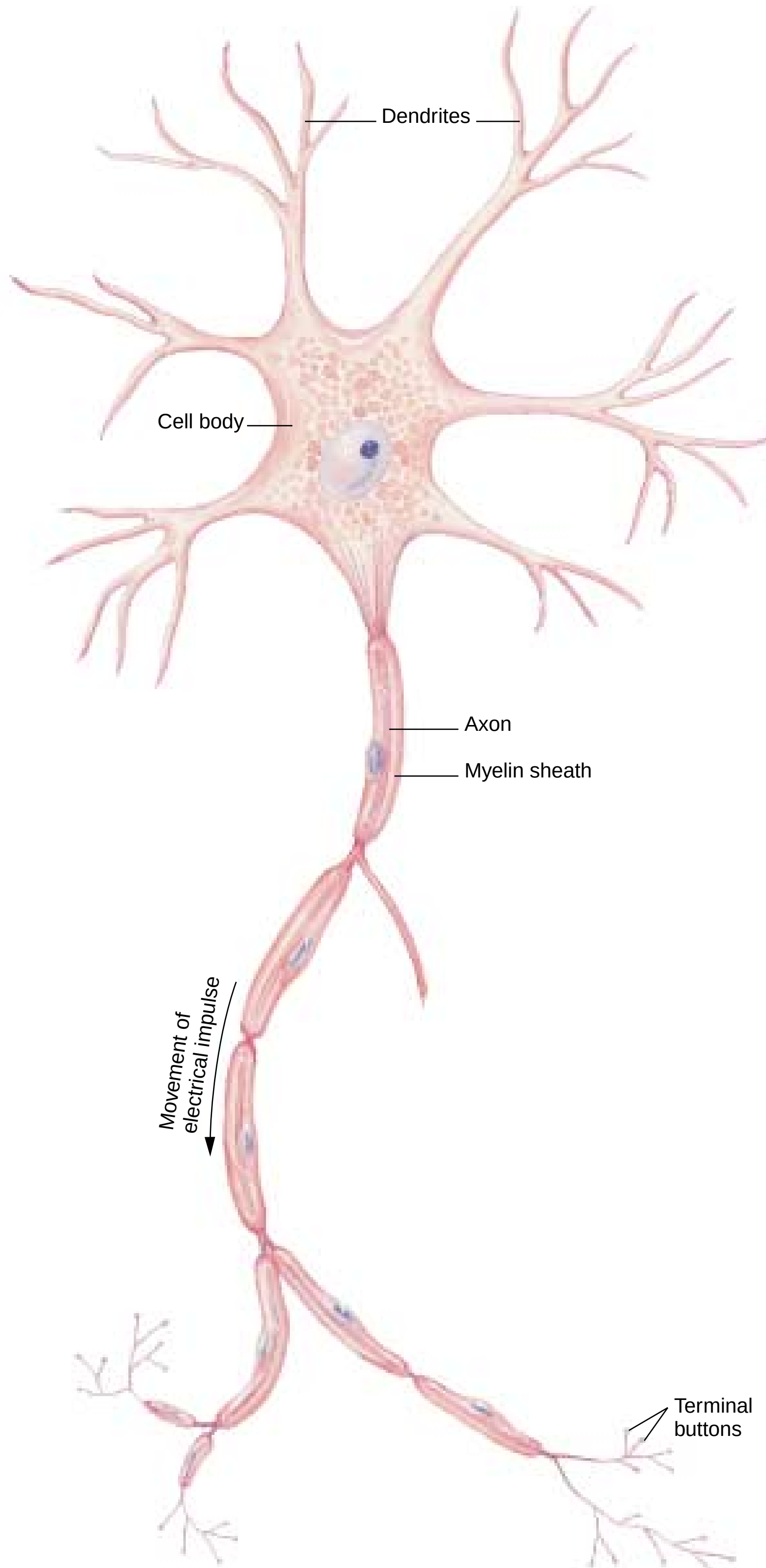

Figure 3-1 The primary components of the specialized cell called the neuron, the basic element of the nervous system (Van de Graaff, 2000). What advantages does the treelike structure of the neuron provide?

touches a painfully hot stove, for example, the information regarding the pain is passed through axons in the hand and arm that have a relatively thick coating of myelin, speeding the message of pain to the brain. In certain diseases, such as multiple sclerosis, the myelin sheath surrounding the axon deteriorates, exposing parts of the axon that are normally covered. This short-circuits messages between the brain and muscles and results in symptoms such as the inability to walk, vision difficulties, and general muscle impairment.

Taken with the aid of an electron microscope, this photograph shows cell bodies, dendrites, and axons in a cluster of neurons.

Firing the Neuron

Like a gun, neurons either fire or don't fire; there is no in-between stage, just as pulling harder on a gun trigger doesn't make the bullet travel faster or move more surely. Similarly, neurons follow an **all-or-none law:** they are either on or off, with nothing in between the on or off state. Once triggered beyond a certain point, a neuron fires.

Before a neuron is triggered—that is, when it is in a **resting state**—it has a negative electrical charge of about −70 millivolts (a millivolt is one one-thousandth of a volt). This charge is caused by the presence of more negatively charged ions (a type of molecule) within the neuron than outside it. You might think of the neuron in terms of a miniature car battery, with the inside of the neuron representing the negative pole and the outside of the neuron the positive pole.

However, when a message arrives, the cell walls in the neuron allow positively charged ions to rush in, at rates as high as 100 million ions per second. The sudden arrival of these positive ions causes the charge within that part of the cell to change momentarily from negative to positive. When the charge reaches a critical level, the "trigger" is pulled, and an electrical nerve impulse, known as an **action potential,** travels down the axon of the neuron (see Figure 3-2).

The action potential moves from one end of the axon to the other like a flame moving across a fuse toward an explosive. As the impulse travels along the axon, the movement of ions causes a sequential change in charge from negative to positive (see Figure 3-3). After the passage of the impulse, positive ions are pumped out of the axon, and the neuron charge returns to negative.

Just after an action potential has passed, the neuron cannot fire again immediately, no matter how much stimulation it receives. It is as if the gun has to be painstakingly reloaded after each shot. There then follows a period in which, though it is possible for the

all-or-none law: The rule that neurons are either on or off

resting state: The state in which there is a negative electrical charge of about −70 millivolts within the neuron

action potential: An electric nerve impulse that travels through a neuron when it is set off by a "trigger," changing the neuron's charge from negative to positive

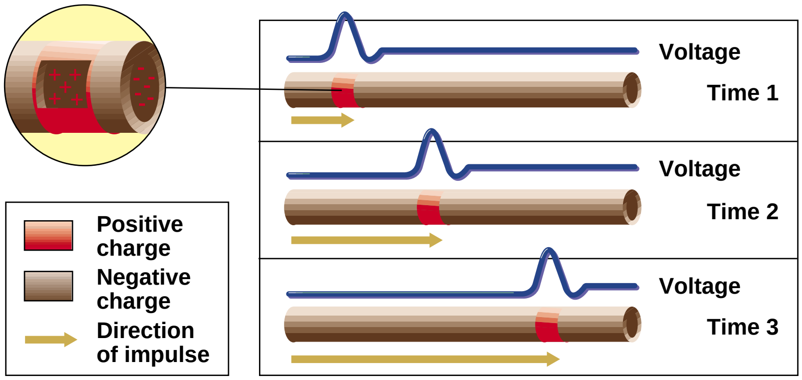

Figure 3-2 Movement of an action potential across an axon. Just prior to time 1, positively charged ions enter the cell walls, changing the charge within that part of the cell from negative to positive. The action potential is thus triggered, traveling down the axon, as illustrated in the changes occurring from Time 1 to Time 3 (from top to bottom in this drawing). Following the passage of the action potential, positive ions are pumped out of the axon, restoring its charge to negative. The change in voltage illustrated at the top of the axon can be seen in greater detail in Figure 3-3 on page 58 (Stevens, 1979).

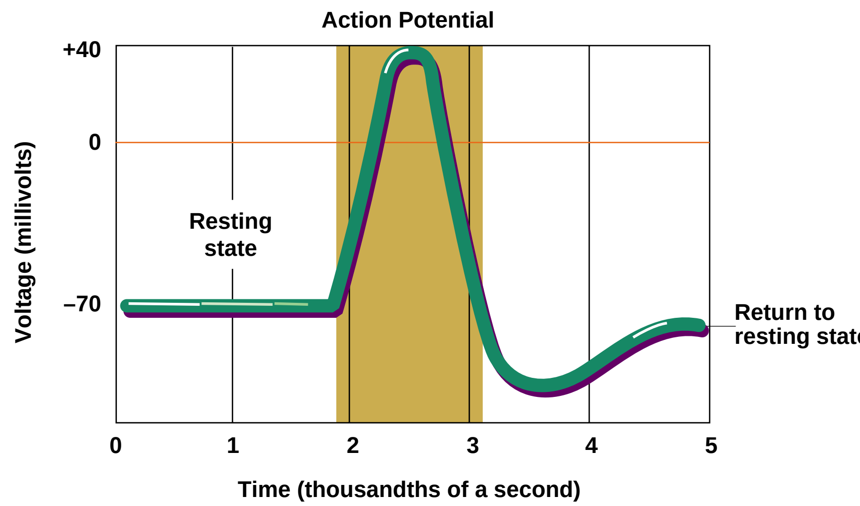

Figure 3-3 Changes in the electrical charge of a neuron during the passage of an action potential. In its normal resting state, a neuron has a negative charge of around −70 millivolts. When an action potential is triggered, however, the cell charge becomes positive, increasing to about +40 millivolts. Following the passage of the action potential, the charge becomes even more negative than it is in its typical state. It is not until the charge returns to its resting state that the neuron will be fully ready to be triggered once again.

neuron to fire, a stronger stimulus is needed than would be needed if the neuron had reached its normal resting state. Eventually, though, the neuron is ready to be fired once again.

These complex events can occur at dizzying speeds, although there is great variation among different neurons. The particular speed at which an action potential travels along an axon is determined by the axon's size and the thickness of its myelin sheath. Axons with small diameters carry impulses at about 2 miles per hour; longer and thicker ones can average speeds of more than 225 miles per hour.

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Neurons differ not only in terms of how quickly an impulse moves across the axon, but in their potential rate of firing. Some neurons have the potential to fire as many as a thousand times per second; others have a maximum potential rate that is much lower. The intensity of a stimulus that provokes a neuron determines how much of this potential rate is reached. A strong stimulus, such as a bright light or a loud sound, leads to a higher rate of firing than a less intense stimulus does. Thus, even though all impulses move at the same strength or speed across a particular axon—because of the all-or-none law—there is variation in the frequency of impulses, providing a mechanism by which we can distinguish the tickle of a feather from the weight of someone standing on our toe.

The structure, operation, and functions of the neuron illustrate how fundamental biological aspects of the body underlie several primary psychological processes. Our understanding of the way we sense, perceive, and learn about the world would be greatly restricted without the information about the neuron that biopsychologists and other researchers have acquired.

synapse: The space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron using chemical messages

neurotransmitters: Chemicals that carry messages across the synapse to the dendrite (and sometimes the cell body) of a receiver neuron

Where Neurons Meet: Bridging the Gap

If you've ever looked inside a computer, you've seen that each part is physically connected to another. In contrast, evolution has produced a neural transmission system that at some points has no need for a structural connection between its components. Instead, a chemical connection bridges the gap, known as a synapse, between two neurons (see Figure 3-4). The **synapse** is the space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron using chemical messages.

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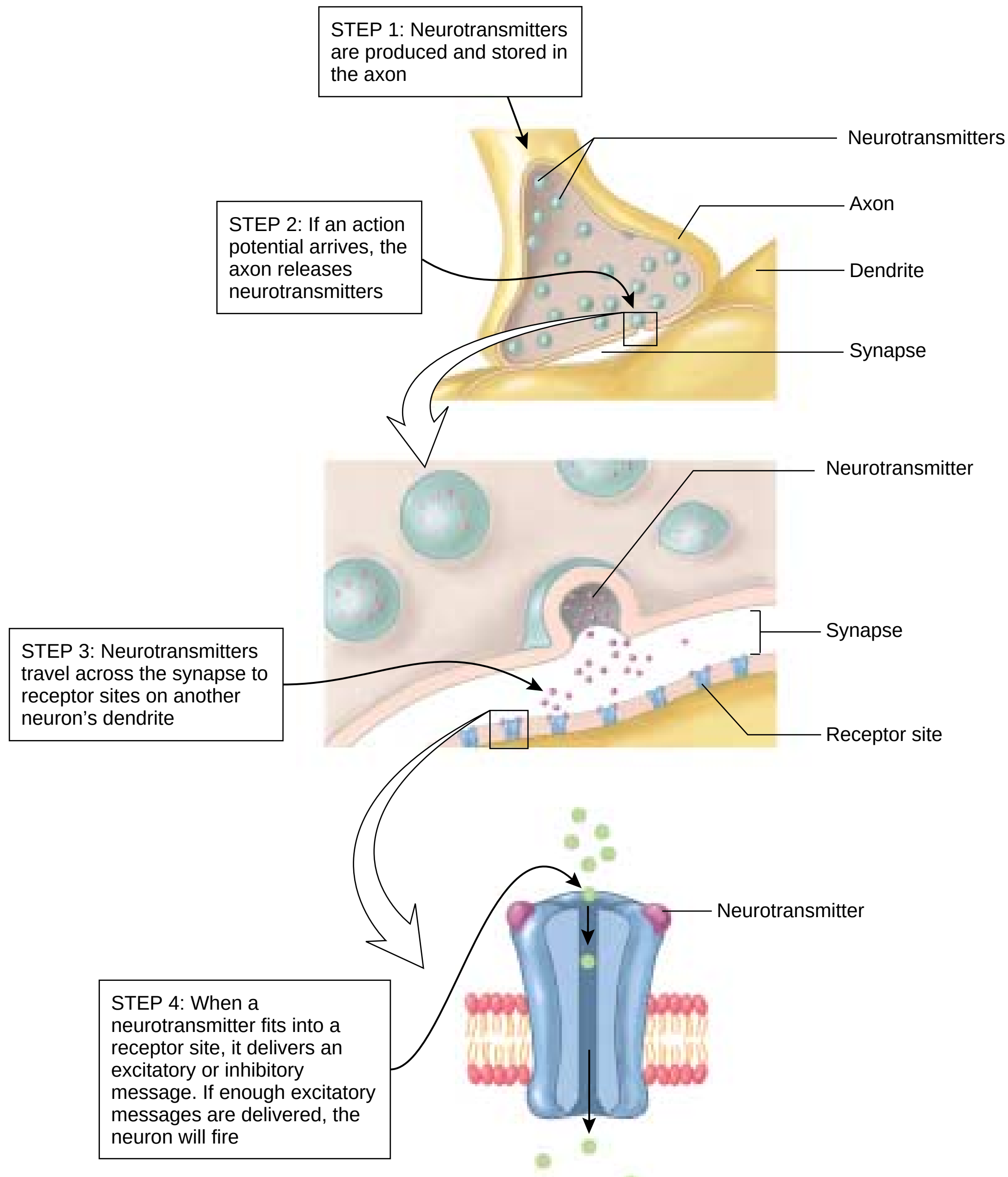
When a nerve impulse comes to the end of the axon and reaches a terminal button, the terminal button releases a chemical courier called a neurotransmitter. **Neurotransmitters** are chemicals that carry messages across the synapse to the dendrite (and sometimes the cell body) of a receiver neuron. Like a boat that ferries passengers across a river, these chemical messengers move toward the shorelines of other neurons. The chemical mode of message transmission that occurs between neurons is strikingly different from the means by which communication occurs inside neurons. It is important

(a)



(b)

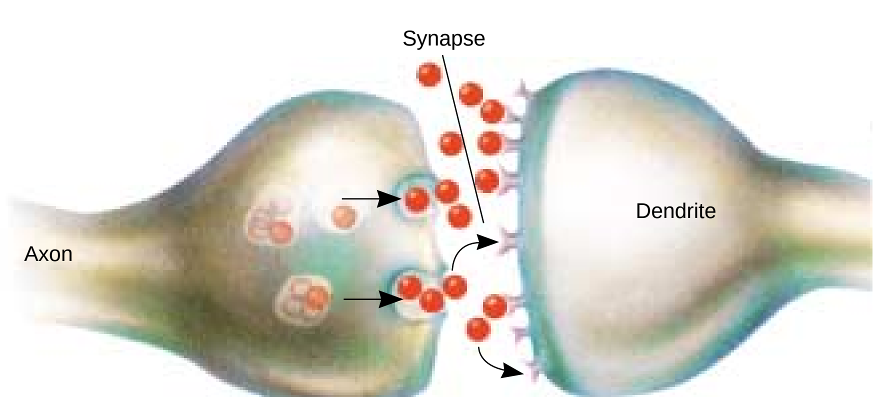


Figure 3-4 *(a)* A synapse is the junction between an axon and a dendrite. The gap between the axon and the dendrite is bridged by chemicals called neurotransmitters (Mader, 2000). *(b)* Just as the pieces of a jigsaw puzzle can fit in only one specific location in a puzzle, each kind of neurotransmitter has a distinctive configuration that allows it to fit into a specific type of receptor cell (Johnson, 2000). Why is it advantageous for axons and dendrites to be linked by temporary chemical bridges rather than by the hard wiring typical of a radio connection or telephone hookup?

to remember, then, that although messages travel in electrical form *within* a neuron, they move *between* neurons through a chemical transmission system.

There are several types of neurotransmitters, and not all receiver neurons are capable of making use of the chemical message carried by a particular neurotransmitter. In the same way as a jigsaw puzzle piece can fit in only one specific location in a puzzle, so each kind of neurotransmitter has a distinctive configuration that allows it to fit into a specific type of receptor site on the receiving neuron (see Figure 3-4b). It is only when a neurotransmitter fits precisely into a receptor site that successful chemical communication is possible.

excitatory message: A chemical message that makes it more likely that a receiving neuron will fire and an action potential will travel down its axons

inhibitory message: A chemical message that prevents a receiving neuron from firing

If a neurotransmitter does fit into a site on the receiving neuron, the chemical message it delivers is basically one of two types: excitatory or inhibitory. **Excitatory messages** make it more likely that a receiving neuron will fire and an action potential will travel down its axon. **Inhibitory messages,** in contrast, do just the opposite; they provide chemical information that prevents or decreases the likelihood that the receiving neuron will fire.

Because the dendrites of a neuron receive both excitatory and inhibitory messages simultaneously, the neuron must integrate the messages by using a kind of chemical calculator. If the concentration of excitatory messages is greater than the concentration of inhibitory ones, the neuron fires. On the other hand, if the inhibitory messages outweigh the excitatory ones, nothing happens, and the neuron remains in its resting state (Thomson, 1997; Miles, 2000).

reuptake: The reabsorption of neurotransmitters by a terminal button

If neurotransmitters remained at the site of the synapse, receptor neurons would be awash in a continual chemical bath, producing constant stimulation of the receptor neurons—and effective communication across the synapse would no longer be possible. To solve this problem, neurotransmitters are either deactivated by enzymes or—more frequently—reabsorbed by the terminal button in an example of chemical recycling called **reuptake.** Like a vacuum cleaner sucking up dust, neurons reabsorb the neurotransmitters that are now clogging the synapse. All this activity occurs at lightning speed, with the process taking just several milliseconds (Helmuth, 2000).

Neurotransmitters: Multitalented Chemical Couriers

Neurotransmitters are a particularly important link between the nervous system and behavior. Not only are they important for maintaining vital brain and body functions, but a deficiency or an excess of a neurotransmitter can produce severe behavior disorders. More than a hundred chemicals have been found to act as neurotransmitters, and biopsychologists believe that more may ultimately be identified (Purves et al., 1997; Penney, 2000).

Neurotransmitters vary significantly in terms of how strong their concentration must be to trigger a neuron to fire. Furthermore, the effects of a given neurotransmitter vary, depending on the area of the nervous system in which it is produced. The same neurotransmitter, then, can cause a neuron to fire when it is secreted in one part of the brain and can inhibit the firing of neurons when it is produced in another part. (The major neurotransmitters are described in Table 3-1.)

One of the most common neurotransmitters is *acetylcholine* (or *ACh,* its chemical symbol), which is found throughout the nervous system. ACh is involved in our every move, because—among other things—it transmits messages relating to our skeletal muscles. ACh is also involved in memory capabilities, and a diminished production of ACh might be related to Alzheimer's disease (Selkoe, 1997).

Another common excitatory neurotransmitter, *glutamate,* plays a role in memory. As we'll discuss in Chapter 7, memories appear to be produced by specific biochemical changes at particular synapses, and glutamate, along with other neurotransmitters, plays an important role in this process (Gibbs et al., 1996; Li et al., 1999; Bennett, 2000).

Gamma-amino butyric acid (GABA), found in both the brain and the spinal cord, appears to be the nervous system's primary inhibitory neurotransmitter. It moderates a

Table 3-1 Some Major Neurotransmitters

Name	Location	Effect	Function
Acetylcholine (ACh)	Brain, spinal cord, peripheral nervous system, especially some organs of the parasympathetic nervous system	Excitatory in brain and autonomic nervous system; inhibitory elsewhere	Muscle movement; cognitive functioning
Glutamate	Brain, spinal cord	Excitatory	Memory
Gamma-amino butyric acid (GABA)	Brain, spinal cord	Main inhibitory neurotransmitter	Eating, aggression, sleeping
Dopamine (DA)	Brain	Inhibitory or excitatory	Muscle disorders, mental disorders, Parkinson's disease
Serotonin	Brain, spinal cord	Inhibitory	Sleeping, eating, mood, pain, depression
Endorphins	Brain, spinal cord	Primarily inhibitory, except in hippocampus	Pain suppression, pleasurable feelings, appetities, placebos

variety of behaviors, ranging from eating to aggression. Several common substances, such as the tranquilizer Valium and alcohol, are effective because they permit GABA to operate more efficiently (Tabakoff & Hoffman, 1996).

Another major neurotransmitter is *dopamine (DA)*. The discovery that certain drugs can have a marked effect on dopamine release has led to the development of effective treatments for a wide variety of physical and mental ailments. For instance, Parkinson's disease, from which actor Michael J. Fox suffers, is caused by a deficiency of dopamine in the brain. Techniques for increasing the production of dopamine in Parkinson's patients are proving effective (Schapira, 1999; LeWitt, 2000).

In other instances, *over*production of dopamine produces negative consequences. For example, researchers have hypothesized that schizophrenia and some other severe mental disturbances are affected or perhaps even caused by the presence of unusually high levels of dopamine. Drugs that block the reception of dopamine reduce the symptoms displayed by some people diagnosed with schizophrenia, as we will examine further in Chapters 16 and 17 (Kahn, Davidson, & Davis, 1996).

Another neurotransmitter, *serotonin*, is associated with the regulation of sleep, eating, mood, and pain. A growing body of research points toward a broader role for serotonin, suggesting its involvement in such diverse behaviors as coping with stress, alcoholism, depression, suicide, impulsivity, and aggression (Smith, Williams, & Cowen, 2000).

Endorphins, another class of neurotransmitters, are a family of chemicals produced by the brain that are similar in structure to painkilling drugs such as morphine. The production of endorphins seems to reflect the brain's effort to deal with pain. For instance, people who are afflicted with diseases that produce long-term, severe pain often develop large concentrations of endorphins in their brains—suggesting an effort by the brain to control the pain. Endorphins can also produce the euphoric feelings that runners sometimes experience after long runs. The exertion and perhaps even the pain involved in a long run stimulate the production of endorphins—ultimately resulting in what has been called "runner's high" (Kremer & Scully, 1994; Dishman, 1997).

Endorphin release might also explain other phenomena that have long puzzled psychologists. For example, acupuncture and placebos (pills or other substances that contain no actual drugs but that patients *believe* will make them better) might induce the release of endorphins, leading to the reduction of pain (Mikamo et al., 1994; Murray, 1995).

Evaluate

1. The ________ is the fundamental element of the nervous system.
2. Neurons receive information through their ________ and they send messages through their ________.
3. Just as electrical wires have an outer coating, so axons are insulated by a coating called the ________ ________.
4. The gap between two neurons is bridged by a chemical connection called a ________.
5. Endorphins are one kind of ________, the chemical "messengers" between neurons.

Answers to Evaluate Questions

1. neuron 2. dendrites; axons 3. myelin sheath 4. synapse 5. neurotransmitter

Rethink

1. Can you use your knowledge of psychological research methods to suggest how researchers can study the effects of neurotransmitters on human behavior?
2. In what ways might endorphins help produce the placebo effect? Is there a difference between believing that one's pain is reduced and actually experiencing reduced pain? Why or why not?

Prepare

In what way are the structures of the nervous system tied together?

Organize

The Nervous System
- Central and Peripheral Nervous Systems
- The Evolutionary Foundations of the Nervous System
- Behavioral Genetics

The Nervous System

Given the complexity of individual neurons and the neurotransmission process, it should come as no surprise that the connections and structures formed by the neurons are complicated. Because just one neuron can be connected to 80,000 other neurons, the total number of possible connections is astonishing. For instance, estimates of the number of neural connections within the brain fall in the neighborhood of 1 quadrillion—a 1 followed by 15 zeros; some experts put the number even higher (McGaugh, Weinberger, & Lynch, 1990; Estes, 1991; Eichenbaum, 1993).

Whatever the actual number of neural connections, the human nervous system has both a logic and an elegance. We turn now to its basic structures.

Central and Peripheral Nervous Systems

As you can see from the schematic representation in Figure 3-5, the nervous system is divided into two main parts: the central nervous system and the peripheral nervous system. The **central nervous system (CNS)** is composed of the brain and spinal cord. The **spinal cord,** about the thickness of a pencil, contains a bundle of nerves that leaves the brain and runs down the length of the back (see Figure 3-6, p. 64). It is the primary means for transmitting messages between the brain and the body.

However, the spinal cord is not just a communications conduit. It also controls some simple kinds of behaviors on its own, without any involvement of the brain. One example is the way your knee jerks forward when it is tapped with a rubber hammer. Such behaviors, called **reflexes,** are automatic, involuntary responses to incoming stimuli. Similarly, when you touch a hot stove and immediately withdraw your hand, a reflex is at work. Although the brain eventually analyzes and reacts to the situation ("Ouch—hot stove—pull away!"), the initial withdrawal is directed only by neurons in the spinal cord.

Three sorts of neurons are involved in reflexes. **Sensory (afferent) neurons** transmit information from the perimeter of the body to the central nervous system. **Motor (efferent) neurons** communicate information from the nervous system to muscles and glands of the body. **Interneurons** connect sensory and motor neurons, carrying messages between the two.

The importance of the spinal cord and reflexes is illustrated by the outcome of accidents in which the cord is injured or severed. Actor Christopher Reeve, who was injured in a horse-riding accident, suffers from *quadriplegia,* a condition in which voluntary muscle movement below the neck is lost. In a less severe but still debilitating condition, *paraplegia,* people are unable to voluntarily move any muscles in the lower half of their body.

central nervous system (CNS): The system that includes the brain and spinal cord

spinal cord: A bundle of nerves that leaves the brain and runs down the length of the back and is the main means for transmitting messages between the brain and the body

reflexes: Automatic, involuntary responses to incoming stimuli

sensory (afferent) neurons: Neurons that transmit information from the perimeter of the body to the central nervous system

motor (efferent) neurons: Neurons that communicate information from the nervous system to muscles and glands of the body

interneurons: Neurons that connect sensory and motor neurons, carrying messages between the two

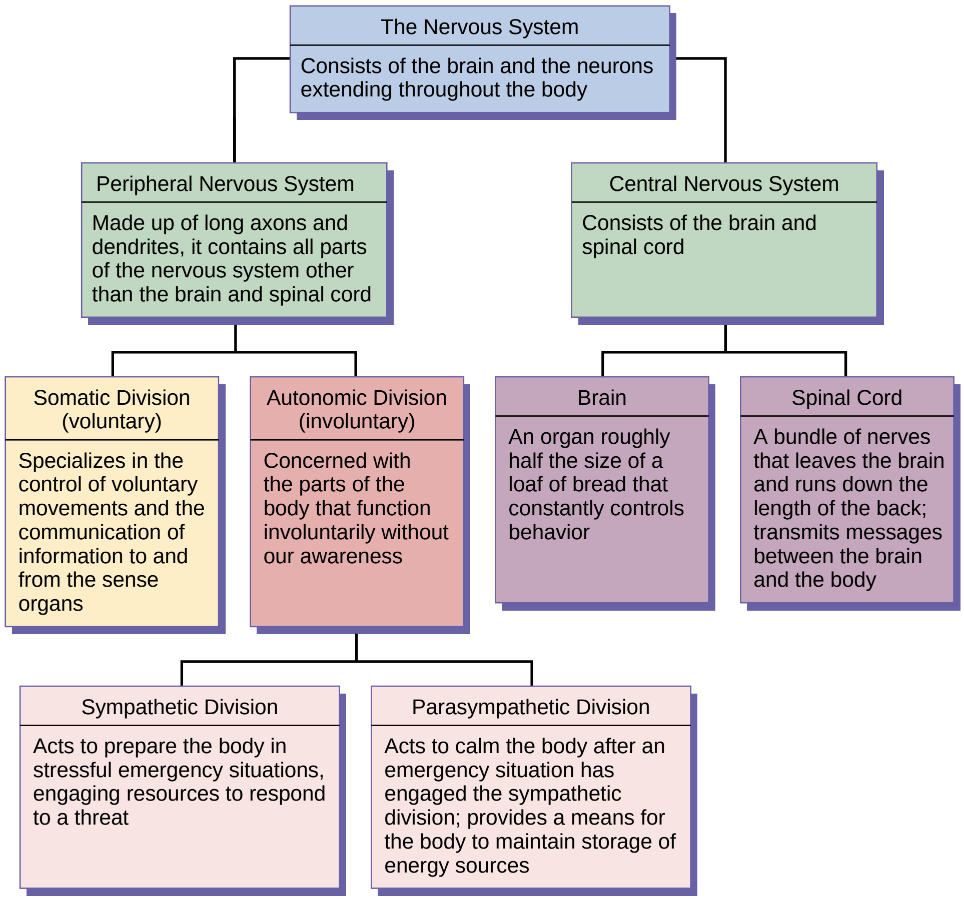


Figure 3-5 A schematic diagram of the relationship of the parts of the nervous system.

As suggested by its name, the **peripheral nervous system** branches out from the spinal cord and brain and reaches the extremities of the body. Made up of long axons and dendrites, the peripheral nervous system encompasses all parts of the nervous system other than the brain and spinal cord. There are two major divisions, the somatic division and the autonomic division, both of which connect the central nervous system with the sense organs, muscles, glands, and other organs. The **somatic division** specializes in the control of voluntary movements—such as the motion of the eyes to read this sentence or of the hand to turn this page—and the communication of information to and from the sense organs. On the other hand, the **autonomic division** is concerned with the parts of the body that keep us alive—the heart, blood vessels, glands, lungs, and other organs that function involuntarily without our awareness. As you are reading at this moment, the autonomic division of the peripheral nervous system is pumping blood through your body, pushing your lungs in and out, overseeing the digestion of the meal you had a few hours ago, and so on—all without a thought or care on your part.

peripheral nervous system: The part of the nervous system that includes the autonomic and somatic subdivisions; made up of long axons and dendrites, it branches out from the spinal cord and brain and reaches the extremities of the body

somatic division: The part of the nervous system that specializes in the control of voluntary movements and the communication of information to and from the sense organs

autonomic division: The part of the nervous system that controls involuntary movement (the actions of the heart, glands, lungs, and other organs)

Activating the Divisions of the Autonomic Nervous System

The autonomic division plays a particularly crucial role during emergency situations. Suppose as you are reading you suddenly sense that a stranger is watching you through the window. As you look up, you see the glint of something that just might be a knife. As confusion races through your mind and fear overcomes your attempts to think rationally, what happens to your body? If you are like most people, you react immediately on a physiological level. Your heart rate increases, you begin to sweat, and you develop goose bumps all over your body.

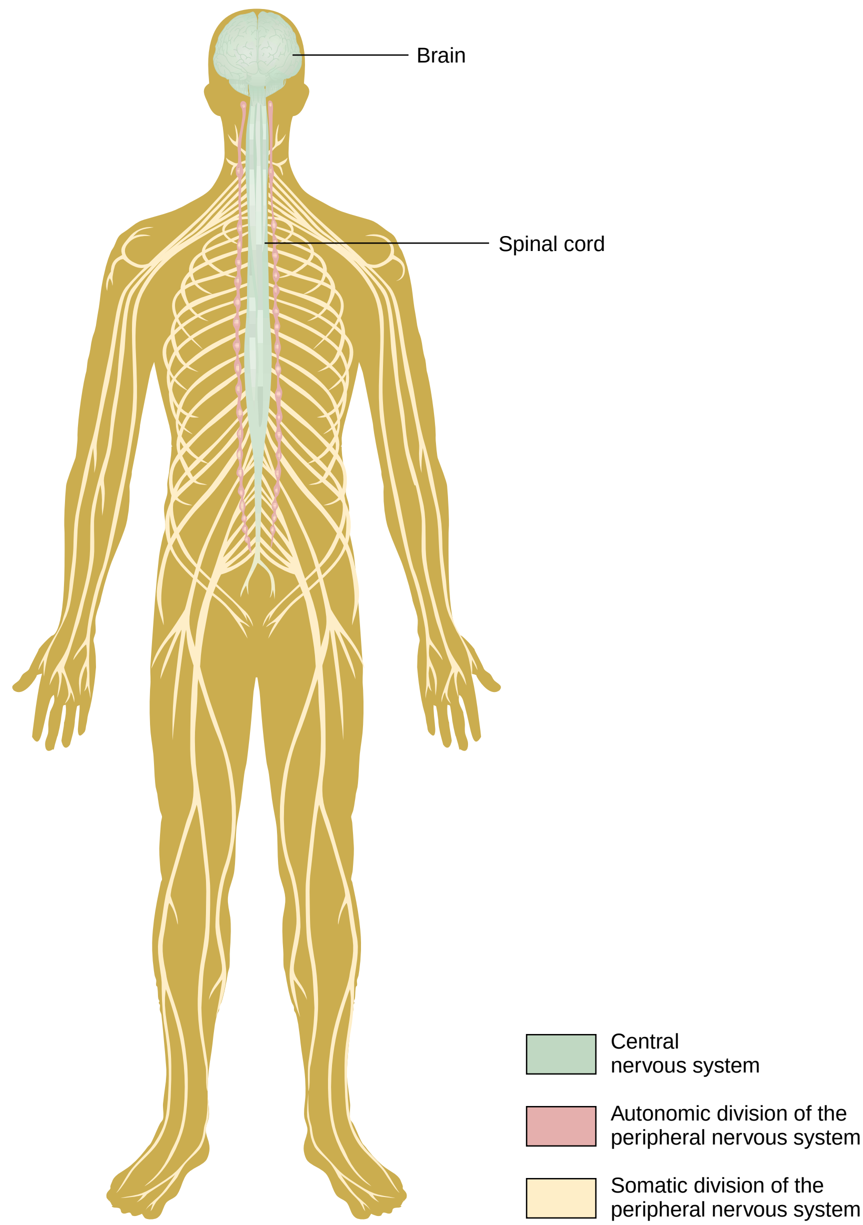


Figure 3-6 The central nervous system—consisting of the brain and spinal cord—and the peripheral nervous system.

sympathetic division: The part of the autonomic division of the nervous system that acts to prepare the body in stressful emergency situations, engaging all the organism's resources to respond to a threat

parasympathetic division: The part of the autonomic division of the nervous system that acts to calm the body after the emergency situation is resolved

The physiological changes that occur result from the activation of one of the two parts that make up the autonomic division: the **sympathetic division.** The sympathetic division acts to prepare the body in stressful emergency situations, engaging all of the organism's resources to respond to a threat. This response often takes the form of "fight or flight." In contrast, the **parasympathetic division** acts to calm the body after the emergency situation is resolved. When you find, for instance, that the stranger at the window is actually your roommate who has lost his keys and is climbing in the window to avoid waking you, your parasympathetic division begins to predominate, lowering your heart rate, stopping your sweating, and returning your body to the state it was in prior to your fright. The parasympathetic division also provides a means for the body to maintain storage of energy sources such as nutrients and oxygen. The sympathetic and parasympathetic divisions work together to regulate many functions of the body (see Figure 3-7). For instance, sexual arousal is controlled by the parasympathetic division but sexual orgasm is a function of the sympathetic division.

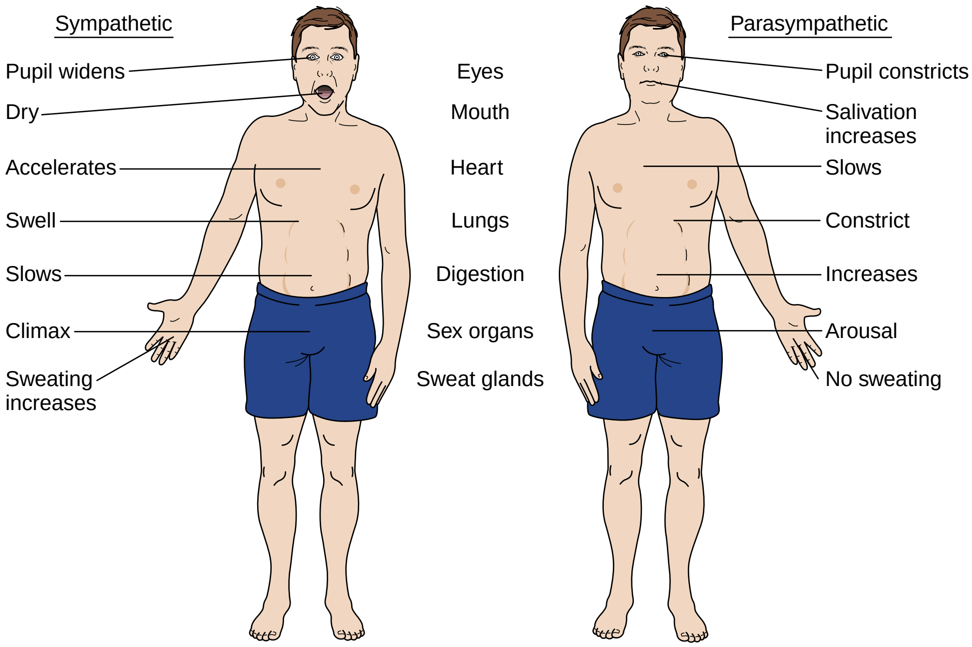


Figure 3-7 The major functions of the autonomic nervous system. The sympathetic division acts to prepare certain organs of the body for stressful emergency situations, and the parasympathetic division acts to calm the body after the emergency situation is resolved. Can you explain why each response of the sympathetic division might be useful in an emergency?

The Evolutionary Foundations of the Nervous System

The complexities of the nervous system can be understood only by taking the course of evolution into consideration. The forerunner of the human nervous system is found in the earliest simple organisms to have a spinal cord. Basically, these organisms were simple input-output devices: When the upper side of their spinal cord was stimulated by for instance, being touched, they reacted with a simple response, such as jerking away. Such responses were completely a consequence of the organism's genetic makeup.

Over millions of years, the front end of the spinal cord became more specialized, and organisms became capable of distinguishing between different kinds of stimuli and responding appropriately to them. Ultimately, the front end of the spinal cord evolved into what we would consider a primitive brain. At first, it had just three parts, devoted to close stimuli (such as smell), more distant stimuli (such as sights and sounds), and the ability to maintain balance and bodily coordination. In fact, many animals, such as fish, still have a nervous system that is structured in roughly similar fashion today. In contrast, the human brain evolved from this three-part configuration into an organ that is far more complex and differentiated (Merlin, 1993).

Furthermore, the nervous system is *hierarchically organized*, meaning that relatively newer (from an evolutionary point of view) and more sophisticated regions of the brain regulate the older, and more primitive, parts of the nervous system. As we move up along the spinal cord and continue upward into the brain, then, the functions controlled by various regions become progressively more advanced.

Why should we care about the evolutionary background of the human nervous system? The answer comes from researchers working in the area of **evolutionary psychology,** the branch of psychology that seeks to identify how behavior is influenced and produced by our genetic inheritance from our ancestors. They argue that the course of evolution is reflected in the structure and functioning of the nervous system, and that evolutionary factors consequently have a significant influence on our everyday behavior. Their work, and that of other scientists, has led to the development of a new field: behavioral genetics.

evolutionary psychology: The branch of psychology that seeks to identify behavior patterns that result from our genetic inheritance from our ancestors

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behavioral genetics: The study of the effects of heredity on behavior

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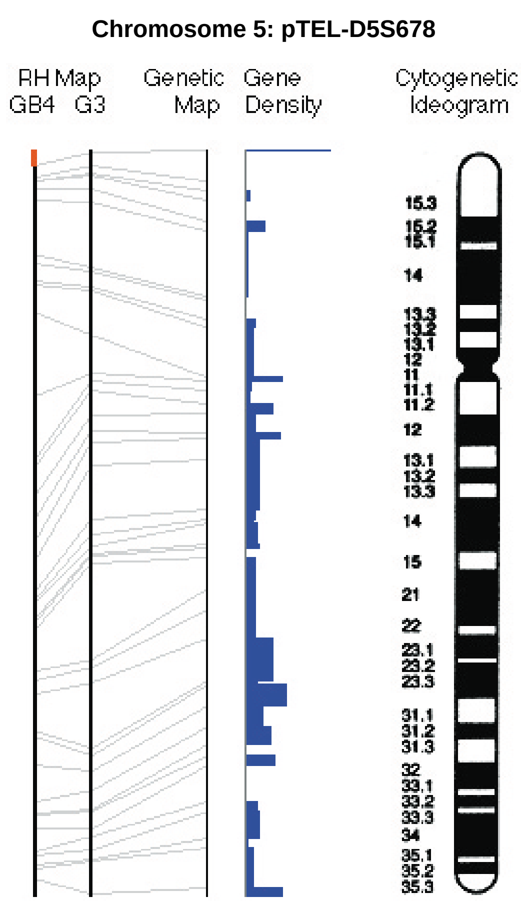
Behavioral Genetics

Our evolutionary heritage manifests itself not only through the structure and functioning of the nervous system, but through our behavior as well. In the view of a blossoming new area of study, people's personality and behavioral habits are affected in part by their genetic heritage. **Behavioral genetics** studies the effects of heredity on behavior. Behavioral genetics researchers are finding increasing evidence that cognitive abilities, personality traits, sexual orientation, and psychological disorders are determined to some extent by genetic factors (Funder, 1997; Craig et al., 2000).

Behavioral genetics gets to the heart of the nature-nurture issue that we first discussed in Chapter 1. Although no one would argue that our behavior is *solely* determined by inherited factors, evidence collected by behavioral geneticists does suggest that our genetic inheritance predisposes us to respond in particular ways to our environment, and even to seek out particular kinds of environments. For instance, research indicates that genetic factors might be related to such diverse behavior as level of family conflict, schizophrenia, learning disabilities, and general sociability (Elkins, McGue, & Iacono, 1997; Berrettini, 2000).

Furthermore, important human characteristics and behaviors are related to the presence (or absence) of particular *genes*, the genetic material that controls the transmission of traits. For example, researchers have found evidence that novelty-seeking behavior is determined, at least in part, by a certain gene.



Part of the human DNA sequence, identified by the Human Genome Project, which has mapped the specific location and sequence of every gene.

Researchers have identified some 100,000 individual genes, each of which appears in a specific sequence on particular chromosomes. Scientists only recently succeeded in mapping these genes as part of a massive, multibillion-dollar project known as the Human Genome Project, which, after a decade of effort, identified the sequence of the three billion chemical pairs that make up the DNA in genes. By understanding the basic structure of the human *genome*, the "map" of humans' total genetic makeup, scientists are a giant step closer to understanding the biochemical recipes that direct human functioning (Human Genome Project, 2000; Pennisi, 2000).

Despite its relative infancy, the field of behavioral genetics has already made substantial contributions. By understanding the relationship between our genetic heritage and the structures of the nervous system, we are gaining new knowledge about the development of various behavioral difficulties, such as the psychological disorders we'll discuss in Chapter 16. Perhaps more importantly, behavioral genetics holds the promise of developing new treatment techniques to remedy genetic deficiencies that can lead to physical and psychological difficulties. For example, analysis of a drop of blood might tell a woman whether she has a form of breast cancer that is likely to be deadly or is treatable, and scientists might be able to analyze our children's genes to determine if they are susceptible to heart disease, as we'll discuss in detail in Chapter 12 (Risch & Merikangas, 1996; Haseltine, 1997; Begley, 2000).

We turn now to a consideration of the particular structures of the brain and the primary functions to which they are related. However, a caution is in order. Although we'll be discussing how specific brain areas are tied to specific behaviors, this approach is an oversimplification. No simple one-to-one correspondence between a distinct part of the brain and a particular behavior exists. Instead, behavior is produced by complex interconnections among sets of neurons located in many areas of the brain: Our behavior, emotions, thoughts, hopes, and dreams are produced by a variety of neurons throughout the nervous system, working in concert (Grillner, 1996; Joseph, 1996; Sharma, Angelucci, & Sur, 2000).

Evaluate

1. If you should put your hand on a red-hot piece of metal, the immediate response of pulling it away would be an example of a(n) ________.
2. The central nervous system is composed of the ________ and ________ .
3. In the peripheral nervous system, the ________ division controls voluntary movements, whereas the ________ division controls organs that keep us alive and function without our awareness.
4. Maria saw a young boy run into the street and get hit by a car. When she got to the fallen child, she was in a state of panic. She was sweating and her heart was racing. Her biological state resulted from the activation of what division of the nervous system?
   a. Parasympathetic
   b. Central
   c. Sympathetic
5. The increasing complexity and hierarchy of the nervous system over millions of years is the subject of study for researchers working in the field of ________ ________.
6. The emerging field of ________ ________ studies how our genetic inheritance predisposes us to behave in certain ways.

Answers to Evaluate Questions

1. reflex 2. brain; spinal cord 3. somatic; autonomic 4. c 5. evolutionary psychology 6. behavioral genetics

Rethink

1. How might communication within the nervous system result in human consciousness?
2. How is the "fight or flight" response helpful to organisms in emergency situations?

The Brain

Prepare

How do researchers identify the major parts and functions of the brain?

What are the major parts of the brain, and for what behaviors is each part responsible?

How do the two halves of the brain operate interdependently?

How can an understanding of the nervous system help us find ways to relieve disease and pain?

Organize

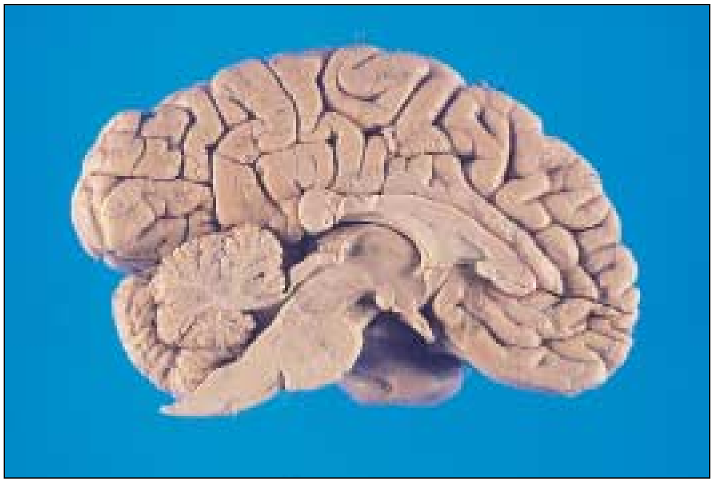
It is not much to look at. Soft, spongy, mottled, and pinkish-gray in color, it can hardly be said to possess much in the way of physical beauty. Despite its physical appearance, however, it ranks as the greatest natural marvel we know of and possesses a beauty and sophistication all its own.

The object to which this description applies? The human brain. Our brain is responsible for our loftiest thoughts—and our most primitive urges. It is the overseer of the intricate workings of the human body. If one were to attempt to design a computer to mimic the range of capabilities of the brain, the task would be nearly impossible; in fact, it has proved difficult even to come close. The sheer quantity of nerve cells in the brain is enough to daunt even the most ambitious computer engineer. Many billions of nerve cells make up a structure weighing just three pounds in the average adult. However, the most astounding thing about the brain is not its number of cells but its ability to allow human intellect to flourish as it guides our behavior and thoughts.

Studying the Brain's Structure and Functions: Spying on the Brain

The brain has posed a continual challenge to those wishing to study it. For most of history, its examination was possible only after an individual was dead. Only then could the skull be opened and the brain cut into without serious injury. Although this was informative, such a limited procedure could hardly tell us much about the functioning of the healthy brain.

Today, however, important advances have been made in the study of the brain through the use of brain-scanning techniques. Using brain scanning, investigators can take a snapshot of the internal workings of the brain without having to cut surgically into a person's skull. The major scanning techniques, described below, are illustrated in Figure 3-8 on the next page.



The brain may not be much to look at but it represents one of the great marvels of human development. Why do most scientists believe that it will be difficult, if not impossible, to duplicate the brain's abilities?

- The *electroencephalogram (EEG)* records electrical activity in the brain through electrodes placed on the outside of the skull. Although traditionally the EEG could produce only a graph of electrical wave patterns, new techniques are now able to transform the brain's electrical activity into a pictorial representation of the brain that allows the diagnosis of such problems as epilepsy and learning disabilities.
- The *computerized axial tomography (CAT) scan* uses a computer to construct an image of the structures of the brain by combining thousands of separate X rays taken at slightly different angles. It is very useful for showing abnormalities in the structure of the brain, such as swelling and enlargement of certain parts, but does not provide information about brain activity.
- The *magnetic resonance imaging (MRI) scan* provides a detailed, three-dimensional computer-generated image of brain structures and activity by aiming a powerful magnetic field at the body. For example, it is capable of producing vivid images of individual bundles of nerves, opening the way for improved diagnosis of such ailments as chronic back pain.
- The *superconducting quantum interference device (SQUID)* is sensitive to tiny changes in magnetic fields that occur when neurons fire. Using SQUID, researchers can pinpoint the location of neural activity.
- The *positron emission tomography (PET) scan* shows biochemical activity within the brain at a given moment in time. PET scans begin by injecting into the bloodstream a radioactive (but safe) liquid that makes its way to the brain. By locating radiation within the brain, a computer can determine which are the more active regions, providing a striking picture of the brain at work.

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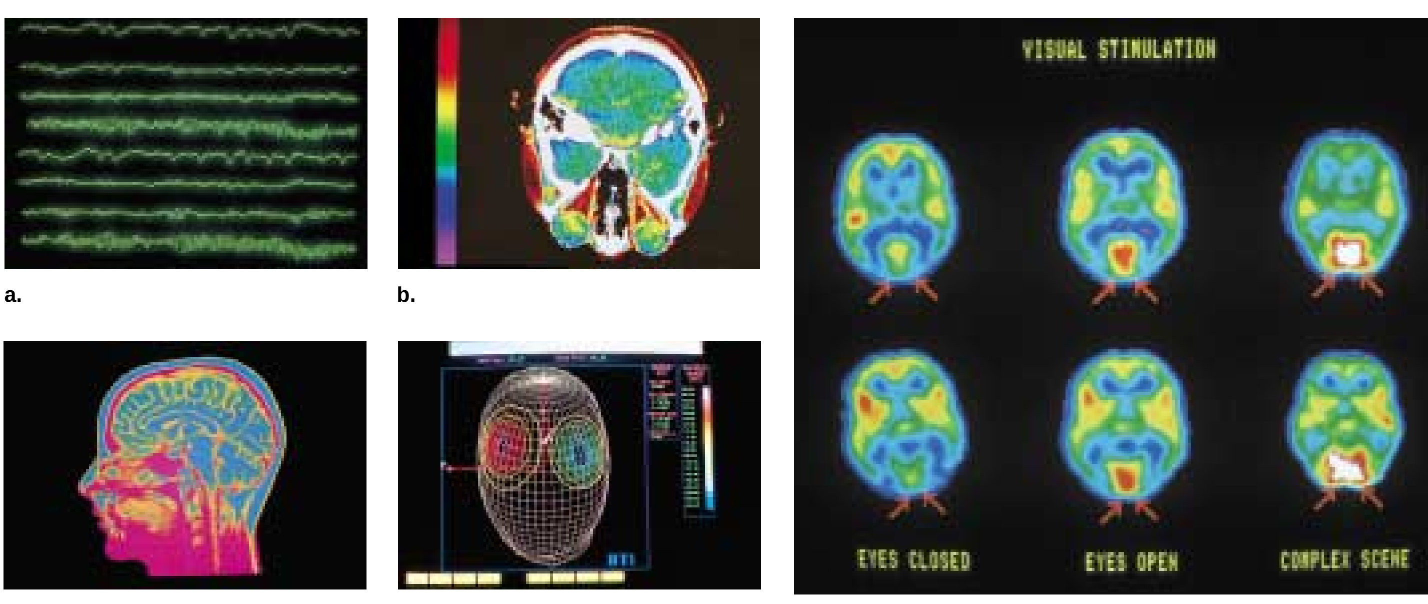


Figure 3-8 Brain scans produced by different techniques. *(a)* A computer-produced EEG image. *(b)* This CAT scan shows the structures of the brain. *(c)* The MRI scan uses a magnetic field to detail the parts of the brain. *(d)* The SQUID scan shows the neural activity of the brain *(e)* The PET scan displays the functioning of the brain at a given moment and is sensitive to the person's activities.

Applying Psychology in the 21st Century

Mind over Cursor: Using Brain Waves to Overcome Physical Limitations

For four years, Hans-Peter Balzmann, a lawyer suffering from Lou Gehrig's disease, was locked within his own body. Paralyzed by the disease and unable to eat, speak, or even breathe on his own, he had relied on a respirator and feeding tube to survive. Although his mind functioned normally, he was unable to communicate with the outside world.

All that changed, however, after Balzmann obtained an experimental device that allows brain waves to be translated into written communication. Using EEG scanning techniques that react to the pattern of brain waves originating in the brain, Balzmann learned to boost and curtail certain types of brain waves. After hundreds of hours of practice, he was able to select letters that appear on a video screen. By stringing letters together, he could spell out messages. The process, which makes use of brain waves called "slow cortical potentials," permitted Balzmann to communicate effectively for the first time in years. Although the method is slow and tedious—Balzmann can produce only about two characters per minute—it holds great promise (Birbaumer et al., 1999).

Other increasingly sophisticated procedures may permit faster communication with brain waves in the future. For example, neurosurgeon Philip Kennedy of Emory University is experimenting with a procedure in which he implants electrodes into a paralyzed patient's motor cortex. When the patient thinks about moving her hands, tongues, or eyes, the brain produces electrical signals that are amplified by the implant and translated into the movement of a cursor. Using this system, the patient can spell out words and hit icons (such as "I'm cold") on the computer screen ("Mind over Matter,," 1999).

Technological advances offer the possibility of treating other brain disorders. For example, an experimental system is being tested to treat seizures due to epilepsy. The system consists of a pacemaker-like device, implanted into the chest, that sends signals to the brain to block seizures. When patients feel that a seizure is about to occur, they can activate the system, short-circuiting the seizure (Forest, 1997).

Ultimately, systems such as these might be useful not just for people with illnesses and disabilities, but for anyone. For instance, it is conceivable that one day you will be able to control your computer's cursor by simply thinking about moving it. Mind-over-cursor could be in everyone's future.

Can you think of a mechanism that would permit brain-wave communication between two people? What implications would there be if people gained the ability to communicate with each other in this way?

Each of these techniques offers exciting possibilities not only for the diagnosis and treatment of brain disease and injuries, but also for an increased understanding of the normal functioning of the brain. In addition, researchers are developing ways to combine separate scanning techniques (such as integrated, simultaneous PET and MRI scans) to produce even more effective portraits of the brain, such as three-dimensional reconstructions of the brain that can be used during surgery (Grimson et al., 1999).

central core: The "old brain," which controls such basic functions as eating and sleeping and is common to all vertebrates

Advances in brain scanning are also aiding the development of new methods for harnessing the brain's neural signals. We consider some of these intriguing findings in the *Applying Psychology in the 21*st *Century* box.

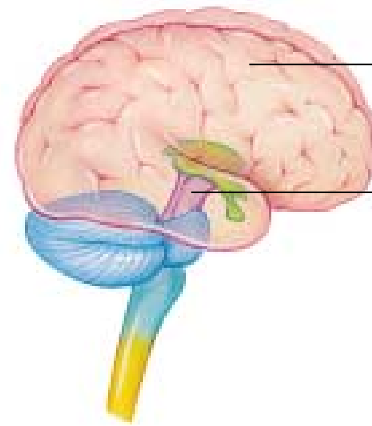
To get a better view of the brain, researchers are experimenting with various scanning techniques; this photo combines PET and MRI scans.

The Central Core: Our "Old Brain"

Even though the capabilities of the human brain far exceed those of the brain of any other species we know of, it is not surprising that the basic functions that we share with more primitive animals, such as breathing, eating, and sleeping, are directed by a relatively primitive part of the brain. The portion of the brain known as the **central core** (see Figure 3-9) is quite similar to that found in all vertebrates (species with backbones). The central core is sometimes referred to as the "old brain" because its evolutionary underpinnings can be traced back some 500 million years to primitive structures found in nonhuman species.

If we were to move up the spinal cord from the base of the skull to locate the structures of the central core of the brain, the first part we would come to would be the *hindbrain*, which contains the medulla, pons, and cerebellum (see Figure 3-10). The *medulla* controls a number of critical body functions, the most important of which are breathing and heartbeat. The *pons* comes next, joining the two halves of the cerebellum, which lies adjacent

Figure 3-9 The major divisions of the brain: the cerebral cortex and the central core (Seeley, Stephens, & Tate, 2000).



to it. Containing large bundles of nerves, the pons acts as a transmitter of motor information, coordinating muscles and integrating movement between the right and left halves of the body. It is also involved in the control of sleep.

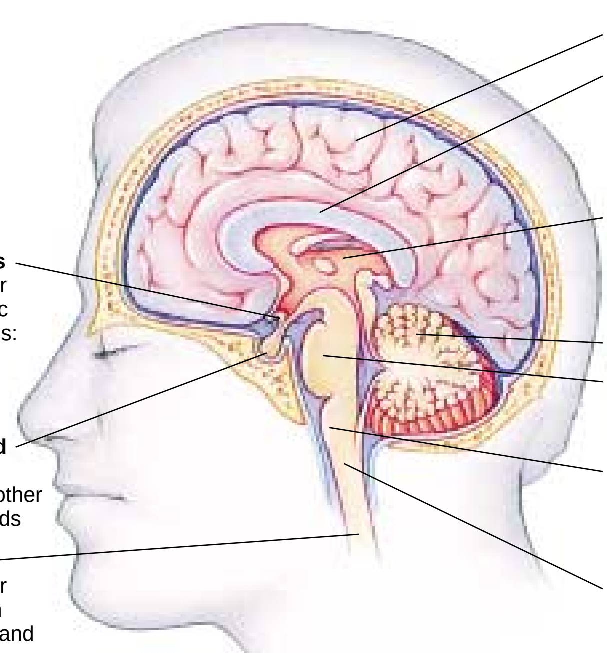
cerebellum (ser uh BELL um): The part of the brain that controls bodily balance

The **cerebellum** is found just above the medulla and behind the pons. Without the help of the cerebellum we would be unable to walk in a straight line without staggering and lurching forward, for it is the job of the cerebellum to control bodily balance. It constantly monitors feedback from the muscles to coordinate their placement, movement, and tension. In fact, drinking too much alcohol seems to depress the activity of the cerebellum, leading to the unsteady gait and movement characteristic of drunkenness. The cerebellum is also involved in several intellectual functions, ranging from analysis of sensory information to problem solving (Gao et al., 1996; Wickelgren, 1998a).

reticular formation: The part of the brain from the medulla through the pons made up of groups of nerve cells that can immediately activate other parts of the brain to produce general bodily arousal

The **reticular formation** extends from the medulla through the pons, passing through the middle section of the brain—or *midbrain*—and into the front-most part of the brain, called the *forebrain*. Like an ever-vigilant guard, the reticular formation is made up of groups of nerve cells that can immediately activate other parts of the brain to produce general bodily arousal. If you are startled by a loud noise, for example, your reticular formation can put you into a heightened state of awareness so you can determine whether

Figure 3-10 The major structures in the brain (Johnson, 2000).



While the cerebellum is involved in several intellectual functions, its main duty is to control balance, constantly monitoring feedback from the muscles to coordinate their placement, movement, and tension. Do you think the cerebellum is under conscious or automatic control as people negotiate difficult balancing tasks?

a response is necessary. In addition, the reticular formation serves a different function when we are sleeping, seeming to filter out background stimuli to allow us to sleep undisturbed.

Hidden within the forebrain, the **thalamus** acts primarily as a busy relay station, mostly for information concerning the senses. Messages from the eyes, ears, and skin travel to the thalamus to be communicated upward to higher parts of the brain. The thalamus also integrates information from higher parts of the brain, sorting it out so that it can be sent to the cerebellum and medulla.

thalamus: The part of the brain located in the middle of the central core that acts primarily as a busy relay station, mostly for information concerning the senses

The **hypothalamus** is located just below the thalamus. Although tiny—about the size of a fingertip—the hypothalamus plays an inordinately important role. One of its major functions is to maintain *homeostasis,* a steady internal environment for the body. As we'll discuss further in Chapter 10, the hypothalamus helps maintain a constant body temperature and monitors the amount of nutrients stored in the cells. A second major function is equally important: It produces and regulates behavior that is critical to the basic survival of the species, such as eating, self-protection, and sex.

hypothalamus: A tiny part of the brain, located below the thalamus of the brain, that maintains homeostasis and produces and regulates vital, basic behavior such as eating, drinking, and sexual behavior

The Limbic System: Beyond the Central Core

In an eerie view of the future, some science fiction writers have suggested that people will someday routinely have electrodes implanted in their brains. These electrodes will permit them to receive tiny shocks that produce the sensation of pleasure by stimulating certain centers of the brain. When they feel upset, people will simply activate their electrodes to achieve an immediate high.

Although farfetched, and ultimately improbable, such a futuristic fantasy is based on fact. The brain does have pleasure centers in several areas, including some in the **limbic system.** Consisting of a series of doughnut-shaped structures including the *amygdala, hippocampus,* and *fornix,* the limbic system borders the top of the central core and has connections with the cerebral cortex (see Figure 3-11).

limbic system: The part of the brain located outside the "new brain" that controls eating, aggression, and reproduction

The structures of the limbic system jointly control a variety of basic functions relating to emotions and self-preservation, such as eating, aggression, and reproduction. Injury to the limbic system can produce striking changes in behavior. It can turn animals that are usually docile and tame into belligerent savages. Conversely, those that are usually wild and uncontrollable might become meek and obedient (Bedard & Parsinger, 1995).

Research examining the effects of mild electric shocks to parts of the limbic system and other parts of the brain have produced some thought-provoking findings (Olds & Milner, 1954; Olds & Fobes, 1981). In one experiment, rats who pressed a bar received mild electric stimulation through an electrode implanted in their brain, which produced pleasurable feelings. Even starving rats on their way to food would stop to press the bar as many times as they could. Some rats would actually stimulate themselves literally thousands of times an hour—until they collapsed with fatigue (Routtenberg & Lindy, 1965).

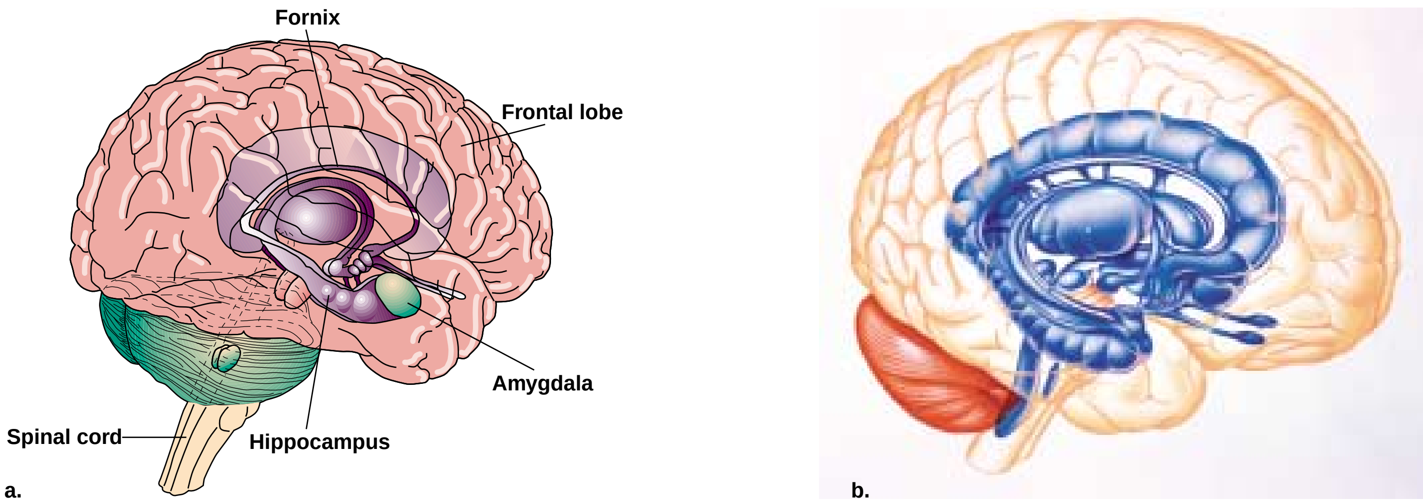


Figure 3-11 *(a)* The limbic system consists of a series of doughnut-shaped structures that are involved in self-preservation, learning, memory, and the experience of pleasure. *(b)* This computer-generated image provides another view of the limbic system (Courtesy of Dr. Robert B. Livingston, University of California-San Diego, and Philip J. Mercurio, Neurosciences Institute).

The extraordinarily pleasurable quality of certain kinds of stimulation has also been experienced by humans, who, as part of treatment for certain kinds of brain disorders, have received electrical stimulation to certain areas of the limbic system. Although at a loss to describe just what it feels like, these people report the experience to be intensely pleasurable, similar in some respects to sexual orgasm.

The limbic system also plays an important role in learning and memory, a finding demonstrated in patients with epilepsy. In an attempt to stop their seizures, such patients have had portions of the limbic system removed. One unintended consequence of the surgery is that these individuals sometimes have difficulty learning and remembering new information. In one case (discussed again when we focus on memory in Chapter 7), a patient who had undergone surgery was unable to remember where he lived, although he had resided at the same address for eight years. Further, even though the patient was able to carry on animated conversations, he was unable, a few minutes later, to recall what had been discussed (B. Milner, 1966).

The limbic system, then, is involved in several important functions, including self-preservation, learning, memory, and the experience of pleasure. These functions are hardly unique to humans; in fact, the limbic system is sometimes referred to as the "animal brain" because its structures and functions are so similar to those of other mammals. To identify the part of the brain that provides the complex and subtle capabilities that are uniquely human, we need to turn to another structure—the cerebral cortex.

Evaluate

1. ________ ________ is a procedure whereby a picture of the brain can be taken without opening the skull.
2. Match the name of each brain scan with the appropriate description:

a. EEG	1. By locating radiation within the brain, a computer can provide a striking picture of brain activity.
b. CAT	2. Electrodes placed around the skull record the electrical signals transmitted through the brain.
c. PET	3. A computer image combines thousands of X-ray pictures into one.

Rethink

1. How would you answer the argument that "psychologists should leave the study of neurons and synapses and the nervous system to biologists"?
2. Before sophisticated brain-scanning techniques were developed, biopsychologists' understanding of the brain was largely based on the brains of people who had died. What limitations would this pose, and in what areas would you expect the most significant advances once brain-scanning techniques were possible?

3. Control of such functions as breathing and sleep is located in the ________ ________.
4. Match the portion of the brain with its function:

a. medulla	1. Maintains breathing and heartbeat
b. pons	2. Controls bodily balance
c. cerebellum	3. Coordinates and integrates muscle movements
d. reticular formation	4. Activates other parts of the brain to produce general bodily arousal

5. The ________, a fingertip-sized portion of the brain, is responsible for the regulation of the body's internal environment.

Answers to Evaluate Questions

1. Brain scanning 2. a-2; b-3; c-1 3. central core or "old brain" 4. a-1; b-3; c-2; d-4 5. hypothalamus

The Cerebral Cortex: Our "New Brain"

As we have proceeded up the spinal cord and into the brain, our discussion has centered on areas of the brain that control functions similar to those found in less sophisticated organisms. But where, you may be asking, are the portions of the brain that enable humans to do what they do best, and that distinguish humans from all other animals? Those unique features of the human brain—indeed, the very capabilities that allow you to come up with such a question in the first place—are embodied in the ability to think, evaluate, and make complex judgments. The principal location of these abilities, along with many others, is the **cerebral cortex.**

cerebral cortex: The "new brain," responsible for the most sophisticated information processing in the brain; contains the lobes

The cerebral cortex is referred to as the "new brain" because of its relatively recent evolution. It consists of a mass of deeply folded, rippled, convoluted tissue that amounts to some 80 percent of the brain's total mass. Although only about one-twelfth of an inch thick, it would, if flattened out, cover an area of more than two feet square. This configuration allows the surface area of the cortex to be considerably greater than if it were smoother and more uniformly packed into the skull. The uneven shape also permits a high level of integration of neurons, allowing sophisticated processing of information.

The cortex has four major sections, called **lobes.** If we take a side view of the brain, the *frontal lobes* lie at the front center of the cortex, and the *parietal lobes* lie behind them. The *temporal lobes* are found in the lower center of the cortex, with the *occipital lobes* lying behind them. These four sets of lobes are physically separated by deep grooves called sulci. Figure 3-12 shows the four areas.

lobes: The four major sections of the cerebral cortex: frontal, parietal, temporal, and occipital

Another way of describing the brain is by considering the functions associated with a given area. Figure 3-12 also shows the specialized regions within the lobes related to specific functions and areas of the body. Three major areas have been discovered: the motor areas, the sensory areas, and the association areas. Although we will discuss these areas as though they were separate and independent, keep in mind that this is an oversimplification. In most instances, behavior is influenced simultaneously by several structures and areas within the brain, operating interdependently. Furthermore, even within a given area, additional subdivisions exist. Finally, when people suffer certain kinds of brain injury, uninjured portions of the brain can sometimes take over the functions that were previously handled by the damaged area. In short, the brain is extraordinarily adaptable (Gibbons, 1990; Sharma, Angelucci, & Sur, 2000).

motor area: The part of the cortex that is largely responsible for the voluntary movement of particular parts of the body

The Motor Area of the Cortex

If you look at the frontal lobe in Figure 3-12, you will see a shaded portion labeled the **motor area.** This part of the cortex is largely responsible for the voluntary movement of particular parts of the body. Every portion of the motor area corresponds to a specific locale within the body. If we were to insert an electrode into a particular part of the motor area of the cortex and apply mild electrical stimulation, there would be involuntary movement in the corresponding part of the body. If we moved to another part of the motor area and stimulated it, a different part of the body would move.

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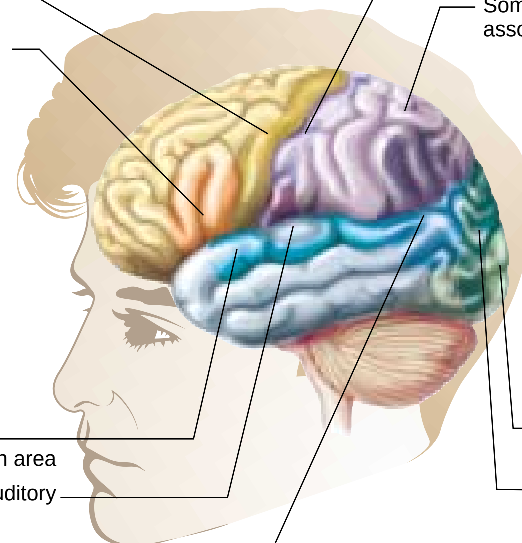

Figure 3-12 The cerebral cortex of the brain. The major physical *structures* of the cerebral cortex are called lobes. This figure also illustrates the *functions* associated with particular areas of the cerebral cortex. Are any areas of the cerebral cortex present in nonhuman animals?

The motor area is so well mapped that researchers have identified the amount and relative location of cortical tissue used to produce movement in specific parts of the human body. For example, the control of body movements that are relatively large scale and require little precision, such as movement of a knee or a hip, is centered in a very small space in the motor area. In contrast, movements that must be precise and delicate, such as facial expressions and finger movements, are controlled by a considerably larger portion of the motor area.

In short, the motor area of the cortex provides a guide to the degree of complexity and the importance of the motor capabilities of specific parts of the body. Keep in mind, however, that behavior is produced by multiple sets of neurons in the nervous system, linked in elaborate ways. Like other behavior, movement is produced through the coordinated firing of a complex variety of neurons, working together but not necessarily lined up neatly in the motor area of the cortex (Sanes et al., 1995; Batista et al., 1999; Kakei, Hoffman, & Strick, 1999).

The Sensory Area of the Cortex

sensory area: The site in the brain of the tissue that corresponds to each of the senses, with the degree of sensitivity relating to the amount of tissue

Given the one-to-one correspondence between motor area and body location, it is not surprising to find a similar relationship between specific portions of the cortex and the senses. The **sensory area** of the cortex includes three regions: one that corresponds primarily to body sensations (including touch and pressure), one relating to sight, and a third relating to sound. For instance, the *somatosensory area* encompasses specific locations associated with the ability to perceive touch and pressure in a particular area of the body. As with the motor area, the amount of brain tissue related to a particular location on the body determines the degree of sensitivity of that location. The greater the space within the cortex, the more sensitive that area of the body. As you can see from the weird-looking individual in Figure 3-13, parts such as the fingers are related to proportionally more space in the somatosensory area and are the most sensitive.

The senses of sound and sight are also represented in specific areas of the cerebral cortex. An *auditory area* located in the temporal lobe is responsible for the sense of hearing. If the auditory area is stimulated electrically, a person will hear sounds such as clicks or hums. It also appears that particular locations within the auditory area respond to specific pitches (deCharms, Blake, & Merzenich, 1998; Klinke et al., 1999).

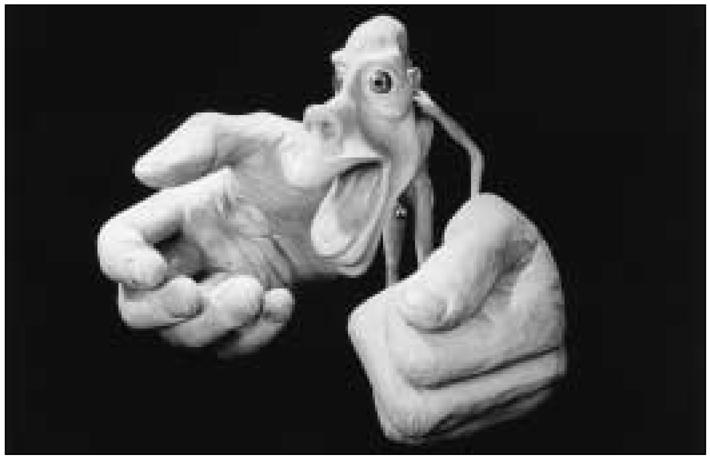

Figure 3-13 The greater the amount of tissue in the somatosensory area of the brain that is related to a specific body part, the more sensitive is that body part. If the size of our body parts reflected the corresponding amount of brain tissue, we would look like this strange creature.

The *visual area* in the cortex, located in the occipital lobe, operates analogously to the other sensory areas. Stimulation by electrodes produces the experience of flashes of light or colors, suggesting that the raw sensory input of images from the eyes is received in this area of the brain and transformed into meaningful stimuli. The visual area also provides another example of how areas of the brain are intimately related to specific areas of the body: Particular areas of the eye's retina are related to a particular part of the cortex—with, as you might guess, more space in the brain given to the most sensitive portions of the retina (Martin et al., 1995; Miyashita, 1995).

The Association Areas of the Cortex

Consider the following case:

> Twenty-five-year-old Phineas Gage, a railroad employee, was blasting rock one day in 1848 when an accidental explosion punched a 3-foot-long spike, about an inch in diameter, completely through his skull. The spike entered just under his left cheek, came out the top of his head, and flew into the air. Gage immediately suffered a series of convulsions, yet a few minutes later was talking with rescuers. In fact, he was able to walk up a long flight of stairs before receiving any medical attention. Amazingly, after a few weeks his wound healed, and he was physically close to his old self again. Mentally, however, there was a difference: Once a careful and hard-working person, Phineas now became enamored with wild schemes and was flighty and often irresponsible. As one of his physicians put it, "Previous to his injury, though untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart businessman, very energetic and persistent in executing all his plans of operation. In this regard his mind was radically changed, so decidedly that his friends and acquaintances said he was 'no longer Gage'" (Harlow, 1869, p. 14).

association areas: One of the major areas of the brain; the site of the higher mental processes such as thought, language, memory, and speech

What had happened to the old Gage? Although there is no way of knowing for sure—science being what it was in the 1800s—we can speculate that the accident injured the association areas of Gage's cerebral cortex. The **association areas** are generally considered to be the site of higher mental processes such as thinking, language, memory, and speech (Rowe et al, 2000).

A model of the injury sustained by Phineas Gage.

The association areas take up a large proportion of the cerebral cortex. Most of our understanding of the association areas comes from patients who have suffered some type of brain injury. In some cases the injury stemmed from natural causes such as a tumor or a stroke, either of which would block certain blood vessels within the cerebral cortex. In other cases, accidents were the culprits, as was true with Phineas Gage. In any event, damage to these areas can result in unusual behavioral changes, indicating the importance of the association area to normal functioning (Herholz, 1995; Gannon et al., 1998).

Gage's case provides evidence that there are specialized areas for making rational decisions. When this area is damaged, people undergo personality changes that affect their ability to make moral judgments and process emotions. At the same time, people with damage in this area can still be capable of reasoning logically, performing calculations, and recalling information (Damasio et al., 1994).

Injuries to other parts of the association areas can produce a condition known as apraxia. *Apraxia* occurs when an individual is unable to integrate activities in a rational or logical manner. The disorder is most evident when people are asked to carry out a sequence of behaviors requiring a degree of planning and foresight, suggesting that the association areas act as "master planners," or organizers of actions.

Injuries to the association areas of the brain can also produce *aphasia*, problems with language. In *Broca's aphasia* (caused by damage to the part of the brain first identified by a French physician, Paul Broca, in 1861), speech becomes halting, laborious, and often ungrammatical. The speaker is unable to find the right words, in a kind of tip-of-the-tongue phenomenon that we all experience from time to time. People with aphasia, though, grope for words almost constantly, eventually blurting out a kind of "verbal telegram." A phrase like "I put the book on the table" comes out as "I . . . put . . . book . . . table" (Cornell, Fromkin, & Mauner, 1993; Goodglass, 1993; Kirshner, 1995).

Wernicke's aphasia is a disorder named for Carl Wernicke, who identified it in the 1870s. Wernicke's aphasia produces difficulties both in understanding others' speech and in the production of language. The disorder is characterized by speech that sounds fluent but makes no sense. For instance, one patient, asked what brought him to a hospital, gave this rambling reply: "Boy, I'm sweating, I'm awful nervous, you know, once in a while I get caught up, I can't mention the tarripoi, a month ago, quite a little, I've done a lot well, I impose a lot, while, on the other hand, you know what I mean, I have to run around, look it over, trebbin and all that sort of stuff" (Gardner, 1975, p. 68).

PsychLink
Description of aphasia
www.mhhe.com/feldmanup6-03links

Brain injuries, such as those that result in aphasia, and brain disorders due to disease and illness have given new impetus to scientists who are seeking to map the neural circuitry of the brain. Using sophisticated computer technology, researchers are seeking to create a database encompassing every facet of the brain (see Figure 3-14). Such efforts are producing significant innovations in the study of the brain.

Mending the Brain

> Shortly after he was born, Jacob Stark's arms and legs started jerking every 20 minutes. Weeks later he could not focus his eyes on his mother's face. The diagnosis: uncontrollable epileptic seizures involving his entire brain.

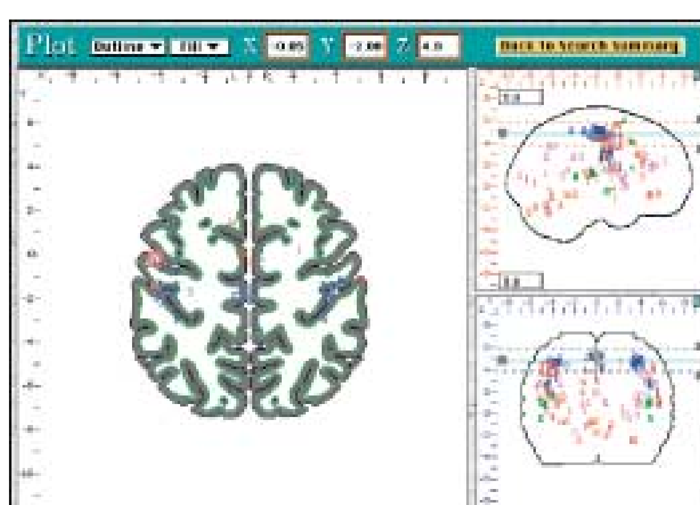

Figure 3-14 A sample computer screen from BrainMap, a computerized data base designed to make every aspect of the brain accessible.

> His mother, Sally Stark, recalled: "When Jacob was two and a half months old, they said he would never learn to sit up, would never be able to feed himself. Nothing could be done to prevent profound retardation. They told us to take him home, love him and find an institution." (Blakeslee, 1992a, C3).

Instead, the Starks brought Jacob to the University of California at Los Angeles for brain surgery when he was five months old. Surgeons removed 20 percent of his brain. The operation was a complete success. Three years later, Jacob seems normal in every way, with no sign of seizures.

Jacob's surgery is representative of increasingly daring approaches in the treatment of brain disorders. It also illustrates how our growing understanding of the processes that underlie brain functioning can be translated into solutions to difficult problems.

The surgery that helped Jacob was based on the premise that the diseased part of his brain was producing seizures throughout the entire brain. Surgeons reasoned that if they removed the misfiring portion, the remaining parts of the brain, which appeared intact in PET scans, would take over. They bet that Jacob could still lead a normal life following surgery, particularly because the surgery was being done at so young an age. Clearly, the gamble paid off.

The success of such surgery is in part related to new findings about the regenerative powers of the brain and nervous system. Although it has been known that the brain has the ability to shift functions to different locations following injury to a specific area or in cases of surgery, it had been assumed for decades that the neurons of the spinal cord and brain could never be replaced.

However, new evidence is beginning to suggest otherwise. For instance, researchers have found that the cells from the brains of adult mice can produce new neurons, at least in a test tube environment. Similarly, researchers have reported partial restoration of movement in rats who had a 1/5-inch-long gap in their spinal cords and, as a result, were unable to move their hind limbs. The researchers transplanted neurons from the peripheral nervous system into the gap, and subsequently the rats were able to flex their legs. One year after the operation, they were able to support themselves and move their legs, and examination of the neurons in the spinal cord showed significant regeneration around the area of the transplantation (Cheng, Cao, & Olson, 1996; McDonald, 1999; Blakeslee, 2000).

The future also holds promise for people who, like Michael J. Fox, suffer from the tremors and loss of motor control produced by Parkinson's disease. Because Parkinson's is caused by a gradual loss of cells that stimulate the production of dopamine in the brain, investigators reasoned that a procedure that increases the supply of dopamine might be effective. They seem to be on the right track. When certain cells from human fetuses are injected directly into the brains of Parkinson's sufferers, they seem to take root, stimulating dopamine production. For most of those who have undergone this procedure, the preliminary results are promising, with some patients showing great improvement. On the other hand, the technique remains experimental, and it also raises some thorny ethical issues, given that the source of the implanted fetal tissue is aborted fetuses (HMHL, 2000; Pollack, 2000).

The Specialization of the Hemispheres: Two Brains or One?

The most recent development, at least in evolutionary terms, in the organization and operation of our brain probably occurred in the last million years: a specialization of the functions controlled by the two sides of the brain, which has symmetrical left and right halves.

Specifically, the brain can be divided into two roughly similar mirror-image halves—just as we have two arms, two legs, and two lungs. Because of the way nerves are connected from the brain to the rest of the body, these two symmetrical left and right halves, called **hemispheres,** control the side of the body opposite to their location. The left hemisphere of the brain, then, generally controls the right side of the body, and the right hemisphere controls the left side of the body. Thus damage to the right side of the brain is typically indicated by functional difficulties in the left side of the body.

hemispheres: The two symmetrical left and right halves of the brain; each controls the side of the body opposite to it

Despite the appearance of similarity between the two hemispheres of the brain, they are involved in somewhat different functions. It appears that certain activities are more likely to occur in one hemisphere than in the other. Early evidence for the functional differences between halves of the brain came from studies of people with aphasia. Researchers found that people with the speech difficulties characteristic of aphasia tended to have physical damage to the left hemisphere of the brain. In contrast, physical abnormalities in the right hemisphere of the brain tended to produce far fewer problems with language. This finding led researchers to conclude that for most people, language is **lateralized,** or located more in one hemisphere than in the other—in this case, in the left side of the brain (Grossi et al., 1996).

lateralization: The dominance of one hemisphere of the brain in specific functions

It now seems clear that the two hemispheres of the brain are somewhat specialized in terms of the functions they carry out. The left hemisphere concentrates more on tasks that require verbal competence, such as speaking, reading, thinking, and reasoning. The right hemisphere has its own strengths, particularly in nonverbal areas such as the understanding of spatial relationships, recognition of patterns and drawings, music, and emotional expression (Ornstein, 1998; Robertson & Ivry, 2000).

In addition, information is processed somewhat differently in the two hemispheres. The left hemisphere tends to consider information sequentially, one bit at a time; the right hemisphere tends to process information globally, considering it as a whole (Turkewitz, 1993; Banich & Heller, 1998).

On the other hand, it is important to keep in mind that the differences in specialization between the hemispheres are not great, and the degree and nature of lateralization vary from one person to another. If you are right-handed, control of language is probably concentrated more in your left hemisphere. If you are among the 10 percent of people who are left-handed or are ambidextrous (you use both hands interchangeably), it is much more likely that the language centers of your brain are located more in the right hemisphere or are divided equally between left and right hemispheres.

Researchers have also unearthed evidence that there may be subtle differences in brain lateralization patterns between males and females. In fact, some scientists have suggested that there are slight differences in the structure of the brain according to gender and culture. As we see next, such findings have led to a lively debate in the scientific community.

EXPLORING DIVERSITY

Human Diversity and the Brain

The interplay of biology and environment is particularly clear when we consider evidence suggesting that there are both sex and cultural differences in brain structure and function. Let's consider sex first. According to accumulating evidence, females and males show some intriguing differences in brain lateralization and weight, although the nature of those differences—and even their very existence—is a matter of considerable controversy (Kimura, 1992; Dorion et al., 2000).

We can be reasonably confident about some differences. For instance, most males tend to show greater lateralization of language in the left hemisphere. For them, language is clearly relegated largely to the left side of the brain. In contrast, women display less lateralization, with language abilities apt to be more evenly divided between the two hemispheres (Gur et al., 1982; Shaywitz et al., 1995; Kulynych et al., 1994). Such differences in brain lateralization could account, in part, for female superiority on certain measures of verbal skills, such as the onset and fluency of speech, and the fact that far more boys than girls have reading problems in elementary school (Kitterle, 1991).

Other research suggests that men's brains are somewhat bigger than women's brains, even after taking into account differences in body size. On the other hand, part of the *corpus callosum*, a bundle of fibers that connects the hemispheres of the brain, is proportionally larger in women than in men. Furthermore, some research suggests that women's brains have a higher proportion of the neurons that are actually involved in thinking than men's brains do (Witelson, 1995; Falk et al., 1999; Gur et al., 1999).

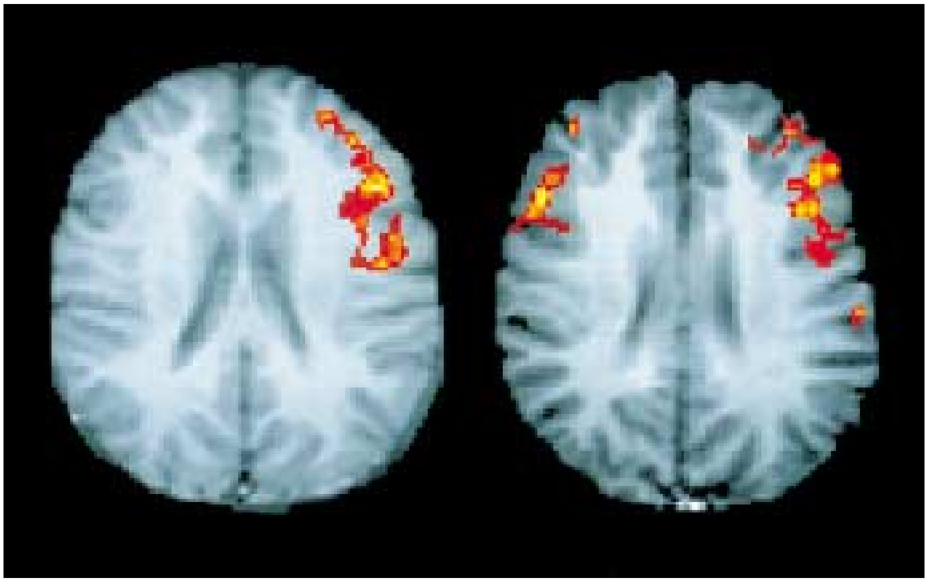

Figure 3-15 These composite MRI brain scans show the distribution of active areas in the brains of males *(left)* and females *(right)* during a verbal task involving rhyming. In males, activation is more lateralized, or confined, to the left hemisphere, while in females, activation is bilateralized, that is, occurring in both hemispheres of the brain.

(Source: B.A. Shaywitz et al., 1995. NMR/Yale Medical School)

Men and women also might process information differently. For example, MRI brain scans of men sounding out words show activation of a small area of the left side of the brain, whereas women use areas on both sides of the brain (Shaywitz et al., 1995; see Figure 3-15). Similarly, PET brain scans of men and women while they are not engaged in mental activity show differences in the use of glucose (Gur et al., 1995; Gur, 1996).

The meaning of such sex differences is far from clear. Consider one possibility related to the differences that have been found in the proportional size of the corpus callosum: Its increased proportion in women might permit stronger connections to develop between those parts of the brain that control speech. In turn, this would explain why speech tends to emerge slightly earlier in girls than in boys.

Before we rush to such a conclusion, though, it is important to consider an alternative hypothesis: It is plausible that the earlier emergence of verbal abilities in girls is due to the fact that infant girls receive greater encouragement to verbalize than infant boys do. This greater early experience could foster growth of certain parts of the brain. Hence, physical brain differences might be a *reflection* of social and environmental influences, rather than a *cause* of the differences in men's and women's behavior. At this point, it is impossible to confirm which of these two alternative hypotheses is correct.

The culture in which we are raised also might give rise to differences in brain lateralization. For example, native speakers of Japanese seem to process information regarding vowel sounds primarily in the brain's left hemisphere. In contrast, North and South Americans, Europeans, and individuals of Japanese ancestry who learn Japanese later in life handle vowel sounds principally in the right hemisphere.

The reason for this cultural difference in lateralization? One explanation could be that certain characteristics of the Japanese language, such as the ability to express complex ideas using only vowel sounds, result in the development of a specific type of brain lateralization in native speakers. Differences in lateralization could account for other dissimilarities between the ways native Japanese speakers and Westerners think about the world (Tsunoda, 1985).

In general, scientists are just beginning to understand the extent, nature, and meaning of sex and cultural differences in lateralization and brain structure. Furthermore, in evaluating the research on brain lateralization, it is important to keep in mind that the two hemispheres of the brain function in tandem. It is a mistake to think of particular kinds of information as being processed solely in the right or the left hemisphere. The hemispheres work interdependently in deciphering, interpreting, and reacting to the world.

In addition, people who suffer injury to the left side of the brain and lose linguistic capabilities often recover the ability to speak. In such cases, the right side of the brain often pitches in and takes over some of the functioning of the left side. This shift is especially true in young children; the earlier the injury occurs, the greater the extent of recovery. Overall, then, the brain is remarkably adaptable. It can significantly modify its functioning in response to adverse circumstances, and, despite earlier beliefs that no new brain cells appear after childhood, recent evidence suggests that new brain cells are created during adulthood in certain parts of the brain such as the hippocampus (Kempermann & Gage, 1999; Gould et al., 1999).

The Split Brain: Exploring the Two Hemispheres

> The patient, V.J., had suffered severe seizures. By cutting her corpus callosum, the fibrous portion of the brain that carries messages between the hemispheres, surgeons hoped to create a firebreak to prevent the seizures from spreading. The operation did decrease the frequency and severity of V.J.'s attacks. But V.J. developed an unexpected side effect: She lost the ability to write at will, although she could read and spell words aloud. (Strauss, 1998, p. 287).

split-brain patient: A person who suffers from independent functioning of the two halves of the brain, as a result of which the sides of the body work in disharmony

People like V.J., whose corpus callosum has been surgically cut to stop seizures and who are therefore called **split-brain patients,** offer a rare opportunity for researchers investigating the independent functioning of the two hemispheres of the brain. For example, psychologist Roger Sperry—who won the Nobel Prize for his work—developed a number of ingenious techniques for studying how each hemisphere operated (Sperry, 1982; Baynes et al., 1998; Gazzaniga, 1998).

In one experimental procedure, blindfolded subjects were allowed to touch an object with their right hand and were asked to name it. Because the right side of the body is connected to the left side of the brain—the hemisphere that is most responsible for language—the split-brain patient was able to name it. But if the blindfolded subjects touched the object with their left hand, they were not able to name it aloud. However, the information had registered: When the blindfold was taken off, subjects could pick out the objects that they had touched. Information can be learned and remembered, then, using only the right side of the brain. (By the way, unless you've had a split-brain operation, this experiment won't work with you, because the bundle of fibers connecting the two hemispheres of a normal brain immediately transfer the information from one hemisphere to the other.)

It is clear from experiments like this one that the right and left hemispheres of the brain specialize in handling different sorts of information. At the same time, it is important to realize that they are both capable of understanding, knowing, and being aware of the world, albeit in somewhat different ways. The two hemispheres, then, should be regarded as different in terms of the efficiency with which they process certain kinds of information, rather than as two entirely separate brains. Moreover, in people with normal, nonsplit brains, the hemispheres work interdependently to allow the full range and richness of thought of which humans are capable.

The Endocrine System: Of Chemicals and Glands

endocrine system: A chemical communication network that sends messages throughout the nervous system via the bloodstream

hormones: Chemicals that circulate through the blood and affect the functioning or growth of other parts of the body

One aspect of the biopsychology of behavior that we have not yet considered is the **endocrine system,** a chemical communication network that sends messages throughout the nervous system via the bloodstream. Although not a structure of the brain itself, the endocrine system is intimately tied to the hypothalamus. The job of the endocrine system is to secrete **hormones,** chemicals that circulate through the blood and affect the functioning or growth of other parts of the body (Crapo, 1985; Kravitz, 1988).

Like neurotransmitters, hormones communicate chemical messages throughout the body, although the speed and mode of transmission are quite different. Whereas neural messages are measured in thousandths of a second, hormonal communications can take minutes to reach their destination. Furthermore, neural messages move across neurons

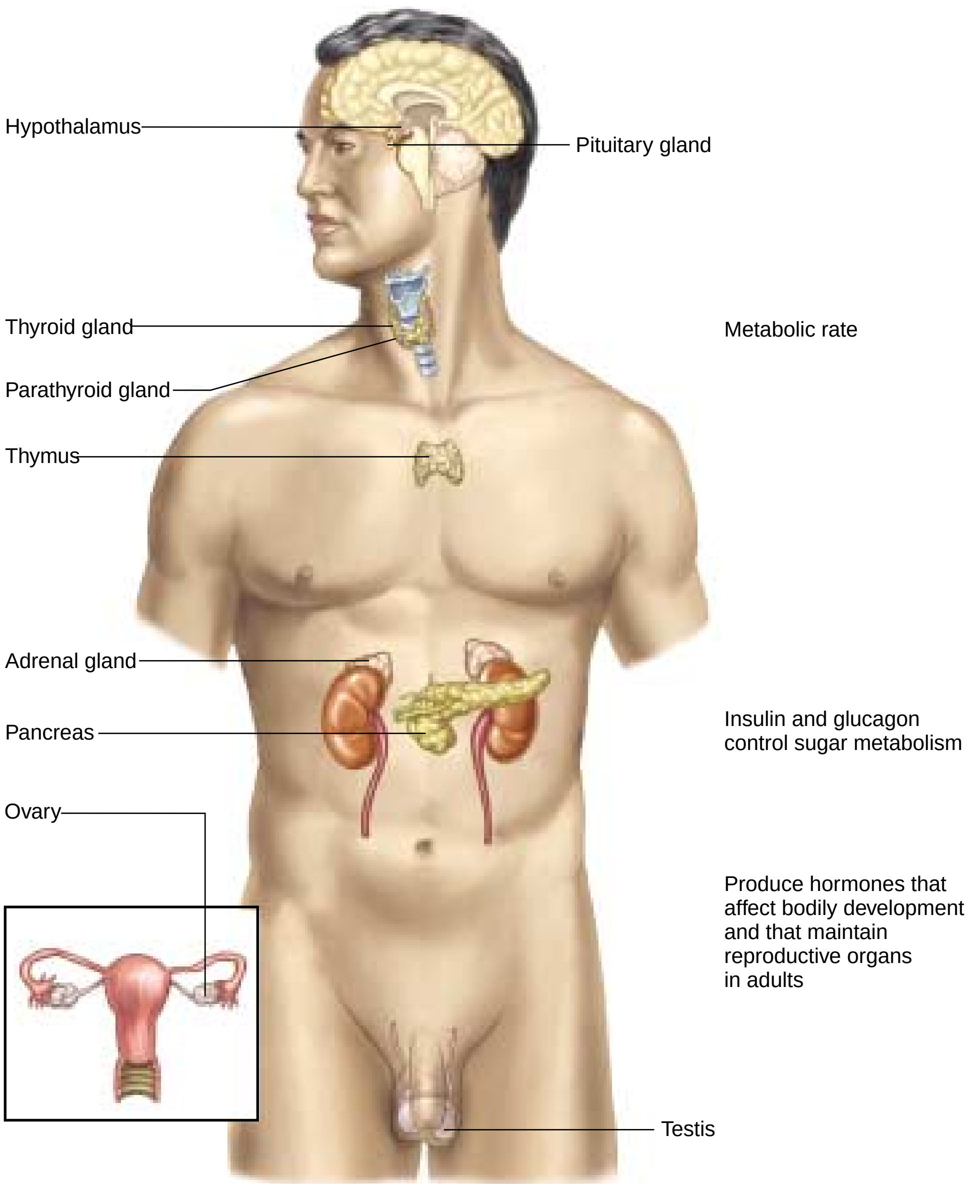

Figure 3-16 Location and function of the major endocrine glands (Mader, 2000).

in specific lines (as with wires strung along telephone poles), whereas hormones travel throughout the entire body, similar to the way radio waves transmit across the entire landscape. Just as radio waves evoke a response only when a radio is tuned to the correct station, so hormones flowing through the bloodstream activate only those cells that are receptive and "tuned" to the appropriate hormonal message.

A major component of the endocrine system is the **pituitary gland,** found near—and regulated by—the hypothalamus. The pituitary gland has sometimes been called the "master gland," because it controls the functioning of the rest of the endocrine system. But the pituitary gland is more than just the taskmaster of other glands; it has important functions in its own right. For instance, hormones secreted by the pituitary gland control growth. Extremely short people and unusually tall ones usually have pituitary gland abnormalities. Other endocrine glands, shown in Figure 3-16, affect emotional reactions, sexual urges, and energy levels.

pituitary gland: The "master gland," the major component of the endocrine system, which secretes hormones that control growth

Despite its designation as the "master gland," the pituitary is actually a servant of the brain, because the brain is ultimately responsible for the endocrine system's functioning. The brain regulates the internal balance of the body, ensuring that homeostasis is maintained through the hypothalamus.

Individual hormones can wear many hats, depending on circumstances. For example, the hormone oxytocin is at the root of many of life's satisfactions and pleasures. In new mothers, oxytocin produces an urge to nurse newborn offspring. The same hormone also seems to stimulate cuddling between species members. And, at least in rats, it encourages sexually active males to seek out females more passionately, and females to be more receptive to males' sexual advances (Angier, 1991).

BECOMING AN INFORMED CONSUMER OF PSYCHOLOGY

Learning to Control Your Heart—and Mind—Through Biofeedback

biofeedback: A procedure in which a person learns to control through conscious thought internal physiological processes such as blood pressure, heart and respiration rate, skin temperature, sweating, and constriction of particular muscles

> On a June evening in 1985, Tammy DeMichael was cruising along the New York State Thruway with her fiancé when he fell asleep at the wheel. The car slammed into the guardrail and flipped, leaving DeMichael with what the doctors called a "splattered C-6, 7"—a broken neck and crushed spinal cord.
>
> After a year of exhaustive medical treatment, she still had no function or feeling in her arms and legs. "The experts said I'd be a quadriplegic for the rest of my life, able to move only from the neck up," she recalls. . . . But DeMichael proved the experts wrong. Today, feeling has returned to her limbs, her arm strength is normal or better, and she no longer uses a wheelchair. "I can walk about 60 feet with just a cane, and I can go almost anywhere with crutches," she says. (Morrow & Wolf, 1991, p. 64)

The key to DeMichael's astounding recovery: biofeedback. **Biofeedback** is a procedure in which a person learns to control through conscious thought internal physiological processes such as blood pressure, heart and respiration rate, skin temperature, sweating, and constriction of particular muscles. Although it had traditionally been thought that the heart, respiration rate, blood pressure, and other bodily functions were under the control of parts of the brain over which we have no influence, psychologists have discovered that these responses are actually susceptible to voluntary control (Rau et al., 1996; Grimsley & Karriker, 1996; Bazell, 1998).

In biofeedback, a person is hooked up to electronic devices that provide continuous feedback relating to particular physiological responses. For instance, a person interested in controlling headaches through biofeedback might have electronic sensors placed on certain muscles on her head and learn to control the constriction and relaxation of those muscles. Later, after she mastered this training, when she felt a headache starting she could relax the relevant muscles and end the pain.

In DeMichael's case, biofeedback was effective because not all of the nervous system's connections between the brain and her legs were severed. Through biofeedback, she learned how to send messages to specific muscles, "ordering" them to move. Although it took more than a year, DeMichael was successful in restoring a large degree of her mobility.

Learning to control physiological processes through the use of biofeedback is not easy, but biofeedback has been employed with success in a variety of ailments, including emotional problems (such as anxiety, depression, phobias, tension headaches, insomnia, and hyperactivity); physical illnesses with a psychological component (such as asthma, high blood pressure, ulcers, muscle spasms, and migraine headaches); and physical problems (such as DeMichael's injuries, strokes, cerebral palsy, and, as we see in Figure 3-17, curvature of the spine).

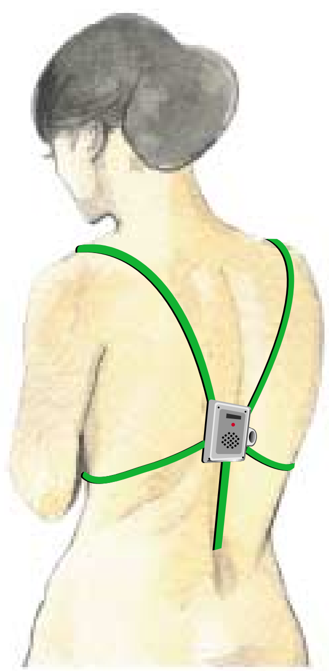

Figure 3-17 The traditional treatment for curvature of the spine employs an unsightly, cumbersome brace. In contrast, biofeedback treatment employs an unobtrusive set of straps attached to a small electronic device that produces tonal feedback when the patient is not standing straight. The person learns to maintain a position that gradually decreases the curvature of the spine until the device is no longer needed (Source: Miller, 1985a). What other disorders might biofeedback devices like this one help to treat?

Evaluate

1. A surgeon places an electrode on a portion of your brain and stimulates it. Immediately, your right wrist involuntarily twitches. The doctor has most likely stimulated a portion of the ________ area of your brain.
2. The ________ its corresponding space within the cortex, the more sensitive an area of the body is.
3. Each hemisphere controls the ________ side of the body.
4. Nonverbal realms, such as emotions and music, are controlled primarily by the ________ hemisphere of the brain, whereas the ________ hemisphere is more responsible for speaking and reading.
5. The left hemisphere tends to consider information ________, whereas the right hemisphere tends to process information ________.
6. As studies with split-brain patients have shown, information can be learned and remembered using only the nonverbal side of the brain. True or False?

Answers to Evaluate Questions

1. motor 2. greater 3. opposite 4. right; left 5. sequentially; globally 5. True

Rethink

1. Suppose that abnormalities in an association area of the brain were linked through research to serious criminal behavior. Would you be in favor of mandatory testing of individuals and surgery to repair or remove those abnormalities? Why or why not?
2. Could personal differences in people's specialization of right and left hemispheres be related to occupational success? For example, might an architect who relies on spatial skills have a different pattern of hemispheric specialization than a writer?

Looking Back

Why do psychologists study the brain and nervous system?

- A full understanding of human behavior requires knowledge of the biological influences underlying that behavior. This chapter reviews what biopsychologists (psychologists who specialize in studying the effects of biological structures and functions on behavior) have learned about the human nervous system. (p. 55)

What are the basic elements of the nervous system?

- Neurons, the most basic elements of the nervous system, allow nerve impulses to pass from one part of the body to another. Information generally follows a route that begins with the dendrites, continues into the cell body, and leads ultimately down the tubelike extension, the axon. (p. 55)

How does the nervous system communicate electrical and chemical messages from one part to another?

- Most axons are protected by a coating called the myelin sheath. When an axon receives a message to fire, it releases an action potential, an electrical charge that travels through the neuron. Neurons operate according to an all-or-none law: Either they are at rest or an action potential is moving through them. There is no in-between state. (p. 55)
- Once a neuron fires, nerve impulses are carried to other neurons through the production of chemical substances, neurotransmitters, that bridge the gaps—known as synapses—between neurons. Neurotransmitters are either excitatory (telling other neurons to fire), or inhibitory (preventing or decreasing the likelihood of other neurons firing). The major neurotransmitters include acetylcholine (ACh), which produces contractions of skeletal muscles, and dopamine, which has been linked to Parkinson's disease and certain mental disorders such as schizophrenia. (p. 57)
- Endorphins, another type of neurotransmitter, are related to the reduction of pain. Endorphins aid in the production of natural painkillers and are probably responsible for creating the kind of euphoria that joggers sometimes experience after running. (p. 61)

In what way are the structures of the nervous system tied together?

- The nervous system is made up of the central nervous system (the brain and spinal cord) and the peripheral nervous system (the remainder of the nervous system). The peripheral nervous system is made up of the somatic division, which controls voluntary movements and the communication of information to and from the sense organs, and the autonomic division, which controls involuntary functions such as those of the heart, blood vessels, and lungs. (p. 62)
- The autonomic division of the peripheral nervous system is further subdivided into the sympathetic and parasympathetic divisions. The sympathetic division prepares the body in emergency situations, and the parasympathetic division helps the body return to its typical resting state. (p. 63)
- Evolutionary psychology, the branch of psychology that seeks to identify behavior patterns that are a result of our genetic inheritance, has led to increased understanding of the evolutionary basis of the structure and organization of the human nervous system. Behavioral genetics extends this study to include the evolutionary and hereditary bases of human personality traits and behavior. (p. 65)

How do researchers identify the major parts and functions of the brain?

- Brain scans take a "snapshot" of the internal workings of the brain without having to cut surgically into a person's skull. Major brain-scanning techniques include the electroencephalogram (EEG), computerized axial tomography (CAT), the functional magnetic resonance imaging (MRI) scan, the superconducting quantum interference device (SQUID), and the positron emission tomography (PET) scan. (p. 68)

What are the major parts of the brain, and for what behaviors is each part responsible?

- The central core of the brain is made up of the medulla (which controls such functions as breathing and the heartbeat), the pons (which coordinates the muscles and the two sides of the body), the cerebellum (which controls balance), the reticular formation (which acts to heighten awareness in emergencies), the thalamus (which communicates sensory messages to and from the brain), and the hypothalamus (which maintains homeostasis, or body equilibrium, and regulates basic survival behaviors). The functions of the central core structures are similar to those found in other vertebrates. This part of the brain is sometimes referred to as the "old brain." Increasing evidence also suggests that female and male brains might differ in structure in minor ways. (p. 69)
- The cerebral cortex—the "new brain"—has areas that control voluntary movement (the motor area); the senses (the sensory area); and thinking, reasoning, speech, and memory (the association area). The limbic system, found on the border of the "old" and "new" brains, is associated with eating, reproduction, and the experiences of pleasure and pain. (p. 73)

How do the two halves of the brain operate interdependently?

- The brain is divided into left and right halves, or hemispheres, each of which generally controls the opposite side of the body. Each hemisphere can be thought of as specialized in the functions it carries out: The left is best at verbal tasks, such as logical reasoning, speaking, and reading; the right is best at nonverbal tasks, such as spatial perception, pattern recognition, and emotional expression. (p. 77)
- The endocrine system secretes hormones, allowing the brain to send messages throughout the nervous system via the bloodstream. A major component is the pituitary gland, which affects growth. (p. 80)

How can an understanding of the nervous system help us find ways to relieve disease and pain?

- Biofeedback is a procedure by which a person learns to control internal physiological processes. By controlling what were previously considered involuntary responses, people are able to relieve anxiety, tension, migraine headaches, and a wide range of other psychological and physical problems. (p. 82)

Key Terms and Concepts

biopsychologists (behavioral neuroscientists) (p. 54)
neurons (p. 55)
dendrites (p. 55)
axon (p. 55)
terminal buttons (p. 55)
myelin sheath (p. 55)
all-or-none law (p. 57)

resting state (p. 57)
action potential (p. 57)
synapse (p. 58)
neurotransmitters (p. 58)
excitatory message (p. 60)
inhibitory message (p. 60)
reuptake (p. 60)
central nervous system (CNS) (p. 62)
spinal cord (p. 62)
reflexes (p. 62)
sensory (afferent) neurons (p. 62)
motor (efferent) neurons (p. 62)
interneurons (p. 62)
peripheral nervous system (p. 63)
somatic division (p. 63)
autonomic division (p. 63)
sympathetic division (p. 64)
parasympathetic division (p. 64)
evolutionary psychology (p. 65)
behavioral genetics (p. 66)
central core (p. 69)
cerebellum (p. 70)
reticular formation (p. 70)
thalamus (p. 71)
hypothalamus (p. 71)
limbic system (p. 71)
cerebral cortex (p. 73)
lobes (p. 73)
motor area (p. 73)
sensory area (p. 74)
association areas (p. 75)
hemispheres (p. 77)
lateralization (p. 78)
split-brain patient (p. 80)
endocrine system (p. 80)
hormones (p. 80)
pituitary gland (p. 81)
biofeedback (p. 82)

OLC **Preview**
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www.mhhe.com/feldmanup6

Psychology on the Web

1. Biofeedback research is continuously changing and being applied to new areas of human functioning. Find at least two websites that discuss recent research on biofeedback and summarize the research and any findings it has produced. Include in your summary your own best estimate of future applications of this technique.
2. Find one or more websites on Parkinson's disease and learn more about this topic. Specifically, find reports of new treatments for Parkinson's that do not involve the use of fetal tissue. Write a summary of your findings.

Epilogue

This chapter has traced the ways in which biological structures and functions of the body affect behavior. Starting with neurons, we considered each of the components of the nervous system, culminating in an examination of how the brain permits us to think, reason, speak, recall, and experience emotions—the hallmarks of being human.

Before we proceed to the next chapter, where we put our knowledge of the biology of behavior to use in a look at sensation and perception, turn back for a moment to the prologue of this chapter, involving television and movie star Michael J. Fox. Consider the following questions.

1. Using what you now know about brain structures and functioning, can you explain what might have produced Fox's Parkinson's disease in the first place?
2. The operation used to treat Fox's disorder destroyed certain cells of his brain. Speculate about what part of the brain the operation might have involved.
3. Do you think biofeedback techniques could be used to control the symptoms of Parkinson's disease? Why or why not?