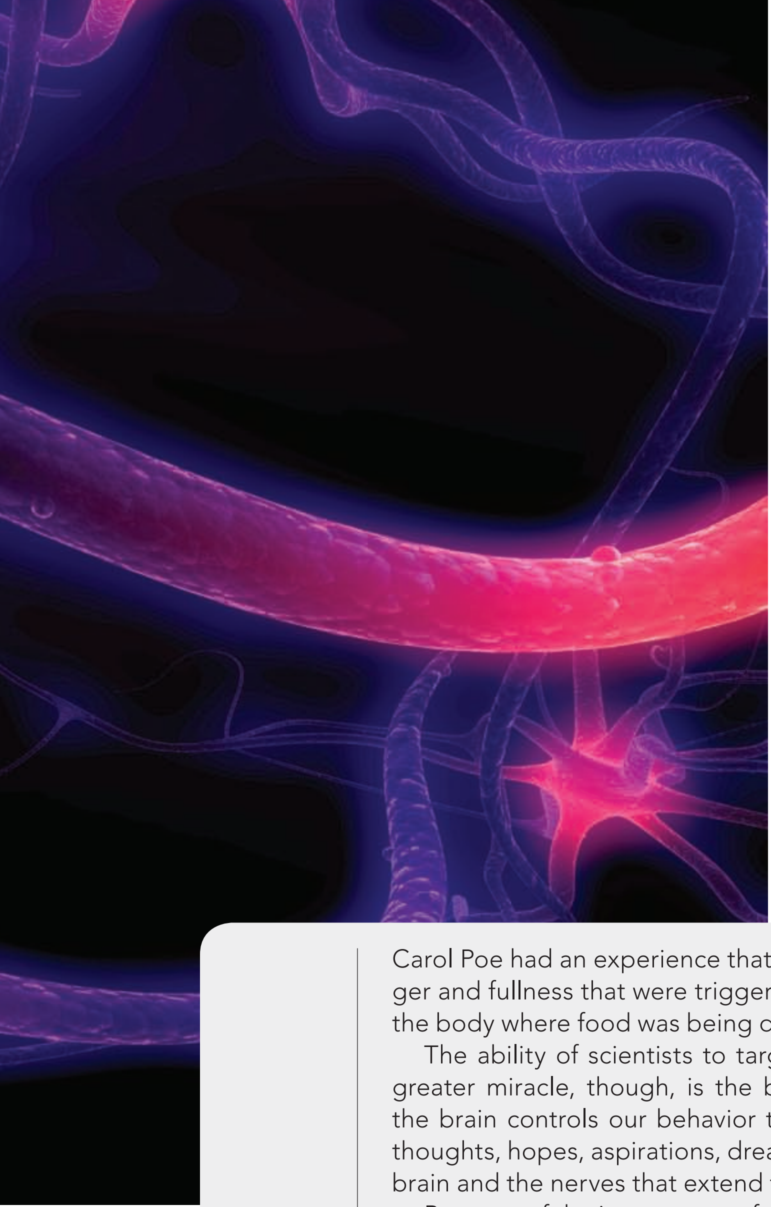
CHAPTER 2

NEUROSCIENCE AND BEHAVIOR

CHAPTER OUTLINE



Brain Diet

Carol Poe, a 60-year-old grandmother from West Virginia, was the second person to receive a new obesity treatment called deep brain stimulation. The procedure involves inserting electrodes into the brain to deliver tiny bursts of electricity to alter the patient's behavior. With obese patients, the idea is to target the hypothalamus, the area of the brain that controls our desire to eat. It works by making the patient feel full.

During the surgery, Carol was asked if she felt hungry or not to help pinpoint the correct position for the electrodes. "I was actually able to experience feelings of hunger and of fullness while the neurosurgeon experimented with the best place to put the electrodes," Carol explained. "Once the electrodes were in the right place, my desire to eat went away. It was amazing going from feeling hungry to feeling full. I'm delighted with what's happened so far. Now I'm hoping to start losing some serious weight." (Halle, 2009)

looking AHEAD

Carol Poe had an experience that is difficult even to imagine: She experienced sensations of hunger and fullness that were triggered by direct stimulation of her brain, rather than by the parts of the body where food was being digested.

The ability of scientists to target precise areas of the brain is little short of miraculous. The greater miracle, though, is the brain itself. An organ roughly half the size of a loaf of bread, the brain controls our behavior through every waking and sleeping moment. Our movements, thoughts, hopes, aspirations, dreams—our very awareness that we are human—all depend on the brain and the nerves that extend throughout the body, constituting the nervous system.

Because of the importance of the nervous system in controlling behavior, and because humans at their most basic level are biological beings, many researchers in psychology and other fields as diverse as computer science, zoology, and medicine have made the biological underpinnings of behavior their specialty. These experts collectively are called neuroscientists (Gazzaniga, Ivry, & Mangun, 2002; Cartwright, 2006; Pickersgill, 2011).

Psychologists who specialize in considering the ways in which the biological structures and functions of the body affect behavior are known as **behavioral neuroscientists (or biopsychologists)**. They seek to answer several key questions: How does the brain control the voluntary and involuntary functioning of the body? How does the brain communicate with other parts of the body? What is the physical structure of the brain, and how does this structure affect behavior? Are psychological disorders caused by biological factors, and how can such disorders be treated?

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

As you consider the biological processes that we'll discuss in this chapter, it is important to keep in mind why behavioral neuroscience is an essential part of psychology: our understanding of human behavior requires knowledge of the brain and other parts of the nervous system. Biological factors are central to our sensory experiences, states of consciousness, motivation and emotion, development throughout the life span, and physical and psychological health. Furthermore, advances in behavioral neuroscience have led to the creation of drugs and other treatments for psychological and physical disorders. In short, we cannot understand behavior without understanding our biological makeup (Compagni & Manderscheid, 2006; Plomin et al., 2008; Gangestad, 2010; Lynch et al., 2011).

module 5

Neurons

The Basic Elements of Behavior

Learning Outcomes

Prepare

LO 5.1 Explain the structure of a neuron.

LO 5.2 Describe how neurons fire.

LO 5.3 Summarize how messages travel from one neuron to another.

LO 5.4 Identify neurotransmitters.

MODULE OUTLINE

Organize

Work

The nervous system is the pathway for the instructions that permit our bodies to carry out everyday activities such as scratching an itch as well as more remarkable skills like climbing to the top of Mount Everest. Here we will look at the structure and function of neurons, the cells that make up the nervous system, including the brain.

LO 5.1 The Structure of the Neuron

Playing the piano, driving a car, or hitting a tennis ball depend, at one level, on exact muscle coordination. But if we consider *how* the muscles can be activated so precisely, we see that there are more fundamental processes involved. For the muscles to produce the complex movements that make up any meaningful physical activity, the brain has to provide the right messages to them and coordinate those messages.

Neurons Nerve cells, the basic elements of the nervous system.

Dendrites A cluster of fibers at one end of a neuron that receives messages from other neurons.

Such messages—as well as those which 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 1 *trillion* neurons throughout the body are involved in the control of behavior (Boahen, 2005).

Although there are several types of neurons, they all have a similar structure, as illustrated in Figure 1. In contrast to most other cells, however, neurons have a distinctive feature: the ability to communicate with other cells and transmit information across relatively long distances. Many of the body's neurons receive signals from the environment or relay the nervous system's messages to muscles and other target cells, but the vast majority of neurons communicate only with other neurons in the elaborate information system that regulates behavior.

STUDY ALERT

Remember that *Dendrites Detect* messages from other neurons; *Axons* carry signals *Away* from the cell body.

As you can see in Figure 1, a neuron has a cell body with a cluster of fibers called **dendrites** at one end. Those fibers, which look like the twisted branches

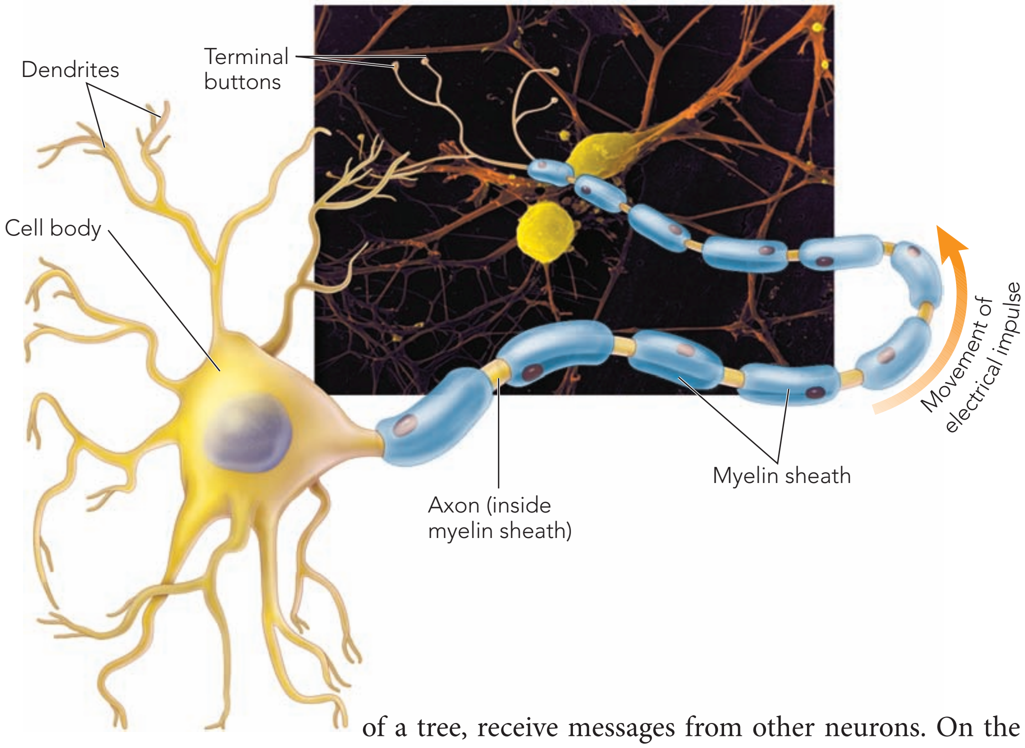


Figure 1 The primary components of the specialized cell called the neuron, the basic element of the nervous system (Van De Graaff, 2000). A neuron, like most types of cells in the body, has a cell body and a nucleus, but it also contains structures that carry messages: the dendrites, which receive messages from other neurons, and the axon, which carries messages to other neurons or body cells. In this neuron, as in most neurons, the axon is protected by the sausagelike myelin sheath. What advantages does the treelike structure of the neuron provide?

of a tree, receive messages from other neurons. On the opposite of the cell body is a long, slim, tubelike extension called an **axon**. The axon carries messages received by the dendrites to other neurons. The axon is considerably longer than the rest of the neuron. Although most axons are several millimeters in length, some are as long as three feet. Axons end in small bulges called **terminal buttons**, which send messages to other neurons.

The messages that travel through a neuron are electrical in nature. Although there are exceptions, those electrical messages, or *impulses*, generally move across neurons in one direction only, as if they were traveling on a one-way street. Impulses follow a route that begins with the dendrites, continues into the cell body, and leads ultimately along the tubelike extension, the axon, to adjacent neurons.

To prevent messages from short-circuiting one another, axons must be insulated in some fashion (just as electrical wires must be insulated). Most axons are insulated by a **myelin sheath**, a protective coating of fat and protein that wraps around the axon like links of sausage.

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.

Myelin sheath A protective coat of fat and protein that wraps around the axon.

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 a neuron.

LO 5.2 How Neurons Fire

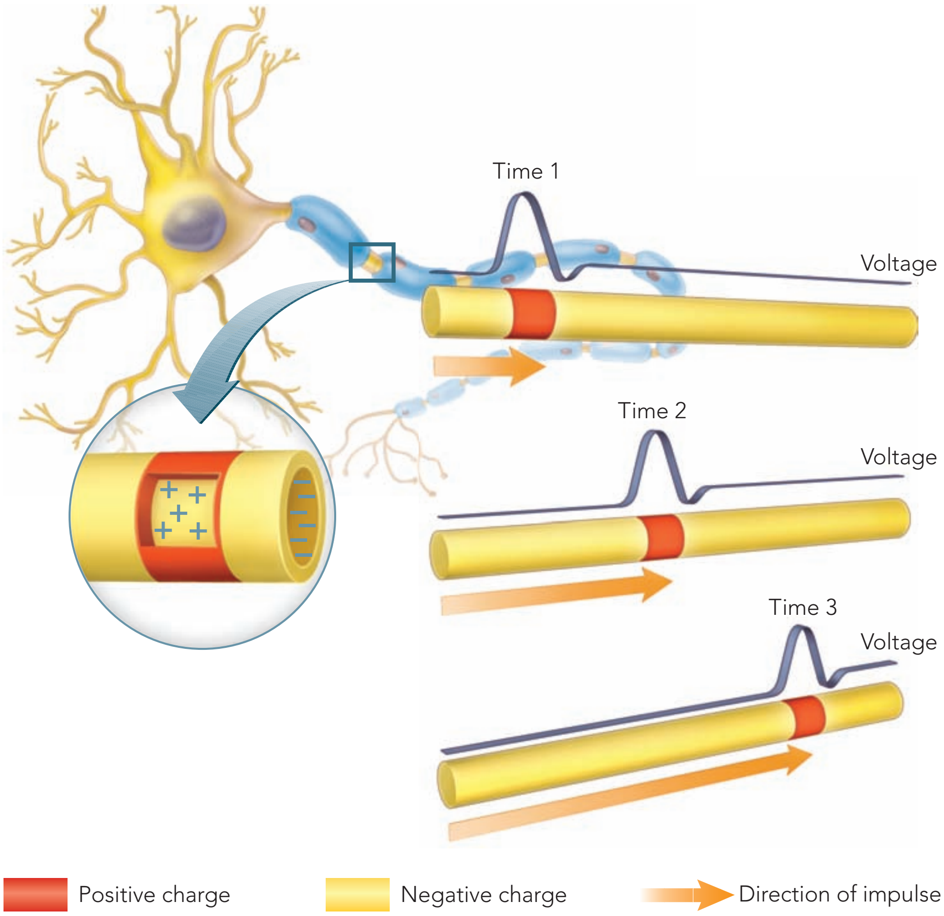
Like a gun, neurons either fire—that is, transmit an electrical impulse along the axon—or don't fire. There is no in-between stage, just as pulling harder on a gun trigger doesn't make the bullet travel faster. Similarly, neurons follow an **all-or-none law**: they are either on or off, with nothing in between the on state and the off state. Once there is enough force to pull the trigger, 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. When a message arrives at a neuron, gates along the cell membrane open briefly to 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 the nearby part of the cell to change momentarily from negative to positive. When the positive charge reaches a critical level, the "trigger" is pulled, and an electrical impulse, known as an action potential, travels along the axon of the neuron (see Figure 2).

STUDY ALERT

Think of a neuron as a sausage, and the myelin sheath as the case around it.

Figure 2 Movement of the action potential across the axon. Just before Time 1, positively charged ions enter the cell membrane, changing the charge in the nearby part of the neuron from negative to positive and triggering an action potential. The action potential travels along the axon, as illustrated in the changes occurring from Time 1 to Time 3 (from top to bottom in this drawing). Immediately after the action potential has passed through a section of the axon, positive ions are pumped out, restoring the charge in that section to negative.



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

Mirror neurons Specialized neurons that fire not only when a person enacts a particular behavior, but also when a person simply observes *another* individual carrying out the same behavior.

The **action potential** moves from one end of the axon to the other like a flame moving along a fuse. Just after an action potential has occurred, a neuron cannot fire again immediately no matter how much stimulation it receives. It is as if the gun has to be reloaded after each shot. Eventually, though, the neuron is ready to fire once again.

Neurons differ not only in terms of how quickly an impulse moves along the axon but also in their potential rate of firing. Some neurons are capable of firing as many as a thousand times per second; others fire at much slower rates. The intensity of a stimulus determines how much of a neuron's potential firing 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 through 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 toes.

Although all neurons operate through the firing of action potentials, there is significant specialization among different types of neurons. For example, in the last decade, neuroscientists have discovered the existence of **mirror neurons**, neurons that fire not only when a person enacts a particular behavior, but also when a person simply observes *another* individual carrying out the same behavior (Lepage & Theoret, 2007; Schulte-Ruther et al., 2007; Schermer, 2010).

Mirror neurons may help explain how (and why) humans have the capacity to understand others' intentions. Specifically, mirror neurons may fire when we view others' behavior, helping us to predict what their goals are and what they may do next (Triesch, Jasso, & Deák, 2007; Hickok, 2010; Avenanti & Urgesi, 2011).

LO 5.3 Where Neurons Connect to One Another: Bridging the Gap

If you have looked inside a computer, you've seen that each part is physically connected to another part. 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). The **synapse** is the space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron by using chemical messages.

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.

Synapse The space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron by using chemical messages.

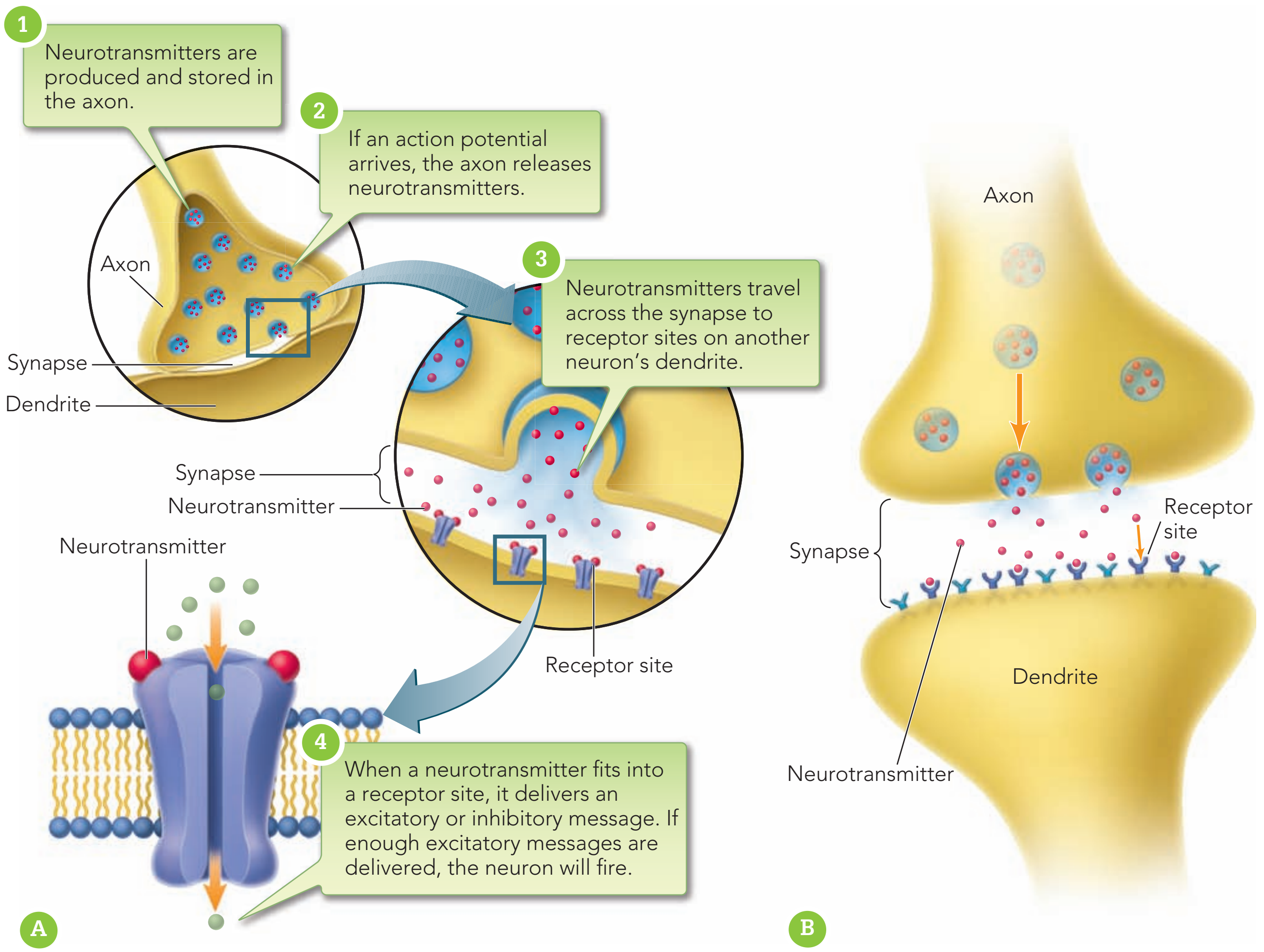


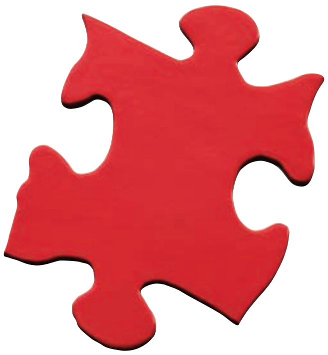
Figure 3 (A) A synapse is the junction between an axon and a dendrite. The gap between the axon and the dendrite is bridged by chemicals called neurotransmitters (Mader, 2000). (B) Just as the pieces of a jigsaw puzzle can fit in only one specific location in a puzzle, each kind of neurotransmitter has 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 landline?

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

Excitatory message A chemical message that makes it more likely that a receiving neuron will fire and an action potential will travel down its axon.

Inhibitory message A chemical message that prevents or decreases the likelihood that a receiving neuron will fire.

Reuptake The reabsorption of neurotransmitters by a terminal button.



Neurotransmitters are chemicals that carry messages across the synapse to a dendrite (and sometimes the cell body) of a receiving neuron. The chemical mode of message transmission that occurs between neurons is strikingly different from the means by which communication occurs inside neurons: 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 neurons are capable of receiving the chemical message carried by a particular neurotransmitter. In the same way that a jigsaw puzzle piece 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 site on the receiving neuron (see Figure 3B on page 51). It is only when a neurotransmitter fits precisely into a receptor site that successful chemical communication is possible.

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. Put simply, if the excitatory messages ("fire!") outnumber the inhibitory ones ("don't fire!"), the neuron fires. In contrast, if the inhibitory messages outnumber the excitatory ones, nothing happens, and the neuron remains in its resting state (Mel, 2002; Flavell et al., 2006; Rapport, 2005).

If neurotransmitters remained at the site of the synapse, receiving neurons would be awash in a continual chemical bath, producing constant stimulation or constant inhibition of the receiving neurons—and effective communication across the synapse would no longer be possible. To solve this problem, neurotransmitters are either deactivated by enzymes or—more commonly—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 (Helmuth, 2000; Holt & Jahn, 2004).

LO 5.4 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, 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 neuroscientists believe that more may ultimately be identified (Penney, 2000; Schmidt, 2006; Alix & Domingues, 2011).

Neurotransmitters vary significantly in terms of how strong their concentration must be to trigger a neuron to fire. Furthermore, the effects of a particular neurotransmitter vary, depending on the area of the nervous system in which it is produced. The same neurotransmitter, then, can act as an excitatory message to a neuron located in one part of the brain and can inhibit firing in neurons located in another part. (The major neurotransmitters and their effects are described in Figure 4.)

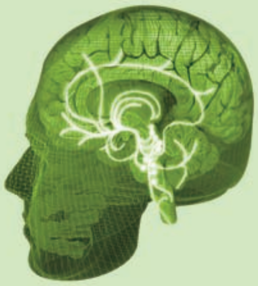
Dopamine Pathways	Name	Location	Effect	Function
	Acetylcholine (ACh)	Brain, spinal cord, peripheral nervous system, especially some organs of the parasympathetic nervous system	Excitatory in brain and autonomic nervous system; inhibitory elsewhere	Muscle movement, cognitive functioning
	Glutamate	Brain, spinal cord	Excitatory	Memory
	Gamma-amino-butyric acid (GABA)	Brain, spinal cord	Main inhibitory neurotransmitter	Eating, aggression, sleeping
Serotonin Pathways				
	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, appetites, placebos

Figure 4 Some major neurotransmitters.

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 diminished production of ACh may be related to Alzheimer's disease (Bazalakova et al., 2007; Del Arco et al., 2010; Van der Zee, Platt, & Riedel, 2011).

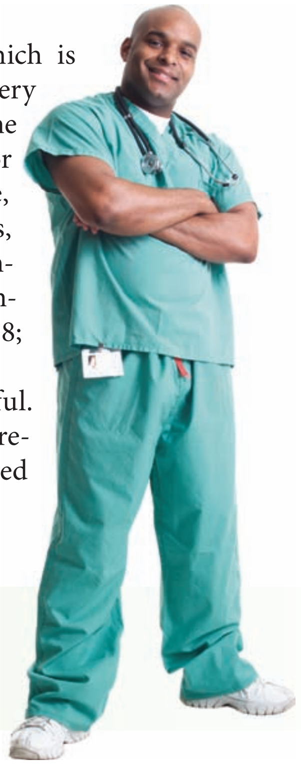
Michael J. Fox, who suffers from Parkinson's disease, like Muhammad Ali, has become a strong advocate for research into this disorder. The pair is seen here asking Congress for additional funds for Parkinson's research.

Another major neurotransmitter is *dopamine* (*DA*), which is involved in movement, attention, and learning. The discovery that certain drugs can have a significant 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 (Antonini & Barone, 2008; Willis, 2005; Iversen & Iversen, 2007).

In other instances, *over*production of dopamine is harmful. 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 (Murray, Lappin, & Di Forti, 2008; Howes & Kapur, 2009; Seeman, 2011).

From the perspective of . . .

A Health Care Provider How might your understanding of the nervous system help you explain the symptoms of Parkinson's disease to a patient with the disorder?



RECAP

Explain the structure of a neuron.

- A neuron has a cell body (which contains a nucleus) with a cluster of fibers called dendrites, which receive messages from other neurons. On the opposite end of the cell body is a tubelike extension, an axon, which ends in a small bulge called a terminal button. Terminal buttons send messages to other neurons. (p. 48)

Describe how neurons fire.

- Most axons are insulated by a coating called the myelin sheath. When a neuron receives a message to fire, it releases an action potential, an electrical charge that travels through the axon. 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. 49)

Summarize how messages travel from one neuron to another.

- Once a neuron fires, nerve impulses are carried to other neurons through the production of chemical substances, neurotransmitters, that actually bridge the gaps—known as synapses—between neurons. Neurotransmitters may be either excitatory, telling other neurons to fire, or inhibitory, preventing or decreasing the likelihood of other neurons firing. (p. 51)

Identify neurotransmitters.

- Neurotransmitters are an important link between the nervous system and behavior. Common neurotransmitters include the following: *acetylcholine,* which transmits messages relating to our muscles and is involved in memory capabilities; *glutamate,* which plays a role in memory; *gamma-aminobutyric* *acid (GABA),* which moderates behaviors from eating to aggression; *dopamine,* which is involved in movement, attention, and learning; *serotonin,* which is associated with the regulation of sleep, eating, mood, and pain; and endorphins, which seem to be involved in the brain's effort to deal with pain and elevate mood. (p. 52)

EVALUATE

1. The ___________ is the fundamental element of the nervous system.
2. Neurons receive information through their ___________ and send messages through their ___________.
3. Just as electrical wires have an outer coating, 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.

RETHINK

How might psychologists use drugs that mimic the effects of neurotransmitters to treat psychological disorders?

Answers to Evaluate Questions 1. neuron; 2. dendrites, axons; 3. myelin sheath; 4. synapse; 5. neurotransmitter

KEY TERMS

Behavioral neuroscientists (or biopsychologists) p. 47

Neurons p. 48

Dendrites p. 48

Axon p. 49

Terminal buttons p. 49

Myelin sheath p. 49

All-or-none law p. 49

Resting state p. 49

Action potential p. 50

Mirror neurons p. 50

Synapse p. 51

Neurotransmitters p. 52

Excitatory messages p. 52

Inhibitory messages p. 52

Reuptake p. 52

module 6

The Nervous System and the Endocrine System

Communicating within the Body

Prepare

Learning Outcomes

LO 6.1 Explain how the structures of the nervous system are linked together.

LO 6.2 Describe the operation of the endocrine system and how it affects behavior.

Organize

MODULE OUTLINE

Work

The complexity of the nervous system is astounding. Estimates of the number of connections between neurons within the brain fall in the neighborhood of 10 quadrillion—a 1 followed by 16 zeros. Furthermore, connections among neurons are not the only means of communication within the body; as we'll see, the endocrine system, which secretes chemical messages that circulate through the blood, also communicates messages that influence behavior and many aspects of biological functioning (Kandel, Schwartz, & Jessell, 2000; Boahen, 2005; Lynn et al., 2010).

Central nervous system (CNS) The part of the nervous system that includes the brain and spinal cord.

Spinal cord A bundle of neurons 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.

LO 6.1 The Nervous System

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

Central and Peripheral Nervous Systems

As you can see from the schematic representation in Figure 1, 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**, which is about the thickness of a pencil, contains a bundle of neurons that leaves the brain and runs down the length of the back (see Figure 2 on page 58). As you can

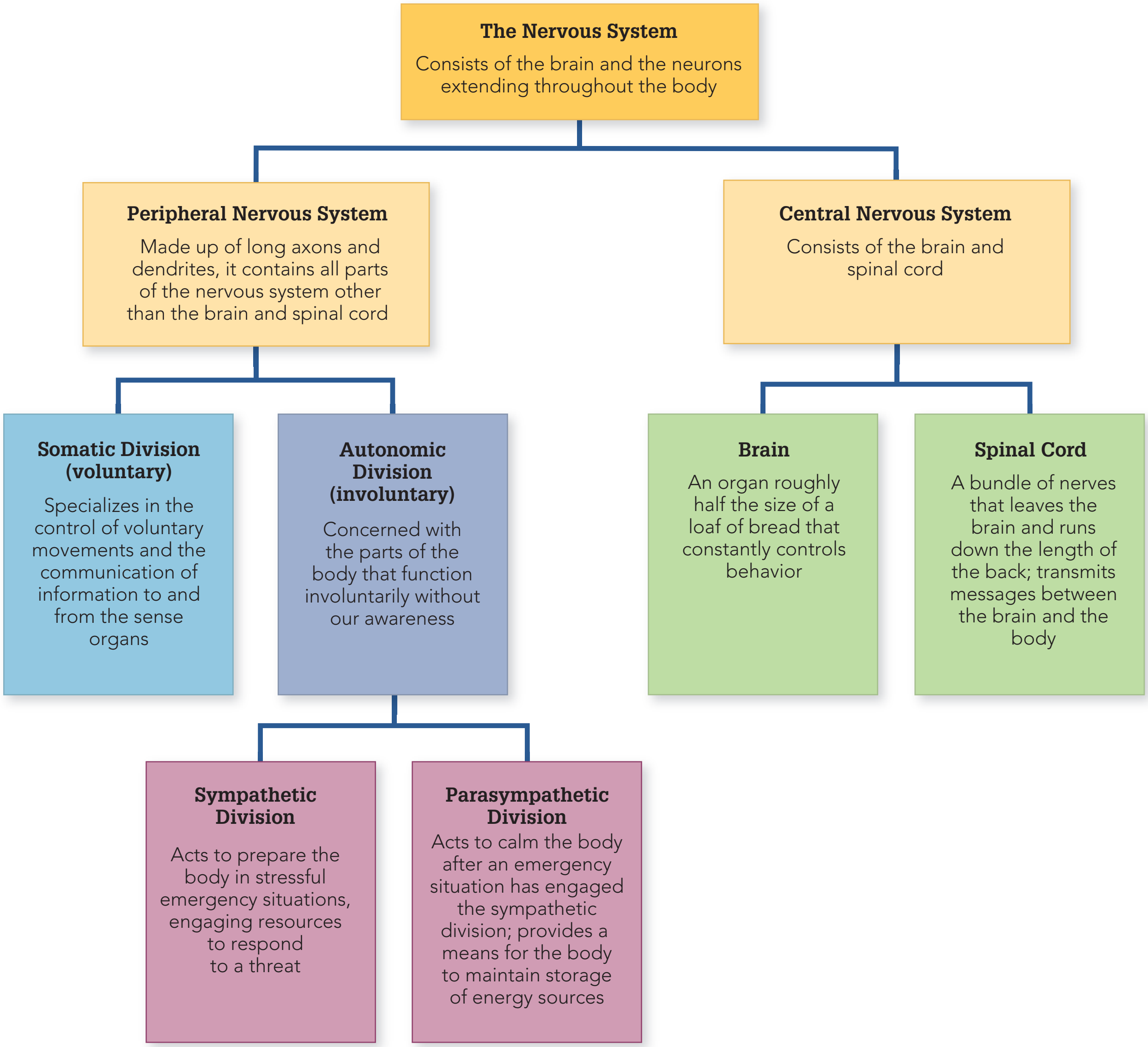


Figure 1 A schematic diagram of the relationship of the parts of the nervous system.

see in Figure 1, the spinal cord is the primary means for transmitting messages between the brain and the rest of the body.

However, the spinal cord is not just a communication channel. It also controls some simple behaviors on its own, without any help from the brain. An example is the way the knee jerks forward when it is tapped with a rubber hammer. This behavior is a type of **reflex**, an automatic, involuntary response to an incoming stimulus. A reflex is also at work when you touch a hot stove and immediately withdraw your hand. 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 kinds 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. **Interneurons** connect sensory and motor neurons, carrying messages between the two.

Reflex An automatic, involuntary response to an incoming stimulus.

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.

Interneurons Neurons that connect sensory and motor neurons, carrying messages between the two.

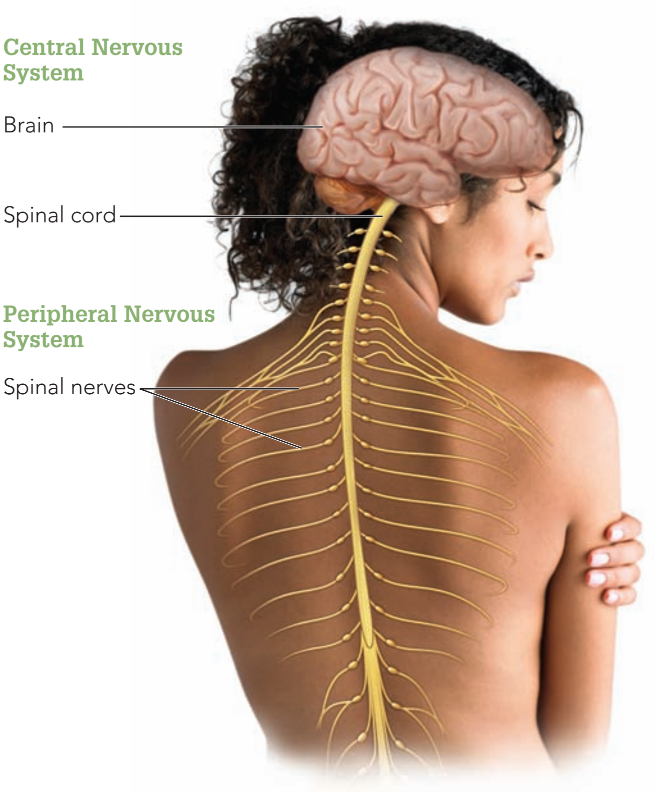


Figure 2 The central nervous system, consisting of the brain and spinal cord, and the peripheral nervous system.

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 neurons with long axons and dendrites, the peripheral nervous system encompasses all the 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 those 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** controls 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, and overseeing the digestion of your last meal.

Peripheral nervous system The part of the nervous system that includes the autonomic and somatic subdivisions; made up of neurons with 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 peripheral 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 peripheral nervous system that controls involuntary movement of the heart, glands, lungs, and other organs.

Sympathetic division The part of the autonomic division of the nervous system that acts to prepare the body for action in stressful 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 an emergency has ended.

Behavioral genetics The study of the effects of heredity on behavior.

Activating the Divisions of the Autonomic Nervous System

The autonomic division plays a particularly crucial role during emergencies. Suppose that as you are reading in bed you suddenly sense that someone is outside your bedroom window. As you look up, you see the glint of an object that might be a knife. As confusion and fear overcome you, 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.

The physiological changes that occur during a crisis result from the activation of one of the two parts of the autonomic nervous system: the **sympathetic division**. The sympathetic division acts to prepare the body for action in stressful situations by engaging all of the organism's resources to run away or confront the threat. This response is often called the "fight-or-flight" response.

In contrast, the **parasympathetic division** acts to calm the body after the emergency has ended. When you find, for instance, that the stranger at the window is actually your boyfriend 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 before you became alarmed. The parasympathetic division also directs the body to store energy for use in emergencies. The sympathetic and parasympathetic divisions work together to regulate many functions of the body (see Figure 3).

Behavioral Genetics

Our personality and behavioral habits are affected in part by our genetic and evolutionary heritage. **Behavioral genetics** studies the effects of heredity on

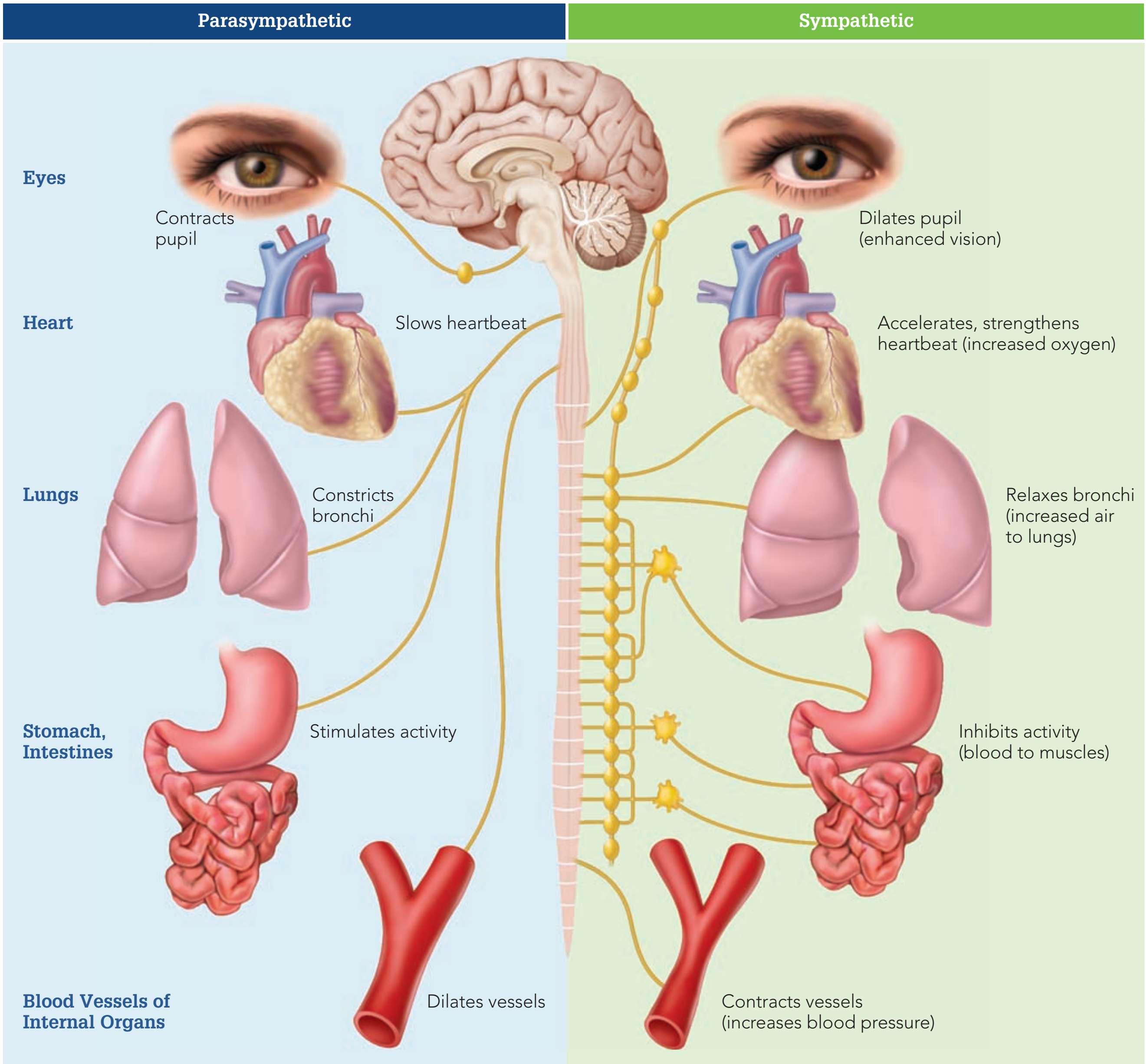


Figure 3 The major functions of the autonomic nervous system. The sympathetic division acts to prepare certain organs of the body for stressful situations, and the parasympathetic division acts to calm the body after the emergency has passed. Can you explain why each response of the sympathetic division might be useful in an emergency? (Source: Adapted from Passer & Smith, 2001.)

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 (Livesley & Jang, 2008; Vernon et al., 2008; O'Neill et al., 2010).

Behavioral genetics lies at the heart of the nature-nurture question, one of the key issues in the study of psychology. Although no one would argue that our behavior is determined *solely* 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 may be related to such diverse behaviors as level of family conflict, schizophrenia, learning disabilities, and general sociability (Davis, Haworth, &

Genetic testing can be done to determine potential risks to an unborn child baed on family history of illness.

Plomin, 2009; Lakhan & Vieira, 2009; Gejman, Sanders & Duan, 2010).

Furthermore, important human characteristics and behaviors are related to the presence (or absence) of particular *genes,* the inherited 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 (Golimbet et al., 2007; Stedenfeld, 2011).

As we will consider later in the book when we discuss human development, researchers have identified some 25,000 individual genes, each of which appears in a specific sequence on a particular *chromosome,* a rod-shaped structure that transmits genetic information across generations. In 2003, after a decade of effort, researchers identified the sequence of the 3 billion chemical pairs that make up human *DNA,* the basic component of genes. Understanding the basic structure of the human *genome*—the "map" of humans' total genetic makeup—brings scientists a giant step closer to understanding the contributions of individual genes to specific human structures and functioning (Dale & von Schantz, 2007; Plomin & Davis, 2009).

STUDY ALERT

The endocrine system produces hormones, chemicals that circulate through the blood via the bloodstream.

Behavioral Genetics, Gene Therapy, and Genetic Counseling.

Behavioral genetics also holds the promise of developing new diagnostic and treatment techniques for genetic deficiencies that can lead to physical and psychological difficulties. In *gene therapy,* scientists inject genes meant to cure a particular disease into a patient's bloodstream. When the genes arrive at the site of defective genes that are producing the illness, they trigger the production of chemicals that can treat the disease (Eberling et al., 2008; Isacson & Kordower, 2008; Odom et al., 2010).

The number of diseases that can be treated through gene therapy is growing, as we will see when we discuss human development. For example, gene therapy is now being used in experimental trials involving people with certain forms of cancer, leukemia, and blindness (Nakamura et al., 2004; Wagner et al., 2004; Hirschler, 2007).

From the perspective of . . .

A Physician's Assistant How valuable would an understanding of the brain and neurosystem be in your job as a physician's assistant?

Advances in behavioral genetics also have led to the development of a profession that did not exist several decades ago: genetic counseling. Genetic counselors help people deal with issues related to inherited disorders. For example, genetic counselors provide advice to prospective parents about the potential risks in a future pregnancy, based on their family history of birth defects and hereditary illnesses. In addition, the counselor will consider the parents' age and problems with children they already have. They also can take blood, skin, and urine samples to examine specific chromosomes.

LO 6.2 The Endocrine System: Of Chemicals and Glands

Another of the body's communication systems, the **endocrine system** is a chemical communication network that sends messages throughout the body via the bloodstream. Its job is to secrete **hormones**, chemicals that circulate through the blood and regulate the functioning or growth of the body. It also influences—and is influenced by—the functioning of the nervous system.

Endocrine system A chemical communication network that sends messages throughout the body via the bloodstream.

Hormones Chemicals that circulate through the blood and regulate the functioning or growth of the body.

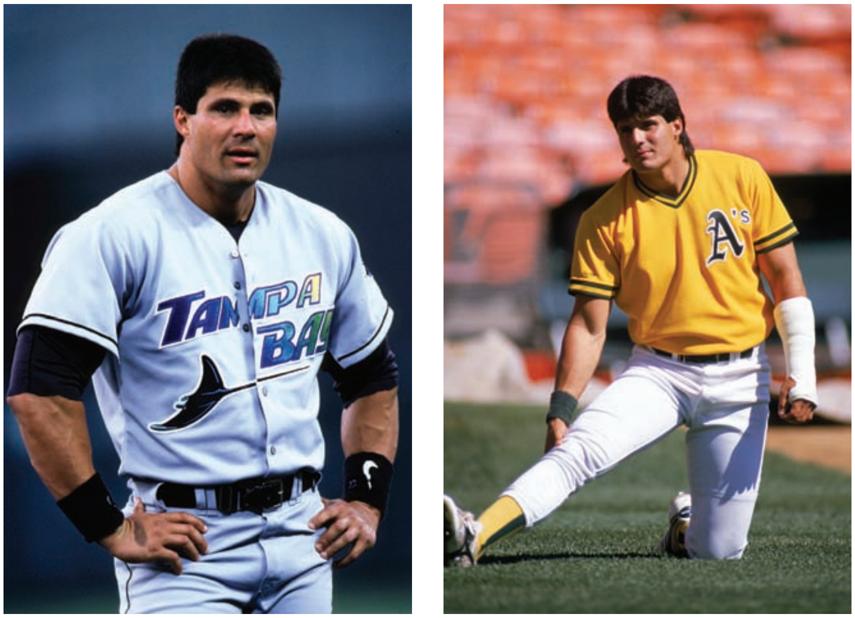
Pituitary gland The major component of the endocrine system, or "master gland," which secretes hormones that control growth and other parts of the endocrine system.

As chemical messengers, hormones are like neurotransmitters, although their speed and mode of transmission are quite different. Whereas neural messages are measured in thousandths of a second, hormonal communications may take minutes to reach their destination. Furthermore, neural messages move through neurons in specific lines (like a signal carried by wires strung along telephone poles), whereas hormones travel throughout the body, similar to the way radio waves are transmitted across the entire landscape. Just as radio waves evoke a response only when a radio is tuned to the correct station, hormones flowing through the bloodstream activate only those cells which are receptive and "tuned" to the appropriate hormonal message.

A key component of the endocrine system is the tiny **pituitary gland**. 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 4 on page 52, affect emotional reactions, sexual urges, and energy levels.

Although hormones are produced naturally by the endocrine system, there are a variety of artificial hormones that people may choose to take. For example, physicians sometimes prescribe hormone replacement therapy (HRT) to treat symptoms of menopause in older women. However, because recent research suggests that the treatment has potentially dangerous side effects, health experts now warn that the dangers outweigh the benefits (Herrington & Howard, 2003; Lagro-Janssen et al., 2010).

Other artificial hormones can be harmful. For example, some athletes use testosterone, a male hormone, and drugs known as *steroids,* which act like testosterone. For athletes and others who want to bulk up their appearance, steroids provide a way to add



Steroids can provide added muscle strength, but they have dangerous side effects. A number of well-known athletes have been accused of using the drugs illegally. Jose Conseco is one of the few major league baseball players to admit steroid use.

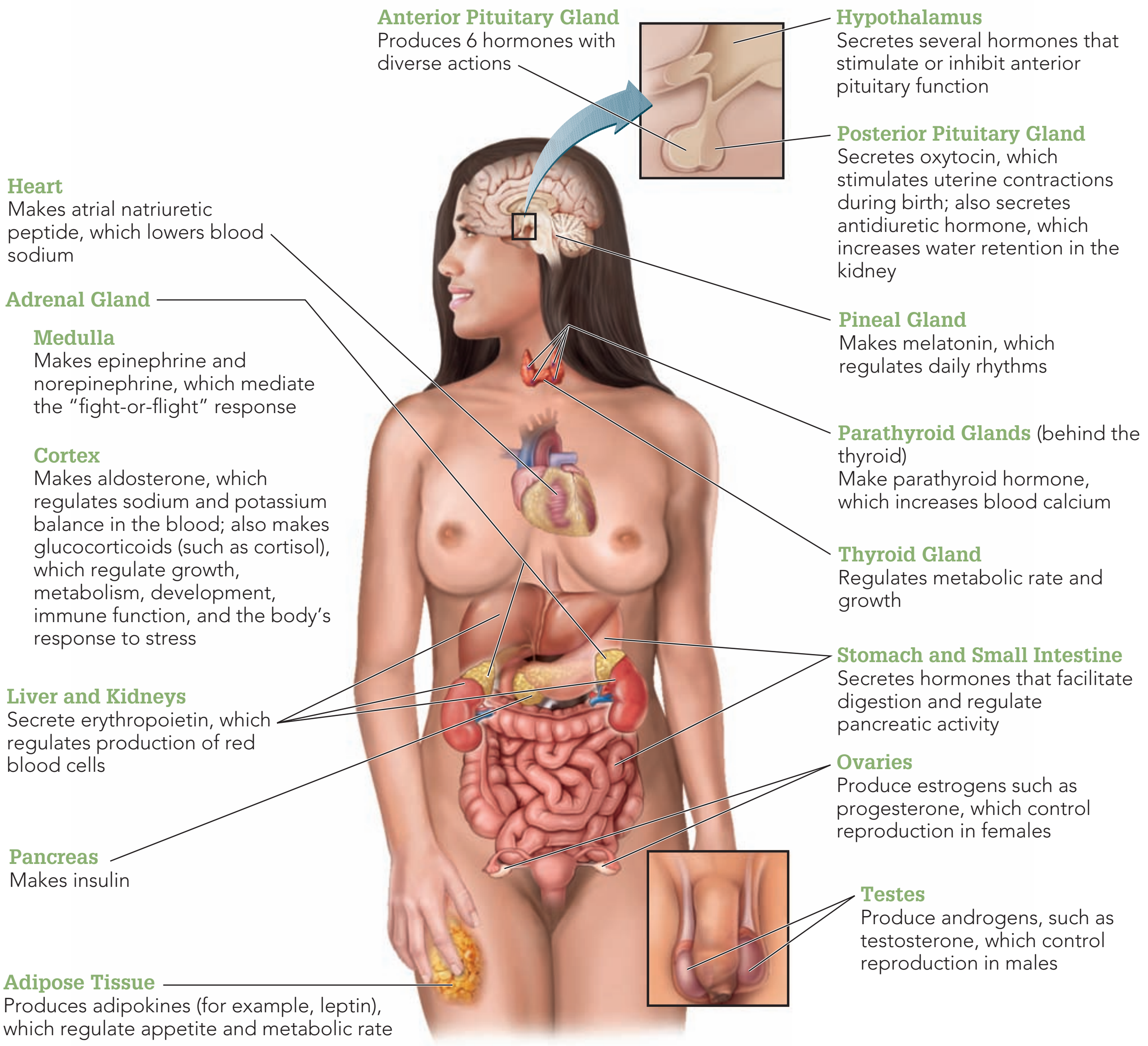


Figure 4 Location and function of the major endocrine glands. The pituitary gland controls the functioning of the other endocrine glands and in turn is regulated by the brain. Steroids can provide added muscle and strength, but they have dangerous side effects. (Source: Adapted from Brooker et al., 2008, p.1062.)

muscle weight and increase strength. However, these drugs can lead to heart attacks, strokes, cancer, and even violent behavior, making them extremely dangerous. For example, in one infamous case, professional wrestler Chris Benoit strangled his wife, suffocated his son, and later hanged himself—acts that were attributed to his use of steroids (Pagonis, Angelopoulos, & Koukoulis, 2006; Sandomir, 2007; Teitelbaum, 2010).

RECAP

Explain how the structures of the nervous system are linked together.

- The nervous system is made up of the central nervous system (the brain and spinal cord) and the peripheral 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. 56)

- 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. 58)
- Behavioral genetics examines the hereditary basis of human personality traits and behavior. (p. 58)

Describe the operation of the endocrine system and how it affects behavior.

- The endocrine system secretes hormones, chemicals that regulate the functioning of the body, via the bloodstream. The pituitary gland secretes growth hormones and influences the release of hormones by other endocrine glands, and in turn is regulated by the hypothalamus. (p. 61)

EVALUATE

Evaluate

1. If you 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

RETHINK

Rethink

In what ways is the "fight-or-flight" response helpful to humans in emergency situations?

Answers to Evaluate Question 1. reflex; 2. brain, spinal cord; 3. somatic, autonomic; 4. sympathetic

KEY TERMS

Central nervous system (CNS) p. 56

Spinal cord p. 56

Reflex p. 57

Sensory (afferent) neurons p. 57

Motor (efferent) neurons p. 57

Interneurons p. 57

Peripheral nervous system p. 58

Somatic division p. 58

Autonomic division p. 58

Sympathetic division p. 58

Parasympathetic division p. 58

Behavioral genetics p. 58

Endocrine system p. 61

Hormones p. 61

Pituitary gland p. 61

module 7

The Brain

Learning Outcomes

Prepare

LO 7.1 Illustrate how researchers identify the major parts and functions of the brain.

LO 7.2 Describe the central core of the brain.

LO 7.3 Describe the limbic system of the brain.

LO 7.4 Describe the cerebral cortex of the brain.

LO 7.5 Recognize neuroplasticity and its implications.

LO 7.6 Explain how the two hemispheres of the brain operate interdependently and the implications for human behavior.

MODULE OUTLINE

Organize

Work

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

The object to which this description applies: the brain. The brain is responsible for our loftiest thoughts—and our most primitive urges. It is the overseer of the intricate workings of the human body. Many billions of neurons make up a structure weighing just three pounds in the average adult. However, it is not the number of cells that is the most astounding thing about the brain but its ability to allow the human intellect to flourish by guiding our behavior and thoughts.

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 discuss specific areas of the brain in relation to specific behaviors, this approach is an oversimplification. No simple one-to-one correspondence exists between a distinct part of the brain and a particular behavior. Instead, behavior is produced by complex interconnections among sets of neurons 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.

LO 7.1 Studying the Brain's Structure and Functions: Spying on the Brain

Modern brain-scanning techniques provide a window into the living brain. Using these techniques, investigators can take a "snapshot" of the internal workings of the brain without having to cut open a person's skull. The

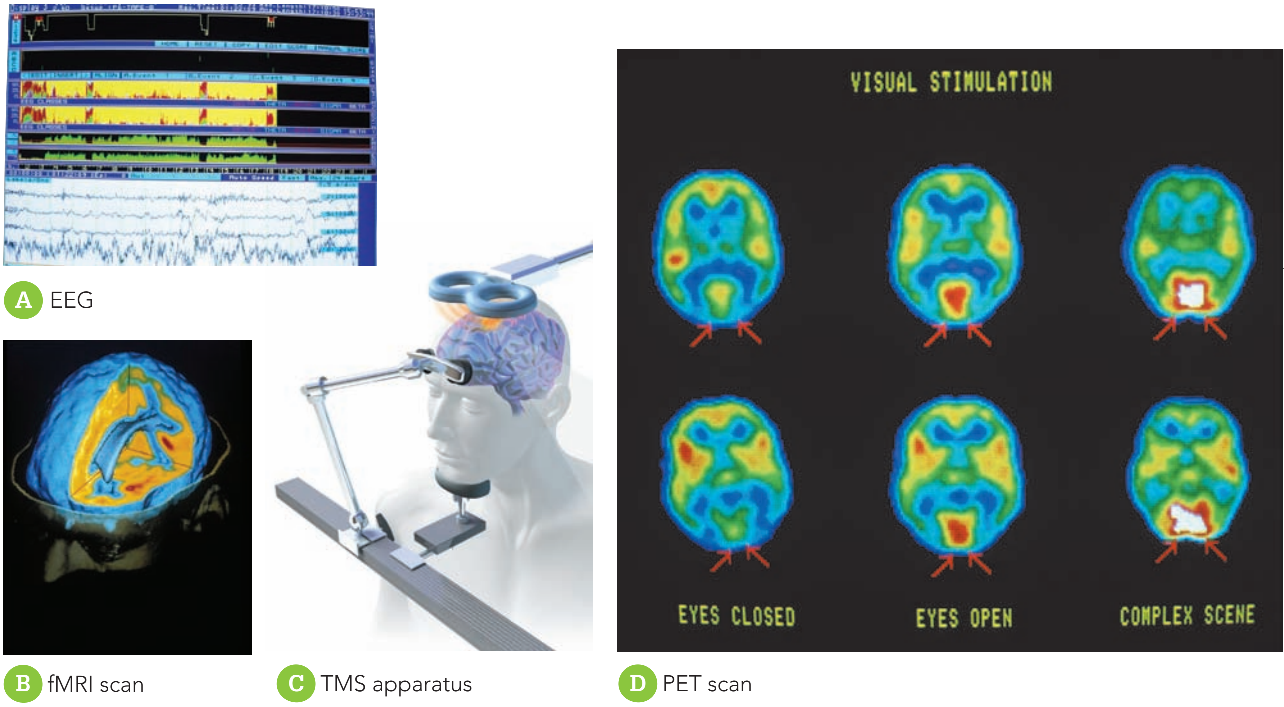


Figure 1 Brain scans produced by different techniques. (A) A computer-produced EEG image. (B) The fMRI scan uses a magnetic field to provide a detailed view of brain activity on a moment-by-moment basis. (C) Transcranial magnetic stimulation (TMS), the newest type of scan, produces a momentary disruption in an area of the brain, allowing researchers to see what activities are controlled by that area. TMS also has the potential to treat some psychological disorders. (D) The PET scan displays the functioning of the brain at a given moment.

most important scanning techniques, illustrated in Figure 1, are the electroencephalogram (EEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation imaging (TMS).

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 used to transform the brain's electrical activity into a pictorial representation of the brain that allows more precise diagnosis of disorders such as epilepsy and learning disabilities.

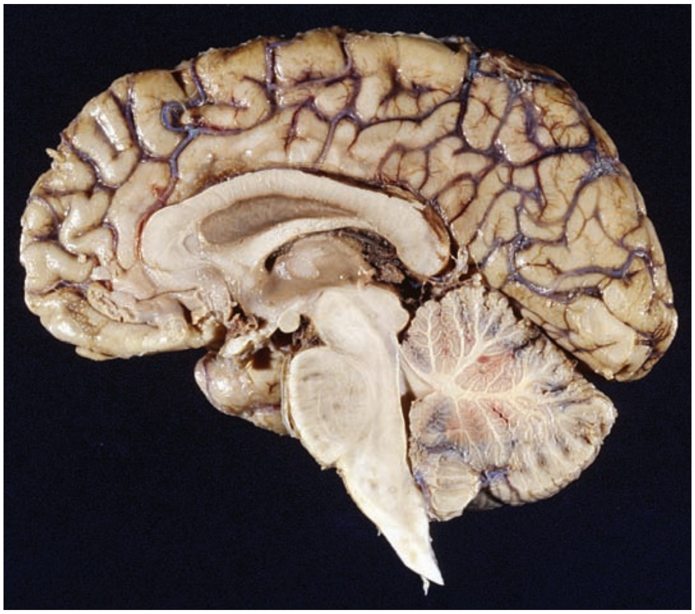
Positron emission tomography (PET) scans show biochemical activity within the brain at a given moment. PET scans begin with the injection of a radioactive (but safe) liquid into the bloodstream, which makes its way to the brain. By locating radiation within the brain, a computer can determine which are the more active regions, providing a striking picture of the brain at work. For example, PET scans may be used in cases of memory problems, seeking to identify the presence of brain tumors (Gronholm et al., 2005; McMurtray et al., 2007).

Functional magnetic resonance imaging (fMRI) scans provide a detailed, three-dimensional computer-generated image of brain structures and activity by aiming a powerful magnetic field at the body. With fMRI scanning, it is possible to produce vivid, detailed images of the functioning of the brain.

Transcranial magnetic stimulation (TMS) is one of the newest types of scan. By exposing a tiny region of the brain to a strong magnetic field, TMS causes a momentary interruption of electrical activity. Researchers then are

STUDY ALERT

Remember that EEG, fMRI, PET, and TMS differ in terms of whether they examine brain *structures* or brain *functioning*.



The brain (shown here in cross section) 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?

able to note the effects of this interruption on normal brain functioning. The procedure is sometimes called a "virtual lesion" because it produces effects analogous to what would occur if areas of the brain were physically cut. The enormous advantage of TMS, of course, is that the virtual cut is only temporary. In addition to identifying areas of the brain that are responsible for particular functions, TMS has the potential to treat certain kinds of psychological disorders, such as depression and schizophrenia, by shooting brief magnetic pulses through the brain (Rado, Dowd, & Janicak, 2008; Pallanti & Bernardi, 2009; Holtzheimer et al., 2010).

Future discoveries may yield even more sophisticated methods of examining the brain. For example, the emerging field of *optogenetics* involves genetic engineering and the use of special types of light to view individual circuits of neurons (Miesenbock, 2008: Gradinaru et al., 2009; LaLumiere, 2010).

LO 7.2 The Central Core: Our "Old Brain"

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

Cerebellum (ser uh BELL um) The part of the brain that controls bodily balance.

Although the capabilities of the human brain far exceed those of the brain of any other species, humans share some basic functions, such as breathing, eating, and sleeping, with more primitive animals. Not surprisingly, those activities are directed by a relatively primitive part of the brain. A portion of the brain known as the **central core** (see Figure 2) is quite similar in all vertebrates (species with backbones). The central core is sometimes referred to as the "old brain" because its evolution 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). *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 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 regulating sleep.

The **cerebellum** is found just above the medulla and behind the pons. Without the help of the cerebellum we would be unable to walk 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 the analysis and

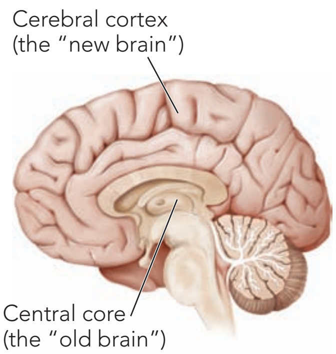


Figure 2 The major divisions of the brain: the cerebral cortex and the central core. (Source: Seeley, Stephens, & Tate, 2000.)

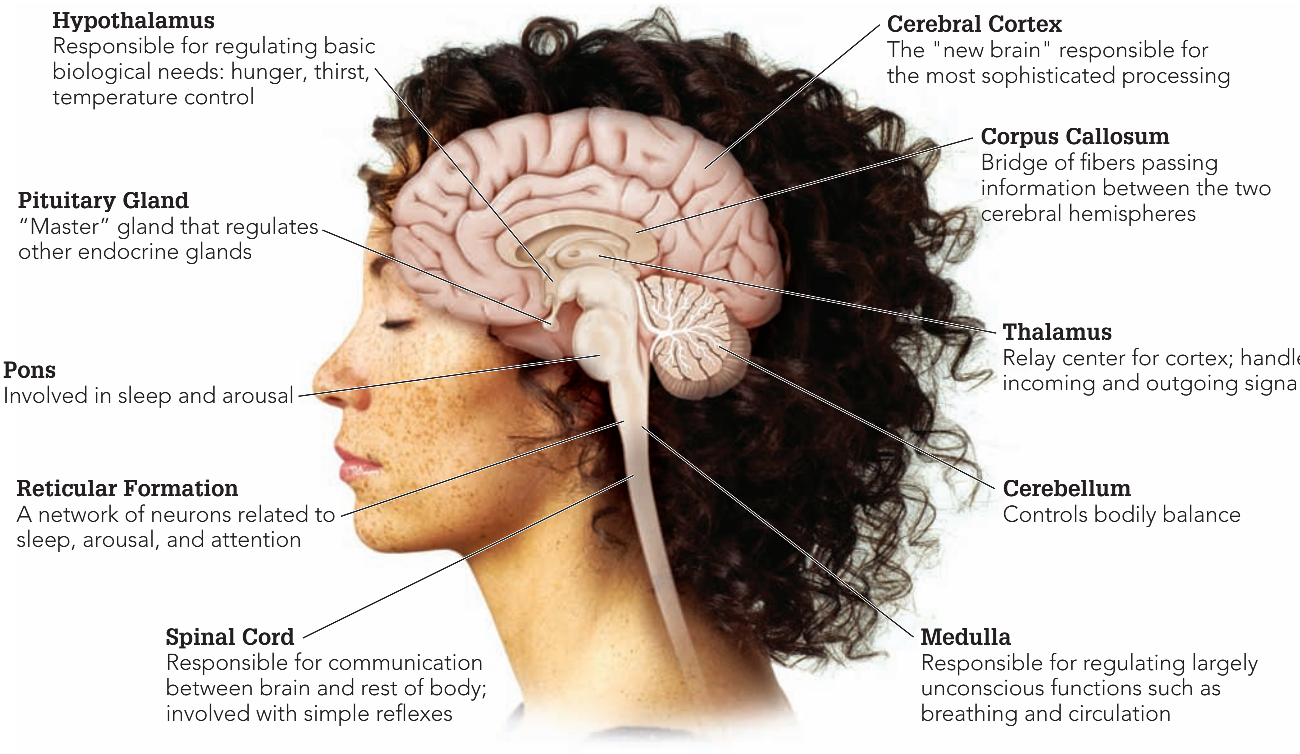


Figure 3 The major structures in the brain. (Source: Johnson, 2000.)

coordination of sensory information to problem solving (Vandervert, Schimpf, & Liu, 2007; Tian et al., 2010, 2011).

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 activate other parts of the brain immediately to produce general bodily arousal. If, for example, we are startled by a loud noise, the reticular formation can prompt a heightened state of awareness to determine whether a response is necessary. The reticular formation serves a different function when we are sleeping, seeming to filter out background stimuli to allow us to sleep undisturbed.

> **Like an ever-vigilant guard, the reticular formation is made up of groups of nerve cells that can activate other parts of the brain immediately to produce general bodily arousal.**

Hidden within the forebrain, the **thalamus** acts primarily as a relay station for information about 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.

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

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

Thalamus The part of the brain located in the middle of the central core that acts primarily to relay information about the senses.

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

LO 7.3 The Limbic System: Beyond the Central Core

Limbic system The part of the brain that includes the amygdala and hippocampus, and controls eating, aggression, and reproduction.

Cerebral cortex The "new brain," responsible for the most sophisticated information processing in the brain; contains four lobes.

The **limbic system** of the brain consists of a series of doughnut-shaped structures that include the *amygdala* and *hippocampus,* the limbic system borders the top of the central core and has connections with the cerebral cortex (see Figure 4). 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. For example, injury to the amygdala, which is involved in fear and aggression, can turn animals that were meek and tame into hostile beasts. Conversely, animals that are usually wild and uncontrollable may become submissive and obedient following injury to the amygdala (Bedard & Persinger, 1995; Gontkovsky, 2005; León-Carrión & Chacartegui-Ramos, 2010).

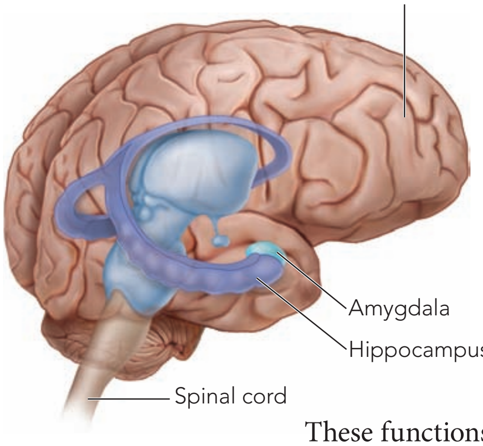


Figure 4 The limbic system consists of a series of doughnut-shaped structures that are involved in self-preservation, learning, memory, and the experience of pleasure.

The limbic system 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.

LO 7.4 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**.

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. Although only about one-twelfth of an inch thick, it would, if flattened out, cover an area more than two feet square. This configuration allows the surface area of the cortex to be considerably greater than it would be 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 information processing.

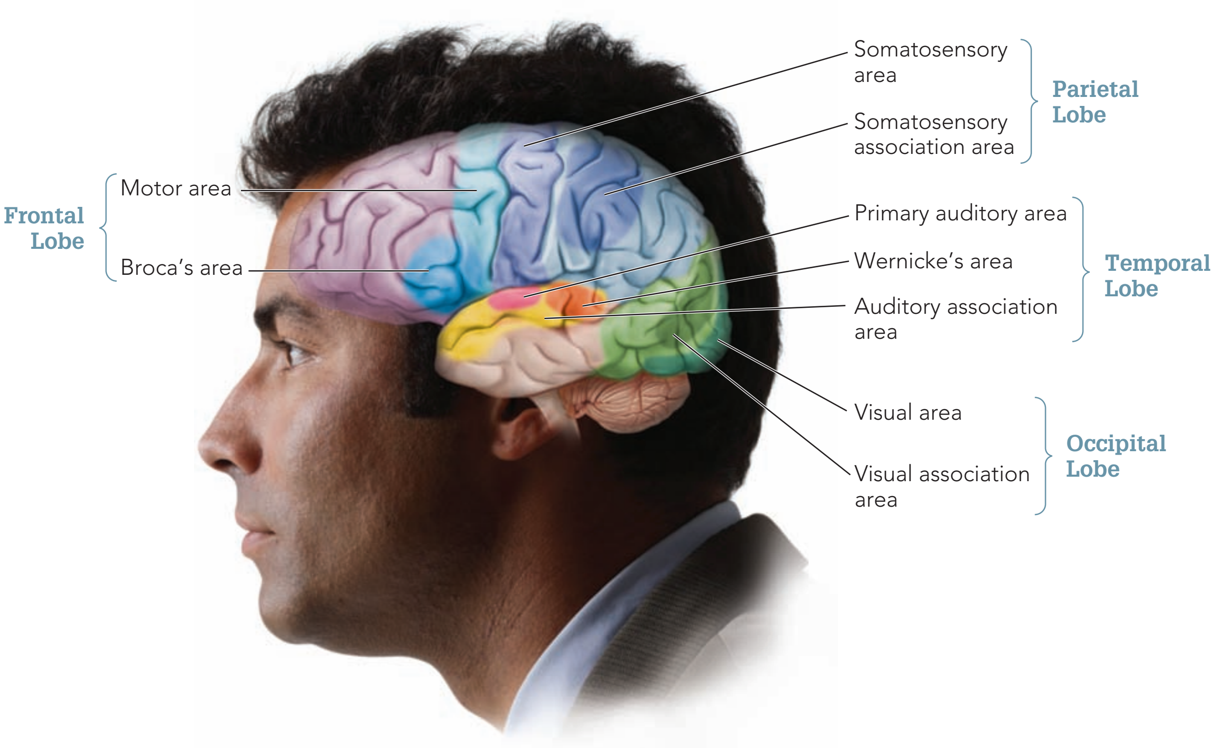


Figure 5 The cerebral cortex of the brain. The major physical structures of the cerebral cortex are called lobes. This figure also illustrates the functions associated with particular areas of the cerebral cortex. Are any areas of the cerebral cortex present in nonhuman animals?

The 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 portion of the cortex, with the *occipital lobes* lying behind them. These four sets of lobes are physically separated by deep grooves called sulci. Figure 5 shows the four areas.

Another way to describe the brain is in terms of the functions associated with a particular area. Figure 5 also shows the specialized regions within the lobes related to specific functions and areas of the body. Three major areas are known: 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.

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

Motor area The part of the cortex that is largely responsible for the body's voluntary movement.

The Motor Area of the Cortex

If you look at the frontal lobe in Figure 5, you will see a shaded portion labeled **motor area**. This part of the cortex is largely responsible for the body's voluntary movement. 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.

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 movements that are relatively large scale and require little precision, such as the 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 (Schwenkreis et al., 2007).

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 related to the amount of tissue allocated to that sense.

Given the one-to-one correspondence between the 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 in the parietal lobe 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 area devoted to a specific area of the body within the cortex, the more sensitive that area of the body. As you can see from the weird-looking individual in Figure 6, parts such as the fingers are related to proportionally more area 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 (Hudspeth, 2000; Brown & Martinez, 2007; Hyde, Peretz, & Zatorre, 2008; Bizley et al., 2009).

The visual area in the cortex, located in the occipital lobe, responds in the same way to electrical stimulation. 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 provides another example of how areas of the brain are intimately related to specific areas of the body: specific structures in the eye are related to a particular part of the cortex—with, as you might guess, more area of the brain given to the most sensitive portions of the retina (Wurtz & Kandel, 2000; Stenbacka & Vanni, 2007; Fergenbaum et al., 2010).

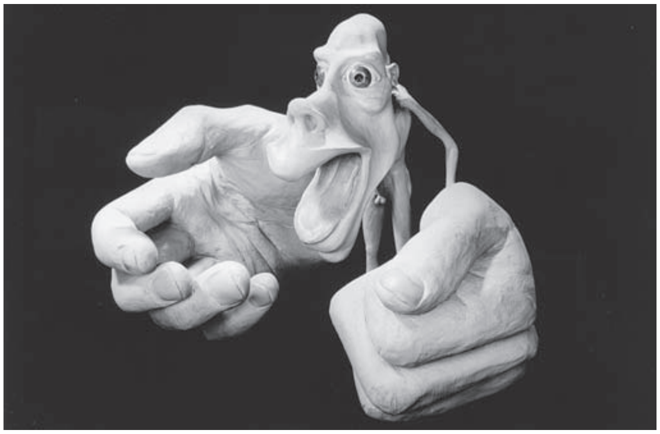


Figure 6 The greater the amount of tissue in the somatosensory area of the brain that is related to a specific body part, the more sensitive is that body part. If the size of our body parts reflected the corresponding amount of brain tissue, we would look like this strange creature.

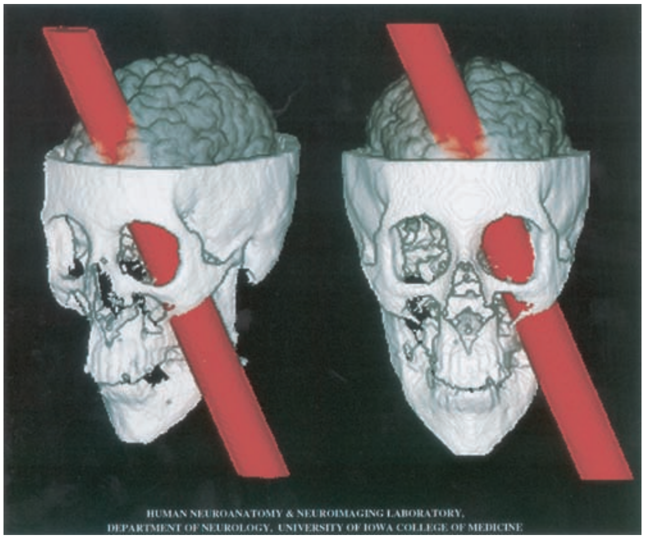
The Association Areas of the Cortex

In a freak accident in 1848, an explosion drove a three-foot-long iron bar completely through the skull of railroad worker Phineas Gage, where it remained after the accident. Amazingly, Gage survived, and, despite the rod lodged through his head, a few minutes later seemed to be fine.

But he wasn't. Before the accident, Gage was hardworking and cautious. Afterward, he became irresponsible, drank heavily, and drifted from one wild scheme to another. In the words of one of his physicians, he was "no longer Gage" (Harlow, 1869, p. 14; Della Sala, 2011).

What had happened to the old Gage? Although there is no way of knowing for sure, we can speculate that the accident may have injured the region of Gage's cerebral cortex known as the **association areas**, which generally are considered to be the site of higher mental processes such as thinking, language, memory, and speech (Rowe et al., 2000).

The association areas make up a large portion of the cerebral cortex and consist of the sections that are not directly involved in either sensory processing or directing movement. The association areas control *executive functions,* which are abilities relating to planning, goal setting, judgment, and impulse control.



A model of the injury sustained by Phineas Gage.

Much of our understanding of the association areas comes from patients who, like Phineas Gage, have suffered some type of brain injury. For example, when parts of the association areas are damaged, people undergo personality changes that affect their ability to make moral judgments and process emotions. At the same time, people with damage in those areas can still be capable of reasoning logically, performing calculations, and recalling information (Damasio, 1999).

Association areas One of the major regions of the cerebral cortex; the site of the higher mental processes, such as thought, language, memory, and speech.

Neuroplasticity Changes in the brain that occur throughout the life span relating to the addition of new neurons, new interconnections between neurons, and the reorganization of information-processing areas.

LO 7.5 Neuroplasticity and 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.
>
> 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. . . . They told us to take him home, love him and find an institution." (Blakeslee, 1992, p. C3)

Instead, Jacob had brain surgery when he was 5 months old in which physicians removed 20 percent of his brain. The operation was a complete success. Three years later Jacob seemed normal in every way, with no sign of seizures.

The surgery that helped Jacob was based on the premise that the diseased part of his brain was producing seizures throughout the 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 correctly bet that Jacob could still lead a normal life after surgery, particularly because the surgery was being done at so young an age.

STUDY ALERT

Remember that neuroplasticity is the reorganization of existing neuronal connections, while neurogenesis is the creation of new neurons.

The success of Jacob's surgery illustrates that the brain has the ability to shift functions to different locations after injury to a specific area or in cases of surgery. But equally encouraging are some new findings about the regenerative powers of the brain and nervous system. Scientists have learned in recent years that the brain continually reorganizes itself in a process termed **neuroplasticity**. Although for many years conventional wisdom held that no new brain cells are created after childhood, new research finds otherwise. Not only do the interconnections between neurons become more complex throughout life, but it now appears that new neurons are also created in certain areas of the brain during adulthood—a process called *neurogenesis*. Each day, thousands of new neurons are created, especially in areas of the brain related to learning and memory (Jang, You, & Ahn, 2007; Poo & Isaacson, 2007; Shors, 2009).

The ability of neurons to renew themselves during adulthood has significant implications for the potential treatment of disorders of the nervous system. For example, drugs that trigger the development of new neurons might be used to counter diseases like Alzheimer's that are produced when neurons die (Tsai, Tsai, & Shen, 2007; Eisch et al., 2008; Waddell & Shors, 2008).

LO 7.6 The Specialization of the Hemispheres: Two Brains or One?

The most recent development, at least in evolutionary terms, in the organization and operation of the human brain probably occurred in the last million years: a specialization of the functions controlled by the left and right sides of the brain (Hopkins & Cantalupo, 2008; MacNeilage, Rogers, & Vallortigara, 2009; Tommasi, 2009).

The brain is divided into two roughly mirror-image halves. Just as we have two arms, two legs, and two lungs, we have a left brain and a right brain. Because of the way nerves in the brain are connected to the rest of the body, these symmetrical left and right halves, called **hemispheres**, control motion in—and receive sensation from—the side of the body opposite 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 Symmetrical left and right halves of the brain that control the side of the body opposite to their location.

Lateralization The dominance of one hemisphere of the brain in specific functions, such as language.

Despite the appearance of similarity between the two hemispheres of the brain, they are somewhat different in the functions they control and in the ways they control them. Certain behaviors are more likely to reflect activity in one hemisphere than in the other, that is, the brain experiences **lateralization**.

It's likely that Vincent Van Gogh created *Wheat Fields with Cypresses* by relying primarily on the right hemisphere brain processing. What are some functions that might involve both hemispheres?

For example, for most people, language processing occurs more in the left side of the brain. In general, the left hemisphere concentrates more on tasks that require verbal competence, such as speaking, reading, thinking, and reasoning. In addition, the left hemisphere tends to process information sequentially, one bit at a time (Hines, 2004; Rogers, 2011).

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. The right hemisphere tends to process information globally, considering it as a whole (Ansaldo, Arguin, & RochLocours, 2002; Holowka & Petitto, 2002).

On the other hand, the differences in specialization between the hemispheres are not great, and the degree and nature of lateralization vary from one person to another. (To get a rough sense of your own degree of

Try It!

Assessing Brain Lateralization

To get a rough sense of your own preferences in terms of brain lateralization, complete the following questionnaire.

1. I often talk about my and others' feelings of emotion. True_______ False_______
2. I am an analytical person. True_______ False_______
3. I methodically solve problems. True _______ False_______
4. I'm usually more interested in people and feelings than objects and things. True_______ False_______
5. I see the big picture, rather than thinking about projects in terms of their individual parts. True_______ False_______
6. When planning a trip, I like every detail in my itinerary worked out in advance. True_______ False_______
7. I tend to be independent and work things out in my head. True_______ False_______
8. When buying a new car, I prefer style over safety. True_______ False_______
9. I would rather hear a lecture than read a textbook. True_______ False_______
10. I remember names better than faces. True_______ False_______

Scoring

Give yourself 1 point for each of the following responses: 1. False; 2. True; 3. True; 4. False; 5. False; 6. True; 7. True; 8. False; 9. False; 10. True. Maximum score is 10, and minimum score is 0.

The higher your score, the more your responses are consistent with people who are left-brain oriented, meaning that you have particular strength in tasks that require verbal competence, analytic thinking, and processing of information sequentially, one bit of information at a time.

The lower your score, the more your responses are consistent with a right-brain orientation, meaning that you have particular strengths in nonverbal areas, recognition of patterns, music, and emotional expression, and process information globally.

Remember, though, that this is only a rough estimate of your processing preferences, and that all of us have strengths in both hemispheres of the brain.

Source: Adapted in part from Morton, 2003.

lateralization, complete the questionnaire in the *Try It!* box.) If, like most people, you are right-handed, the control of language is probably concentrated more in your left hemisphere. By contrast, 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 the left and right hemispheres.

Furthermore, 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.

Researchers also have unearthed evidence that there may be subtle differences in brain lateralization patterns between males and females and members of different cultures, as we see next.

EXPLORING diversity

Human Diversity and the Brain

The interplay of biology and environment in behavior is particularly clear when we consider evidence suggesting that even in brain structure and function there are both sex and cultural differences. Let's consider sex first. Accumulating evidence seems to show intriguing differences in males' and females' brain lateralization and weight (Boles, 2005; Clements, Rimvodt, & Abel, 2006).

The interplay of biology and environment in behavior is particularly clear when we consider evidence suggesting that even in brain structure and function there are both sex and cultural 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. Such differences in brain lateralization may account, in part, for the superiority often displayed by females on certain measures of verbal skills, such as the onset and fluency of speech (Frings et al., 2006; Petersson et al., 2007).

Other research suggests that men's brains are somewhat bigger than women's brains even after taking differences in body size into account. In contrast, part of the *corpus callosum,* a bundle of fibers that connects the hemispheres of the brain, is proportionally larger in women than in men (Cahill, 2005; Luders et al., 2006; Smith et al., 2007).

Men and women also may process information differently. For example, in one study, fMRI brain scans of men making judgments discriminating real from false words showed activation of the left hemisphere, of the brain, whereas women used areas on both sides of the brain (Rossell et al., 2002).

From the perspective of . . .

An Office Worker Could personal differences in people's specialization of right and left hemispheres be related to occupational success? For example, might a designer who relies on spatial skills have a different pattern of hemispheric specialization than a paralegal?

The meaning of such sex differences is far from clear. Consider one possibility related to differences in the proportional size of the corpus callosum. Its greater size in women may permit stronger connections to develop between the 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: the reason verbal abilities emerge earlier in girls may be that infant girls receive greater encouragement to talk than do infant boys. In turn, this greater early experience may foster the growth of certain parts of the brain. Hence, physical brain differences may 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 know which of these alternative hypotheses is correct.

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)

People like V.J., whose corpus callosum has been surgically cut to stop seizures and who are 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 operates (Sperry, 1982; Savazzi et al., 2007; Kingstone, 2010).

In one experimental procedure, blindfolded patients touched an object with their right hand and were asked to name it (see Figure 7). Because the right side of the body corresponds to the language-oriented left side of the brain, split-brain patients were able to name it. However, if blindfolded patients touched the object with their left hand, they were unable to name it aloud, even though the information had registered in their brains: when the blindfold was removed, patients could identify the object 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

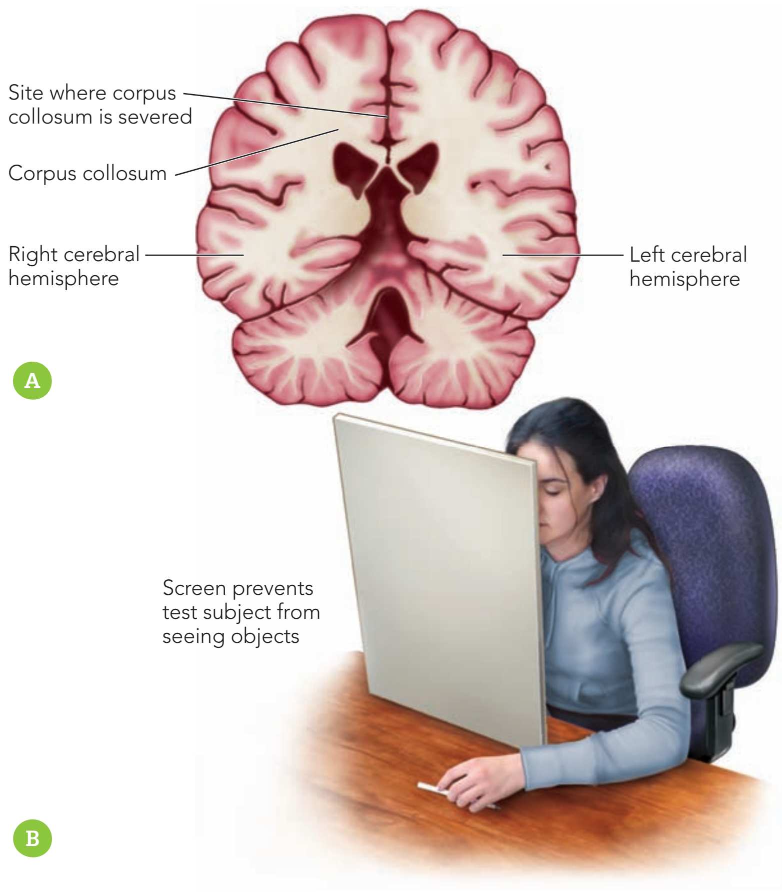
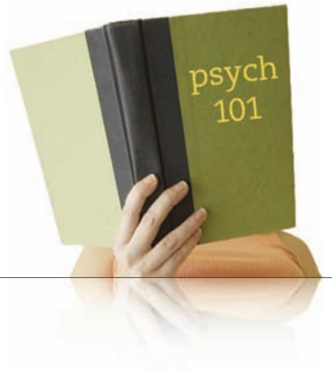


Figure 7 The hemispheres of the brain. (A) The corpus callosum connects the cerebral hemispheres of the brain. (B) A split-brain patient is tested by touching objects behind a screen. Patients could name objects when they touched it with their right hand, but couldn't if they touched with their left hand. If a split-brain patient with her eyes closed was given a pencil to hold and called it a pencil, what hand was the pencil in? (Source: Brooker, Widmaier, Graham, & Stilling, 2008, p. 943.)

hemispheres of a normal brain immediately transfers 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 both hemispheres are capable of understanding, knowing, and being aware of the world, 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. The hemispheres work interdependently to allow the full range and richness of thought of which humans are capable.



BECOMING AN informed consumer OF PSYCHOLOGY

Learning to Control Your Heart—and Mind—through Biofeedback

When Tammy DeMichael was involved in a horrific car accident that broke her neck and crushed her spinal cord, experts told her that she was doomed to be a quadriplegic for the rest of her life, unable to move from the neck down. But they were wrong. Not only did she regain the use of her arms, but she was able to walk 60 feet with a cane (Morrow & Wolff, 1991; Hess et al., 2007; Lofthouse et al., 2011).

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 the constriction of particular muscles.

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 the constriction of particular muscles. Although it traditionally had been thought that the heart rate, respiration rate, blood pressure, and other bodily functions are 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 (Nagai et al., 2004; Cho et al., 2007).

In biofeedback, a person is hooked up to electronic devices that provide continuous feedback relating to the physiological response in question. For instance, someone 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, when she felt a headache starting, she could relax the relevant muscles and abort the pain (Andrasik, 2007; Nestoriuc et al., 2008).

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.

Although the control of physiological processes through the use of biofeedback is not easy, it 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 curvature of the spine) (Morone & Greco, 2007; Reiner, 2008; Ugbolue & Nicol, 2010).

You can get a sense of how biofeedback works in the accompanying Try It!

Try It!

Biofeedback on Your Own

You can demonstrate to yourself how biofeedback works by trying this procedure for raising the temperature of your finger (Brown, 1982; Schwartz & Andrasik, 2005):

First purchase or borrow an ordinary thermometer, about 6 to 8 inches long and filled with red mercury. Tape the bulb end of the thermometer to the pad of your middle finger with masking tape, making sure that it is not so tight that circulation is blocked.

After about five minutes of sitting quietly with your eyes closed, see what the temperature reading is. Then, while still sitting quietly, say these phrases to yourself:

"I feel relaxed and warm."

"My hand feels heavy."

"My arm feels heavy."

My hand feels warm."

My hands feel warm and relaxed."

"I feel calm and relaxed."

Say each of these phrases slowly, and then go through the series again. Every 5 to 10 minutes check your finger temperature.

After 10 or 20 minutes, most people begin to show a rise in finger temperature—some just a few degrees, and some as many as 10 degrees. Do you?

RECAP

Illustrate how 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), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation imaging (TMS). (p. 64)

Describe the central core of the brain.

- The central core of the brain is made up of the medulla (which controls functions such 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 behavior related to basic survival). The functions of the central core structures are similar to those found in other vertebrates. This central core is sometimes referred to as the "old brain." Increasing evidence also suggests that male and female brains may differ in structure in minor ways. (p. 66)

Describe the limbic system of the brain.

- The limbic system, found on the border of the "old" and "new" brains, is associated with eating, aggression, reproduction, and the experiences of pleasure and pain. (p. 68)

Describe the cerebral cortex of the brain.

- 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 areas). (p. 68)

Recognize neuroplasticity and its implications.

- Neuroplasticity refers to changes in the brain relating to the addition of new neurons, new interconnections between neurons, and the reorganization of information-processing areas. (p. 71)

Explain how the two hemispheres of the brain operate interdependently and the implications for human behavior.

- The brain is divided into left and right halves, or hemispheres, each of which generally controls the opposite side of the body. (p. 72)
- The left hemisphere specializes in verbal tasks, such as logical reasoning, speaking, and reading. (p. 75)
- The right side of the brain specializes in nonverbal tasks, such as spatial perception, pattern recognition, and emotional expression. (p. 75)

EVALUATE

Evaluate

1. 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. fMRI	2. Electrodes placed around the skull record the electrical signals transmitted through the brain.
c. PET	3. Provides a three-dimensional view of the brain by aiming a magnetic field at the body.

2. 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.

3. 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.
4. Each hemisphere controls the ___________ side of the body.
5. 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.

RETHINK

Rethink

Before sophisticated brain-scanning techniques were developed, behavioral neuroscientists' understanding of the brain was based largely 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 became possible?

Answers to Evaluate Question 1. a-2, b-3, c-1; 2. a-1, b-3, c-2, d-4; 3. motor; 4. opposite; 5. right, left

KEY TERMS

Central core p. 66

Cerebellum (ser uh BELL um) p. 66

Reticular formation p. 67

Thalamus p. 67

Hypothalamus p. 67

Limbic system p. 68

Cerebral cortex p. 68

Lobes p. 69

Motor area p. 69

Sensory area p. 70

Association areas p. 71

Neuroplasticity p. 71

Hemispheres p. 72

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«« looking BACK

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 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 disease that do not involve the use of fetal tissue. Write a summary of your findings.

the case of . . . THE FALLEN ATHLETE

Since he was a boy, Tim Levesque has always loved sports. From football and basketball in high school through rugby in college, Tim enjoyed the hours of training, the satisfaction of mastering complex plays, and especially the thrill of facing challenging competitors. He remained physically active in the years that followed and spent many evenings and weekends coaching his son Adam's Little League baseball team. He continued to challenge himself to learn new skills, as when he took up bowling and practiced regularly until he was good enough to join a league.

Six months ago, Tim suffered a stroke while he was taking his morning jog. Immediately afterward, much of the right side of Tim's body was paralyzed and he was having great difficulty trying to talk. When Adam saw him in the hospital, he barely recognized his strong, active father now lying weak and incapacitated in a hospital bed. Although his physicians could not give him a clear prognosis, Tim was determined to regain his strength and mobility and fully resume his active lifestyle.

Today Tim has not quite reached his goal, but he has made a remarkable recovery. He is out of the hospital and receiving regular physical therapy. His speech has returned with only occasional difficulty, and he is able to walk and move well enough to return to work. He can't quite manage to roll a 12-pound bowling ball with the ease and accuracy as he previously could, but that doesn't bother him much. What really excites Tim is the ever increasing likelihood that he'll be back to coach Adam's team next season.

1. Is there any evidence to suggest which hemisphere of Tim's brain suffered damage during his stroke?

2. What imaging technology would best reveal the location and extent of damage to Tim's brain produced by his stroke, and why?

3. If physicians did not have any means of viewing the damage to Tim's brain directly, what other clues might they have to the location of the damage? Where might the damage be if Tim had lost his vision after the stroke? Where might it be if he lost sensation on the left side of his body? Where might it be if his personality suddenly changed?

4. Explain how the endocrine system played a role in keeping Tim's body performing optimally whether he was exercising strenuously or relaxing. How might Tim have been able to manipulate his endocrine system function to enhance his athletic performance, if he so chose? What might be some risks of doing so?

5. Describe the brain phenomena that are chiefly responsible for Tim's recovery of lost speech and motor functions. How likely do you think Tim is to completely return to his prestroke level of functioning, and why?

profiles OF SUCCESS

NAME: **Morgan N. Wells, CCMA-AC**

EDUCATION: **Specialized Associates Degree in Medical Assisting, Empire College, Santa Rosa, CA**

POSITION: **Lead Medical Assistant, Sutter Pacific Medical Foundation at the California Pacific Medical Center**

In some ways, the odds did not look good for Morgan Wells. As a teenage mother, she dropped out of high school. And though she eventually returned and graduated and enrolled at a local junior college, without a clear focus and frustrated with the slower pace of her classes, she knew it was not the right place for her.

Then, following a suggestion from a friend, Wells enrolled in Empire College. At Empire she was able to identify a focus in her studies and take advantage of an environment that was suitable to her style of learning.

"At Empire I felt sure that I had chosen the right place," Wells says. "I had guidance as to which classes I should take, rather than having to figure out my entire course load by myself. And, Empire provides job placement for life. Empire helped me find an externship at the office where I still work today. Six years later, I still love to get up and go to work with such a great group of doctors and staff."

Wells describes how her position as a medical assistant gives her the opportunity to participate in a variety of specialized medical procedures.

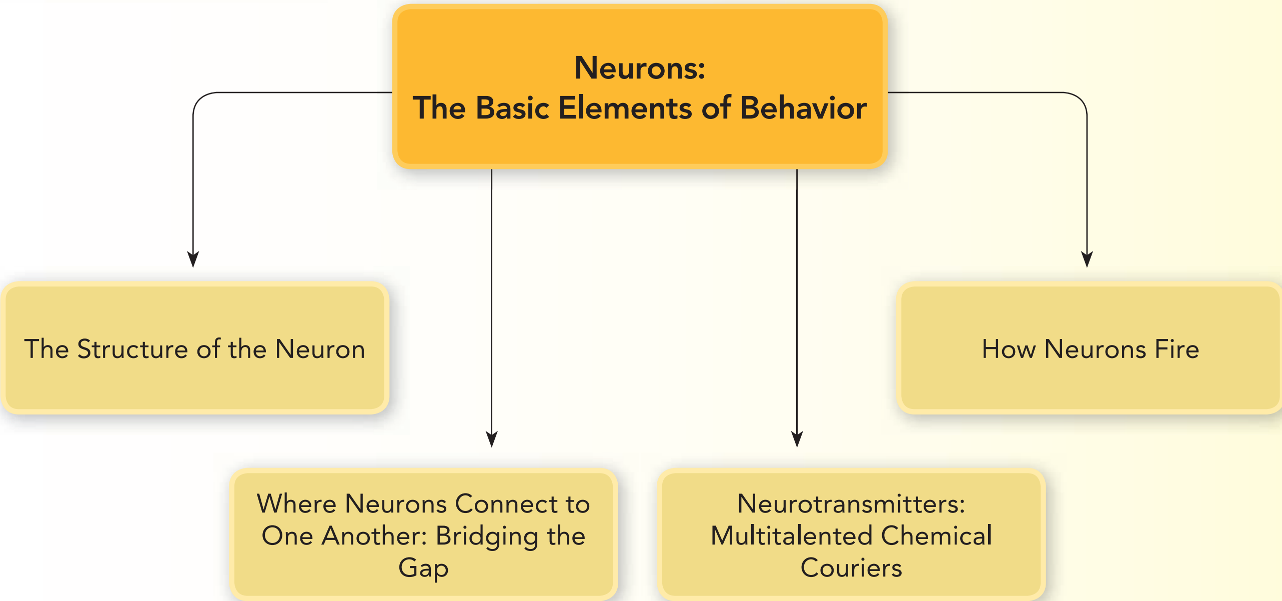
"I work in many specialized areas, like pediatric cardiology, liver transplantation, and the one I enjoy the most, prenatal diagnosis and genetics," she explains. "In prenatal diagnosis, we see pregnant women who desire some form of prenatal testing, and we offer a number of procedures such as amniocentesis and chorionic villus sampling (CVS).

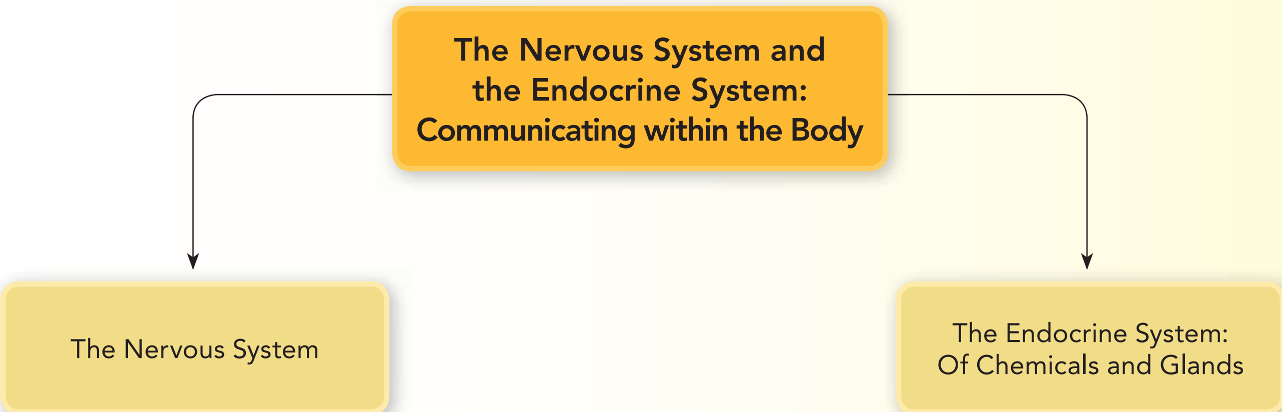
"I also perform EKGs, remove sutures, check vital signs, and do a variety of administrative duties, as well," Wells continues. "I work with an excellent staff and the doctors are always appreciative of my contributions."

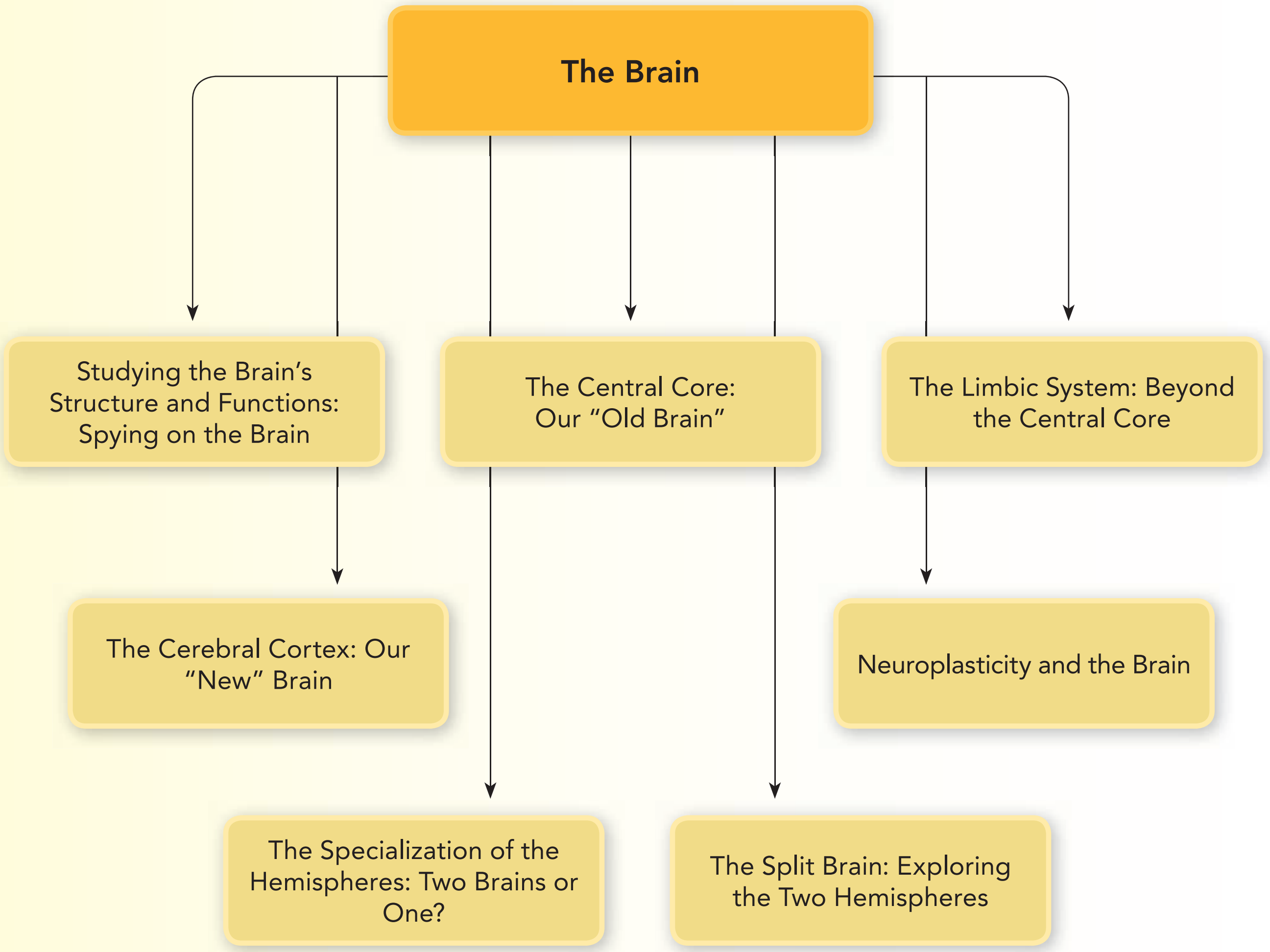
Wells plans to continue to pursue a career in medicine.

"My goal for the future is to further my education and become an RN," she says. "I love helping and caring for patients, and enjoy learning and researching new diagnoses."

full circle NEUROSCIENCE AND BEHAVIOR






The Brain
Studying the Brain's Structure and Functions: Spying on the Brain
The Central Core: Our "Old Brain"
The Limbic System: Beyond the Central Core
The Cerebral Cortex: Our "New" Brain
Neuroplasticity and the Brain
The Specialization of the Hemispheres: Two Brains or One?
The Split Brain: Exploring the Two Hemispheres