3

CHAPTER THREE

Neuroscience and Behavior

TWO PATIENTS WERE ADMITTED TO A hospital emergency room late one evening, complaining of problems with their vision. One patient was a 17-year-old named David, and the other was a 75-year-old named Betty. David saw people who weren't there and Betty didn't recognize her own husband, but these weren't problems with their eyes: They were disorders of their brains.

David was brought in by some fellow members of his gang. They told the doctors that David had become frantic, believing he kept seeing members of a rival gang sneaking up on him. At first David's friends listened to his warnings and searched for their rivals. After repeated scares and false alarms, they decided David had gone crazy. The doctors didn't find any problems with David's eyes. Instead, they discovered he was suffering from hallucinations–a side effect of abusing methamphetamine (McKetin et al., 2006). David's prolonged crystal meth habit altered the normal functioning of some chemicals in his brain, distorting his perception of reality and "fooling" his brain into perceiving things that were not actually there. After he stopped taking the drug, the hallucinations disappeared, and David was back to his normal calm self.

The second patient, Betty, had fainted earlier in the day. After she was revived, Betty no longer recognized her husband, George. She didn't recognize her two sons, either, but she insisted it was just a problem with her eyes and had the family bring her to the emergency room for examination. The doctor who examined Betty's eyes found her vision to be perfectly normal. A brain scan showed that Betty had suffered a stroke that damaged a small area on the right side of her brain. Doctors diagnosed Betty with a rare disorder called *prosopagnosia,* which is an inability to recognize familiar faces (Duchaine et al., 2006; Yin, 1970)—a result of the brain damage caused by her stroke.

David and Betty both complained of problems with their vision, but their symptoms were actually caused by disorders in the brain. David's problem resulted from a malfunction in the brain's system for passing chemical messages between cells. Betty's problem resulted from damage to an area of the brain that integrates and interprets visual information. Our ability to perceive the world around us and recognize familiar people depends not only on information we take in through our senses but, perhaps more importantly, on the interpretation of this information performed by the brain. ■

Betty and David both complained of problems with their vision, but their symptoms were actually caused by disorders in the brain. Brain disorders, whether caused by taking drugs or suffering from a stroke, can produce bizarre and sometimes dangerous distortions of perception.

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Neurons: The Origin of Behavior

Humans have thoughts, feelings, and behaviors that are often accompanied by visible signals. For example, anticipating seeing a friend waiting up the block for you in the movie ticket line may elicit a range of behaviors. An observer might see a smile on your face or notice how fast you are walking; internally, you might mentally rehearse what you'll say to your friend and feel a surge of happiness as you approach her. But all those visible and experiential signs are produced by an underlying invisible physical component coordinated by the activity of your brain cells. The anticipation you have, the happiness you feel, and the speed of your feet are the result of information processing in your brain. In a way, all of your thoughts, feelings, and behaviors spring from cells in the brain that take in information and produce some kind of output.

The cells that perform this function trillions of times a day are called neurons. **Neurons** are *cells in the nervous system that communicate with one another to perform information-processing tasks* (see **FIGURE 3.1**). There are approximately *100 billion* neurons

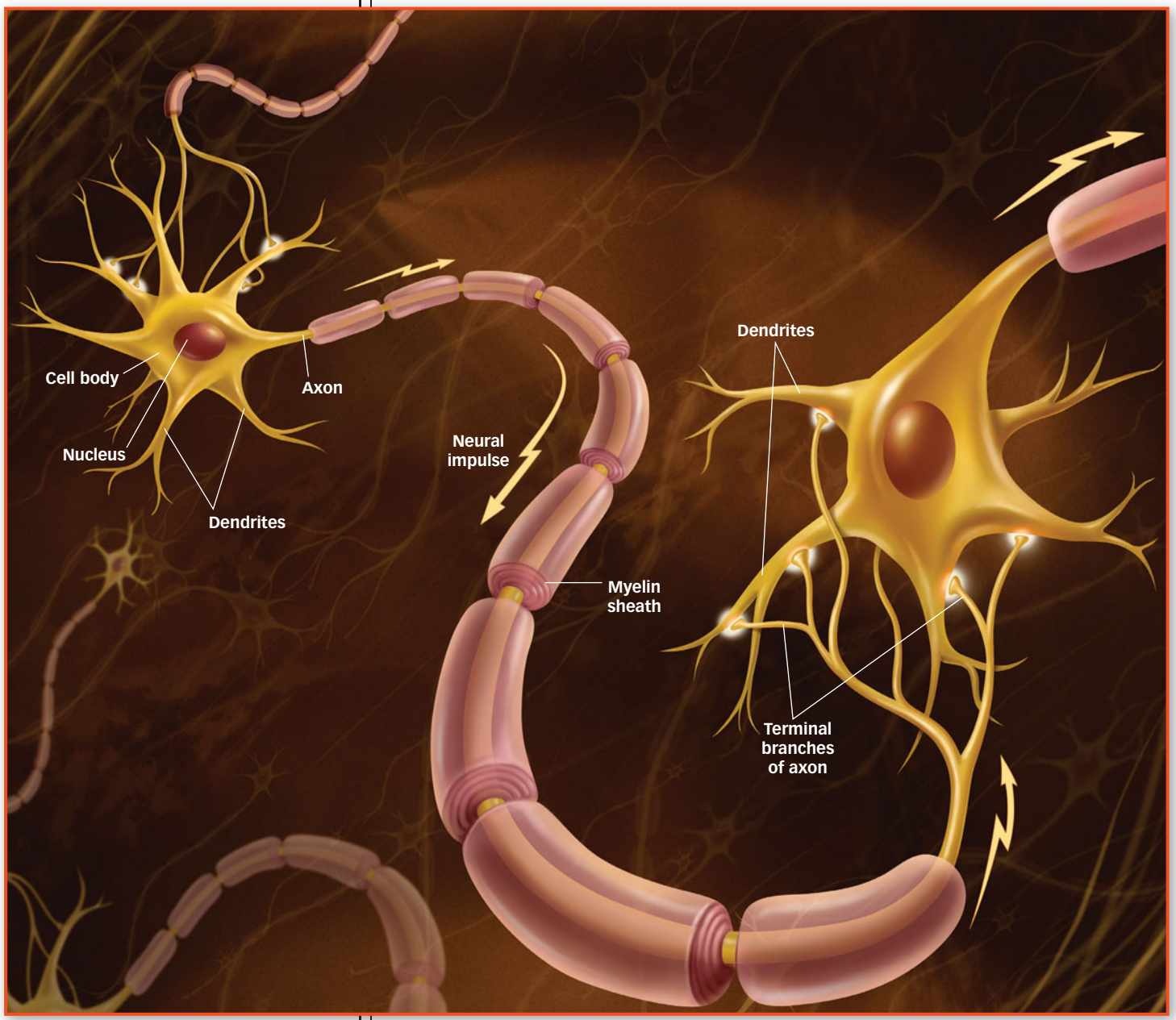


FIGURE 3.1
Components of a Neuron *A neuron is made up of three parts: a cell body that houses the chromosomes with the organism's DNA and maintains the health of the cell, dendrites that receive information from other neurons, and an axon that transmits information to other neurons, muscles, and glands.*

in your brain. To give you a sense of just how big that number is, it's more than five times the estimated 6.5 billion people currently living on Earth. These neurons come in different shapes and sizes, and they perform a variety of tasks that allow you to function as a human being.

Like cells in all organs of the body, neurons have a **cell body** (also called the *soma*), the component of the neuron that *coordinates the information-processing tasks and keeps the cell alive*. Functions such as protein synthesis, energy production, and metabolism take place here. The cell body contains a *nucleus;* this structure houses chromosomes that contain your DNA, the genetic blueprint of who you are. The cell body is surrounded by a porous cell membrane that allows molecules to flow into and out of the cell. Unlike other cells in the body, neurons have two types of specialized extensions of the cell membrane that allow them to communicate: dendrites and axons. **Dendrites** *receive information from other neurons and relay it to the cell body.* The term *dendrite* comes from the Greek word for "tree"; indeed, most neurons have many dendrites that look like tree branches. The **axon** t*ransmits information to other neurons, muscles, or glands*. Each neuron has a single axon that sometimes can be very long, even stretching up to a meter from the base of the spinal cord down to the big toe.

In addition to the 100 billion neurons processing information in your brain, there are 10 to 50 times as many **glial cells**, which are *support cells found in the nervous system*. Some glial cells digest parts of dead neurons; others provide physical and nutritional support for neurons. Some glial cells form **myelin sheaths**, *insulating layers of fatty material around the axons of some neurons*. Axons insulated with myelin can more efficiently transmit signals to other neurons, organs, or muscles.

In fact, in *demyelinating diseases,* such as multiple sclerosis, the myelin sheath deteriorates, causing a slowdown in the transmission of information from one neuron to another (Schwartz & Westbrook, 2000). This condition leads to a variety of problems, including loss of feeling in the limbs, partial blindness, and difficulties in coordinated movement. Multiple sclerosis often entails cycles of myelin loss and subsequent recovery.

Although neurons look like they form a continuously connected lattice in the brain, the dendrites and axons of neurons do not actually touch each other. There's a small gap between the axon of one neuron and the dendrites or cell body of another. This gap is part of the **synapse:** *the junction or region between the axon of one neuron and the dendrites or cell body of another* (see **FIGURE 3.2** on the next page). Many of the 100 billion neurons in your brain have a few thousand synaptic junctions, so most adults have between 100 trillion and 500 trillion synapses. As you'll read shortly, the transmission of information across the synapse is fundamental to communication between neurons, a process that allows us to think, feel, and behave.

How do the three types of neurons work together to transmit information?

There are three major types of neurons, each performing a distinct function: sensory neurons, motor neurons, and interneurons. **Sensory neurons** *receive information from the external world and convey this information to the brain via the spinal cord*. Sensory neurons have specialized endings on their dendrites that receive signals for light, sound, touch, taste, and smell. For example, in our eyes, sensory neurons' endings are sensitive to light. **Motor neurons** *carry signals from the spinal cord to the muscles to produce movement*. These neurons often have long axons that can stretch to muscles at our extremities. However, most of the nervous system is composed of the third type of neuron, **interneurons**, which *connect sensory neurons, motor neurons, or other interneurons*. Some interneurons carry information from sensory neurons into the nervous system, others carry information from the nervous system to motor neurons, and still others perform a variety of information-processing functions within the nervous system. Interneurons work together in small circuits to perform simple tasks, such as identifying the location of a sensory signal, and much more complicated ones, such as recognizing a familiar face.)

neurons Cells in the nervous system that communicate with one another to perform information-processing tasks.

cell body The part of a neuron that coordinates information-processing tasks and keeps the cell alive.

dendrites The part of a neuron that receives information from other neurons and relays it to the cell body.

axon The part of a neuron that transmits information to other neurons, muscles, or glands.

myelin sheath An insulating layer of fatty material.

glial cells Support cells found in the nervous system.

synapse The junction or region between the axon of one neuron and the dendrites or cell body of another.

sensory neurons Neurons that receive information from the external world and convey this information to the brain via the spinal cord.

motor neurons Neurons that carry signals from the spinal cord to the muscles to produce movement.

interneurons Neurons that connect sensory neurons, motor neurons, or other interneurons.

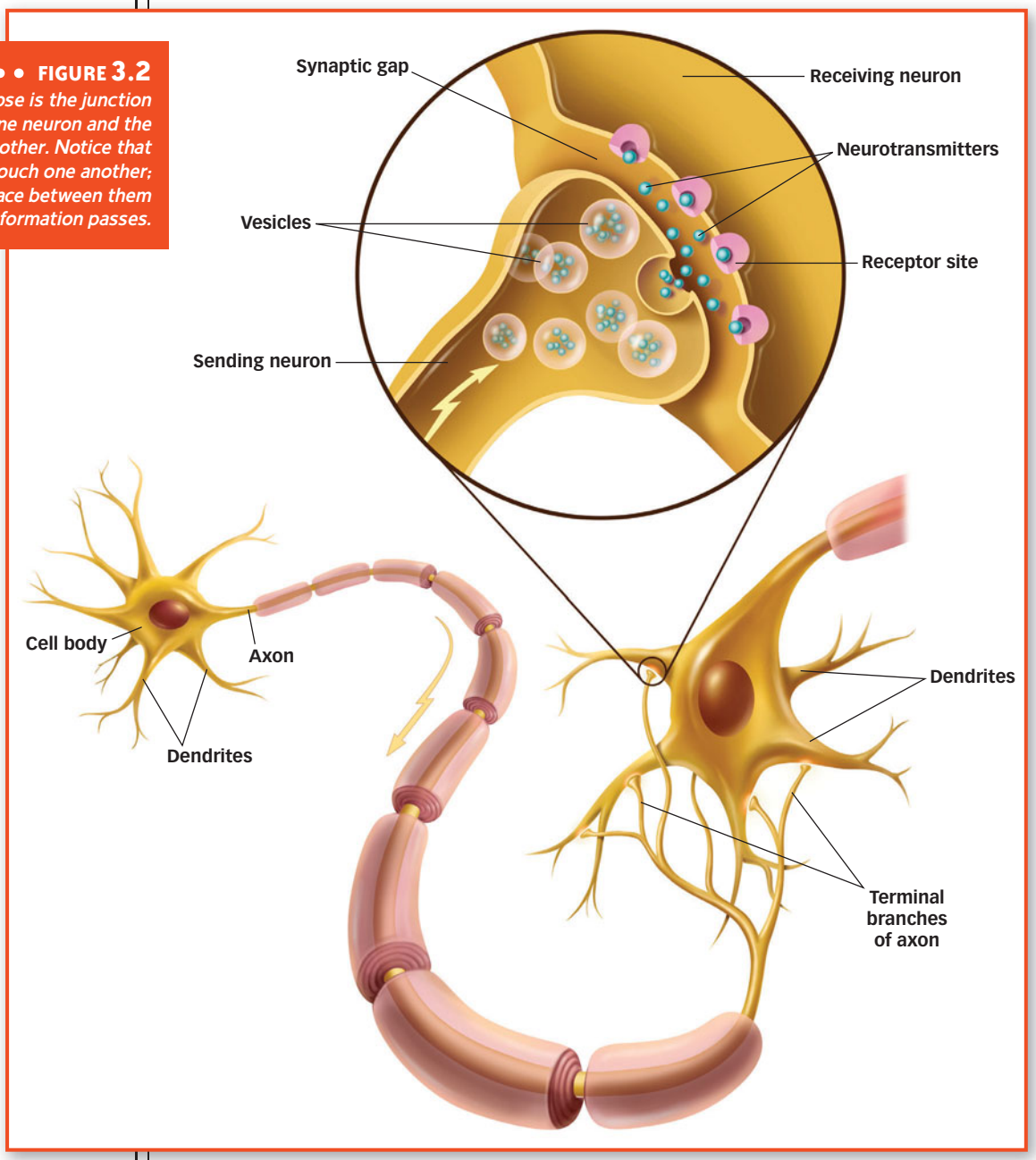


FIGURE 3.2
The Synapse *The synapse is the junction between the dendrites of one neuron and the axon or cell body of another. Notice that neurons do not actually touch one another; there is a small synaptic space between them across which information passes.*

Electric Signaling: Communicating Information within a Neuron

Understanding how neurons process information is key to appreciating how the brain works—that is, how these tiny cells make it possible for us to think, feel, and act. The communication of information within and between neurons proceeds in two stages—*conduction* and *transmission*. The first stage is the conduction of an electric signal over relatively long distances within neurons, from the dendrites to the cell body, then throughout the axon. The second stage is the transmission of chemical signals between neurons over the synapse.

The neuron's cell membrane is porous: It allows small electrically charged molecules, called *ions,* to flow in and out of the cell. The idea is similar to using a strainer while you're preparing spaghetti: The pasta is trapped inside but small particles of water can still seep in and out of it. Similarly, the neuron's cell membrane has small channels that allow different ions to flow in and out. When the neuron is at rest, the channels that allow small, positively charged potassium ions (K^+) to pass are open; channels that

resting potential The difference in electric charge between the inside and outside of a neuron's cell membrane.

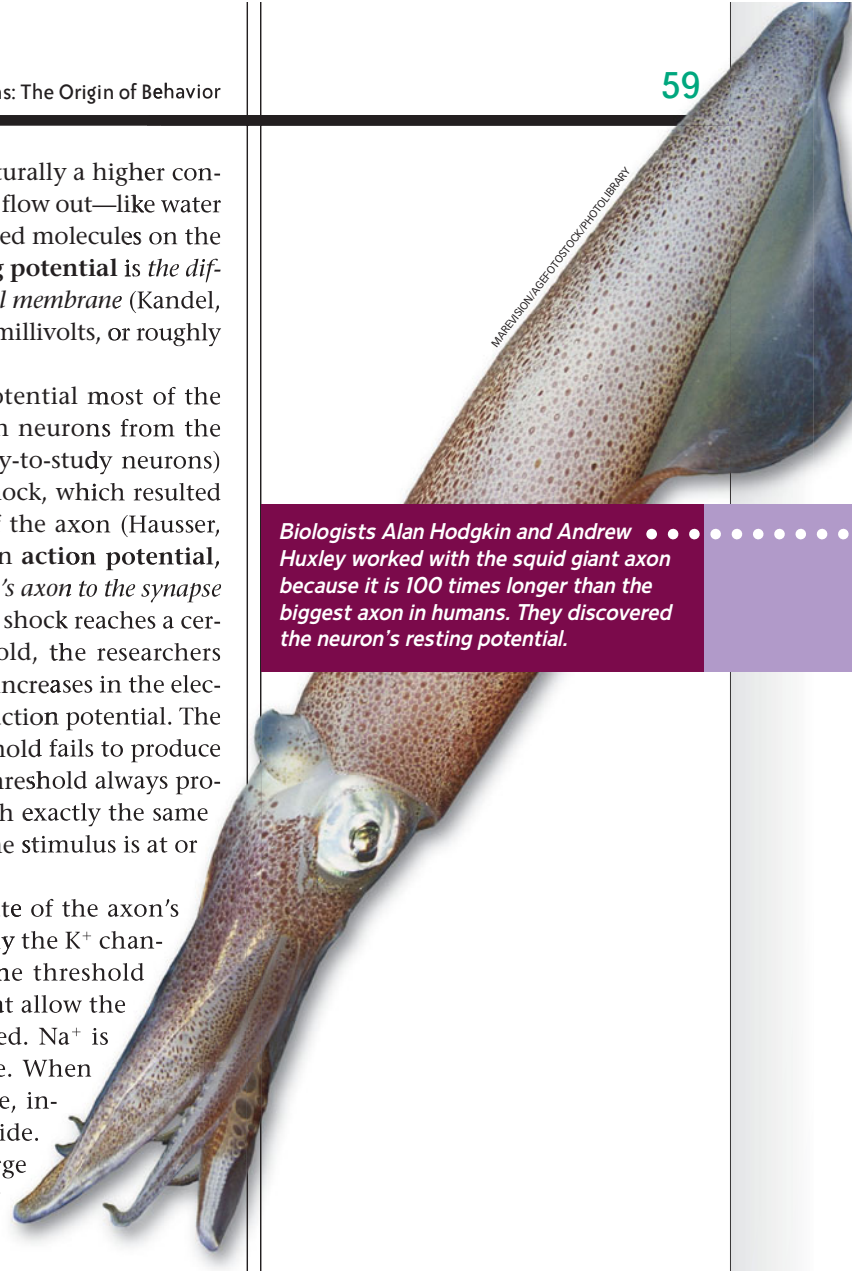
action potential An electric signal that is conducted along an axon to a synapse.

allow the flow of other molecules are normally closed. There is naturally a higher concentration of potassium ions *inside* the neuron, and so some K^+ ions flow out—like water out of a strainer. This leaves the neuron with fewer positively charged molecules on the inside relative to the outside. This natural electric charge or **resting potential** is *the difference in electric charge between the inside and outside of a neuron's cell membrane* (Kandel, 2000). The resting potential is about –70 millivolts, or roughly 1/200 of the charge of an AA battery.

Why is an action potential an all-or-nothing event?

The neuron maintains its resting potential most of the time. However, biologists working with neurons from the squid (which has particularly large, easy-to-study neurons) noticed that they could stimulate the axon with a brief electric shock, which resulted in the conduction of a large electric impulse down the length of the axon (Hausser, 2000; Hodgkin & Huxley, 1939). This electric impulse is called an **action potential**, which is *an electric signal that is conducted along the length of a neuron's axon to the synapse* (see **FIGURE 3.3**). The action potential occurs only when the electric shock reaches a certain level, or *threshold*. When the shock was below this threshold, the researchers recorded only tiny signals, which dissipated rapidly. Interestingly, increases in the electric shock above the threshold did *not* increase the strength of the action potential. The action potential is *all or none*: Electric stimulation below the threshold fails to produce an action potential, whereas electric stimulation at or above the threshold always produces the action potential. The action potential always occurs with exactly the same characteristics and at the same magnitude regardless of whether the stimulus is at or above the threshold.

The action potential occurs when there is a change in the state of the axon's membrane channels. Remember, during the resting potential, only the K^+ channels are open. However, when an electric charge is raised to the threshold value, the K^+ channels briefly shut down, and other channels that allow the flow of another positively charged ion, sodium (Na^+), are opened. Na^+ is typically much more concentrated outside the axon than inside. When the Na^+ channels open, those positively charged ions flow inside, increasing the positive charge inside the axon relative to that outside. This flow of Na^+ into the axon pushes the neuron's electrical charge all the way from its resting potential of –70 millivolts all the way to +40 millivolts.



Biologists Alan Hodgkin and Andrew Huxley worked with the squid giant axon because it is 100 times longer than the biggest axon in humans. They discovered the neuron's resting potential.

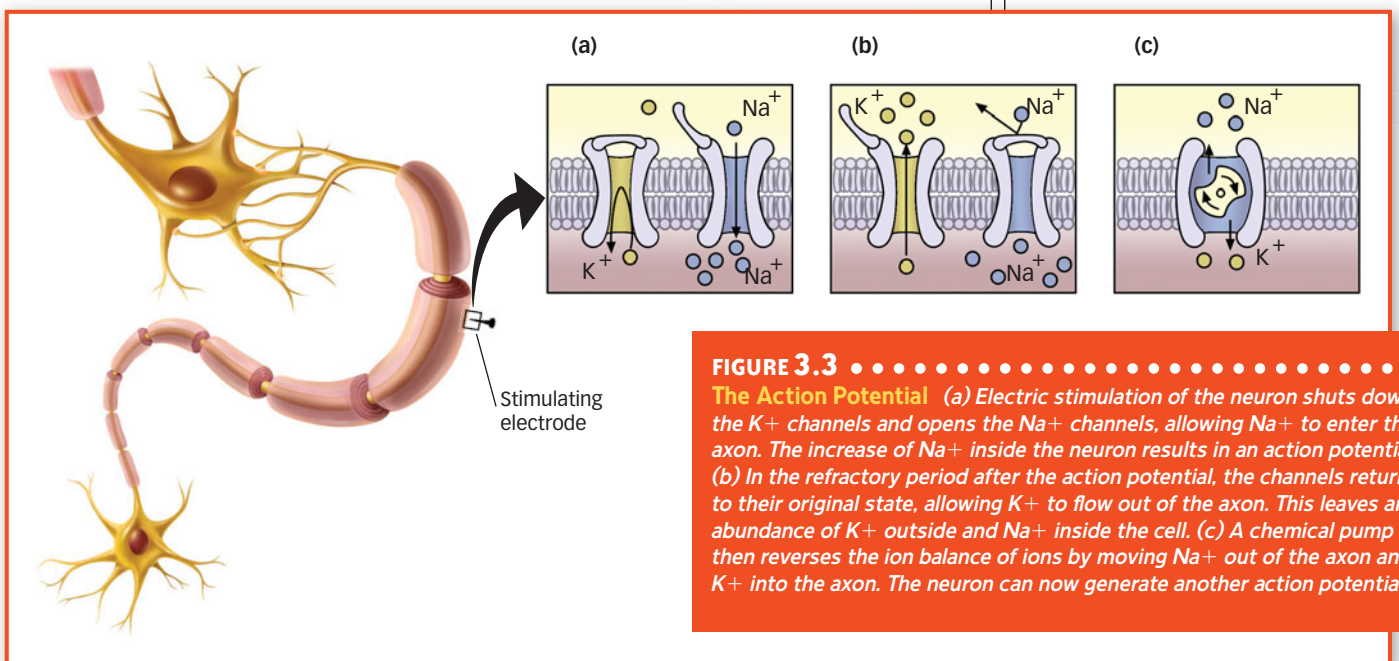


FIGURE 3.3 **The Action Potential** *(a) Electric stimulation of the neuron shuts down the K+ channels and opens the Na+ channels, allowing Na+ to enter the axon. The increase of Na+ inside the neuron results in an action potential. (b) In the refractory period after the action potential, the channels return to their original state, allowing K+ to flow out of the axon. This leaves an abundance of K+ outside and Na+ inside the cell. (c) A chemical pump then reverses the ion balance of ions by moving Na+ out of the axon and K+ into the axon. The neuron can now generate another action potential.*

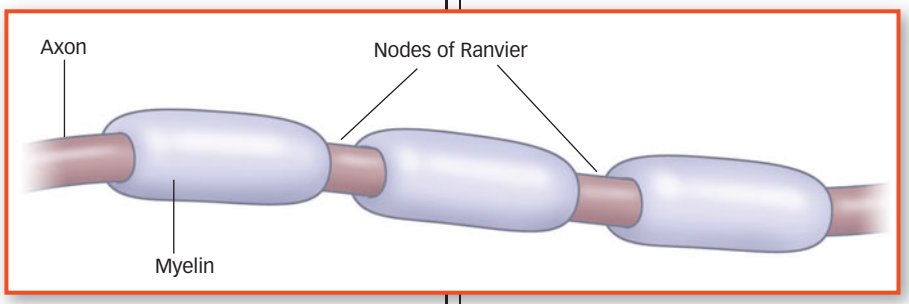


FIGURE 3.4
Myelin and Nodes of Ranvier *Myelin is formed by a type of glial cell, and it wraps around a neuron's axon to speed the transmission of the action potential along the length of the axon. Breaks in the myelin sheath are called the nodes of Ranvier. The electric impulse jumps from node to node, thereby speeding the conduction of information down the axon.*

When an action potential is generated at the beginning of the axon, it spreads a short distance, which generates an action potential at a nearby location on the axon (see Figure 3.5). That action potential also spreads, initiating an action potential at another nearby location, and so on, thus transmitting the charge down the length of the axon. This simple mechanism ensures that the action potential travels the full length of the axon and that it achieves its full intensity at each step, regardless of the distance traveled.

The myelin sheath, which is made up of glial cells that coat and insulate the axon, facilitates the transmission of the action potential. Myelin doesn't cover the entire axon; rather, it clumps around the axon with little break points between clumps, looking kind of like sausage links. These breakpoints are called the *nodes of Ranvier*, after French pathologist Louis-Antoine Ranvier, who discovered them (see **FIGURE 3.4**). When an electric current passes down the length of a myelinated axon, the charge "jumps" from node to node rather than having to traverse the entire axon. This jumping helps speed the flow of information down the axon.

After the action potential reaches its maximum, the membrane channels return to their original state, and K^+ flows out until the axon returns to its resting potential. This leaves a lot of extra Na^+ ions inside the axon and a lot of extra K^+ ions outside the axon. During this period where the ions are imbalanced, the neuron cannot initiate another action potential, so it is said to be in a **refractory period**, *the time following an action potential during which a new action potential cannot be initiated*. The imbalance in ions eventually is reversed by an active chemical "pump" in the cell membrane that moves Na^+ outside the axon and moves K^+ inside the axon.

Chemical Signaling: Synaptic Transmission between Neurons

When the action potential reaches the end of an axon, the electric charge of the action potential takes a form that can cross the relatively small synaptic gap by relying on a bit of chemistry. Axons usually end in **terminal buttons**, *which are knoblike structures that branch out from an axon*. When the action potential reaches the terminal button, it stimulates the release of **neurotransmitters**, *chemicals that transmit information across the synapse to a receiving neuron's dendrites*. These neurotransmitters float across the synapse and bind to sites on the dendrites of the receiving neuron called **receptors**, *parts of the cell membrane that receive neurotransmitters and initiate a new electric signal*. Just as a particular key will only fit in a particular lock, so too will only some neurotransmitters bind to specific receptor sites on a dendrite. The molecular structure of the neurotransmitter must "fit" the molecular structure of the receptor site. Activation of receptors on the receiving neuron, or *postsynaptic neuron*, can cause a new electric potential to be initiated in that neuron, and the process continues down that neuron's axon to the next synapse and the next neuron. This electrochemical action, called *synaptic transmission*, allows neurons to communicate with one another and ultimately underlies your thoughts, emotions, and behavior (see **FIGURE 3.5**).

How does a neuron communicate with another neuron?

Neurotransmitters left in the synapse after the chemical message is relayed to the postsynaptic neuron have to be cleared up; otherwise, there would be no end to the signals that they send. Neurotransmitters leave the synapse through three processes. First, *reuptake* occurs when neurotransmitters are reabsorbed by the terminal buttons of the presynaptic neuron's axon. Second, neurotransmitters can be destroyed by enzymes in the synapse in a process called *enzyme deactivation*; specific enzymes break down specific neurotransmitters. Finally, neurotransmitters can bind to the receptor sites

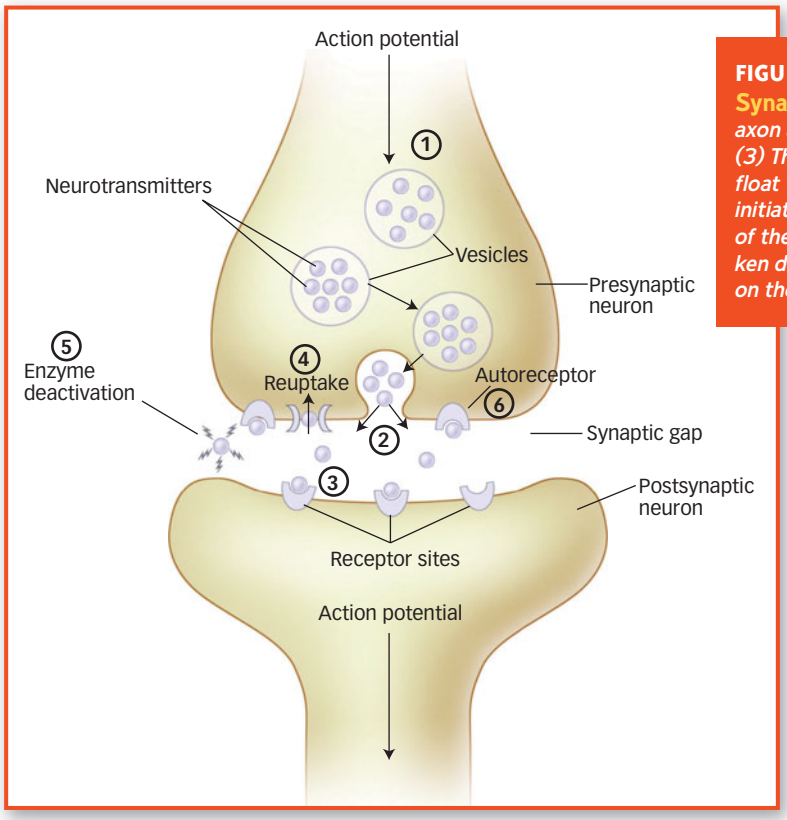


FIGURE 3.5
Synaptic Transmission *(1) The action potential travels down the axon and (2) stimulates the release of neurotransmitters from vesicles. (3) The neurotransmitters are released into the synapse, where they float to bind with receptor sites on a dendrite of a postsynaptic neuron, initiating a new action potential. The neurotransmitters are cleared out of the synapse by (4) reuptake into the sending neuron, (5) being broken down by enzymes in the synapse, or (6) binding to autoreceptors on the sending neuron.*

called *autoreceptors* on the presynaptic neurons. Autoreceptors detect how much of a neurotransmitter has been released into a synapse and signal the neuron to stop releasing the neurotransmitter when an excess is present.

Types of Neurotransmitters

Given that different kinds of neurotransmitters can activate different kinds of receptors, like a lock and key, you might wonder how many types of neurotransmitters are floating across synapses in your brain right now. Today, we know that some 60 chemicals play a role in transmitting information throughout the brain and body, each differently affecting thought, feeling, and behavior. But a few major classes seem particularly important. We'll summarize those here, and you'll meet some of these neurotransmitters again, in later chapters.

- **Acetylcholine (Ach)**, *a neurotransmitter involved in a number of functions, including voluntary motor control*, was one of the first neurotransmitters discovered. Acetylcholine is found in neurons of the brain and in the synapses where axons connect to muscles and body organs, such as the heart. Acetylcholine activates muscles to initiate motor behavior, but it also contributes to the regulation of attention, learning, sleeping, dreaming, and memory (Gais & Born, 2004; Hasselmo, 2006; Wrenn et al., 2006). Alzheimer's disease, a medical condition involving severe memory impairments, is associated with the deterioration of Ach-producing neurons.
- **Dopamine** is *a neurotransmitter that regulates motor behavior, motivation, pleasure, and emotional arousal*. Because of its role in basic motivated behaviors, such as seeking pleasure or associating actions with rewards, dopamine plays a role in drug addiction (Baler & Volkow, 2006). High levels of dopamine have been linked to schizophrenia (Winterer & Weinberger, 2004), while low levels have been linked to Parkinson's disease.

refractory period The time following an action potential during which a new action potential cannot be initiated.

terminal buttons Knoblike structures that branch out from an axon.

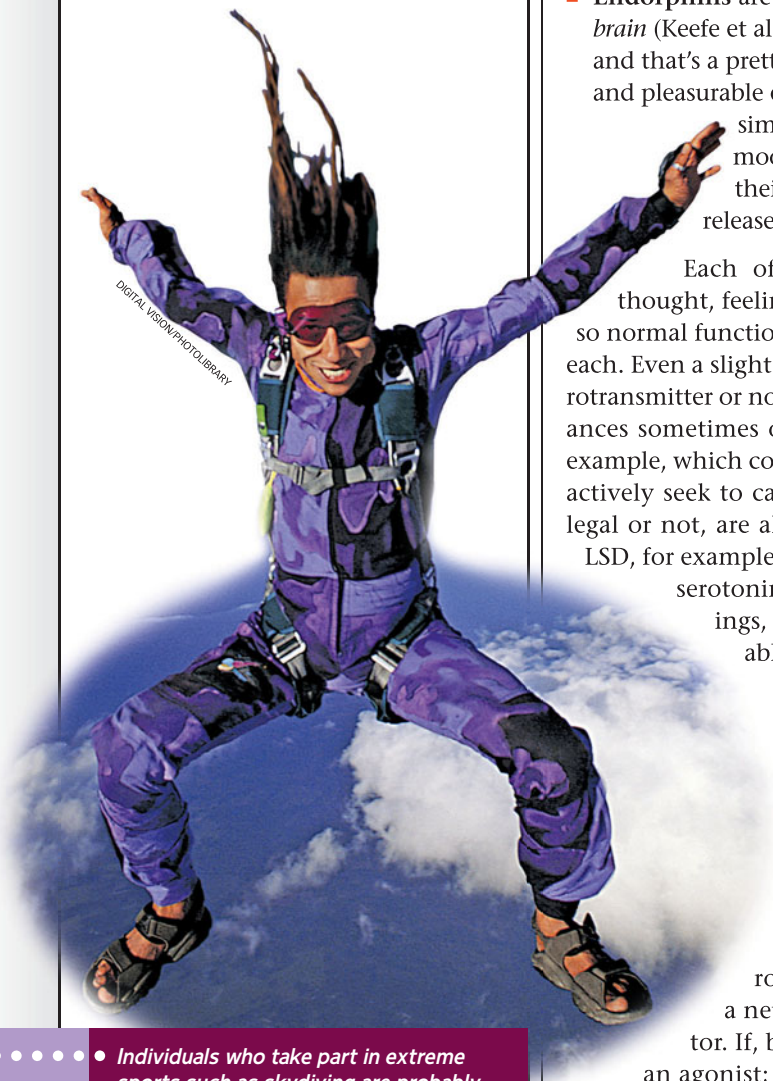
neurotransmitters Chemicals that transmit information across the synapse to a receiving neuron's dendrites.

receptors Parts of the cell membrane that receive the neurotransmitter and initiate a new electric signal.

- **Glutamate** is *a major excitatory neurotransmitter involved in information transmission throughout the brain*. This means that glutamate enhances the transmission of information. Too much glutamate can overstimulate the brain, causing seizures. **GABA (gamma-aminobutyric acid)**, in contrast, is *the primary inhibitory neurotransmitter in the brain*. Inhibitory neurotransmitters stop the firing of neurons, an activity that also contributes to the function of the organism. Too little GABA, just like too much glutamate, can cause neurons to become overactive, causing seizures.
- **Norepinephrine**, *a neurotransmitter that influences mood and arousal*, is particularly involved in states of vigilance, or a heightened awareness of dangers in the environment (Ressler & Nemeroff, 1999). Another neurotransmitter, **serotonin** is *involved in the regulation of sleep and wakefulness, eating, and aggressive behavior* (Kroeze & Roth, 1998). Because both of these neurotransmitters affect mood and arousal, low levels of each have been implicated in mood disorders (Tamminga et al., 2002).
- **Endorphins** are *chemicals that act within the pain pathways and emotion centers of the brain* (Keefe et al., 2001). The term *endorphin* is a contraction of *end*ogenous m*orphine*, and that's a pretty apt description. Morphine is a synthetic drug that has a calming and pleasurable effect; an endorphin is an internally produced substance that has similar properties, such as dulling the experience of pain and elevating moods. The "runner's high" experienced by many athletes as they push their bodies to painful limits of endurance can be explained by the release of endorphins in the brain.

How do neurotransmitters create the feeling of a "runner's high"?

Each of these neurotransmitters affects thought, feeling, and behavior in different ways, so normal functioning involves a delicate balance of each. Even a slight imbalance—too much of one neurotransmitter or not enough of another—can dramatically affect behavior. These imbalances sometimes occur naturally. The brain doesn't produce enough serotonin, for example, which contributes to depressed or anxious moods. Other times a person may actively seek to cause imbalances. People who smoke, drink alcohol, or take drugs, legal or not, are altering the balance of neurotransmitters in their brains. The drug LSD, for example, is structurally very similar to serotonin, so it binds very easily with serotonin receptors in the brain, producing similar effects on thoughts, feelings, or behavior. In the next section, we'll look at how some drugs are able to "trick" receptor sites in just this way.



Individuals who take part in extreme sports such as skydiving are probably seeking the kind of pleasurable effect associated with the release of endorphins. Individuals who avoid such sports, such as your textbook authors, take considerable pleasure from remaining in contact with Mother Earth.

How Drugs Mimic Neurotransmitters

Many drugs that affect the nervous system operate by increasing, interfering with, or mimicking the manufacture or function of neurotransmitters (Cooper, Bloom, & Roth, 2003; Sarter, 2006). *Agonists* are drugs that increase the action of a neurotransmitter. *Antagonists* are drugs that block the function of a neurotransmitter. Some drugs alter a step in the production or release of the neurotransmitter, whereas others have a chemical structure so similar to a neurotransmitter that the drug is able to bind to that neuron's receptor. If, by binding to a receptor, a drug activates the neurotransmitter, it is an agonist; if it blocks the action of the neurotransmitter, it is an antagonist. For example, Parkinson's disease is a movement disorder characterized by tremors and difficulty initiating movement, and it is caused by the loss of neurons that produce the neurotransmitter dopamine. Dopamine is created in neurons by a modification of a common molecule called L-dopa. Ingesting L-dopa will elevate the amount of L-dopa in the brain and spur the surviving neurons to produce more dopamine. In other words, L-dopa acts as an agonist for dopamine. The use of L-dopa has become a major success in alleviating Parkinson's disease symptoms (Muenter & Tyce, 1971).

Some unexpected evidence also highlights the central role of dopamine in regulating movement and motor performance. In 1982, six people ranging in age from 25 to 45 from the San Francisco Bay Area were admitted to emergency rooms with a bizarre set of symptoms: paralysis, drooling, and an inability to speak (Langston, 1995). A diagnosis of advanced Parkinson's disease was made, as these symptoms are consistent with the later stages of this degenerative disease. It was unusual for six fairly young people to come down with advanced Parkinson's at the same time in the same geographic area. Indeed, none of the patients had Parkinson's, but they were all heroin addicts.

How does giving patients L-dopa alleviate symptoms of Parkinson's disease?

These patients thought they were ingesting a synthetic form of heroin (called MPPP), but instead they ingested a close derivative called MPTP, which unfortunately had the effects of destroying dopamine-producing neurons in an area of the brain crucial for motor performance. Hence, these "frozen addicts" exhibited paralysis and masklike expressions. The patients experienced a remarkable recovery after they were given L-dopa. Just as L-dopa acts as an agonist by enhancing the production of dopamine, drugs such as MPTP act as antagonists by destroying dopamine-producing neurons.

Like MPTP, other street drugs can alter neurotransmitter function. Amphetamine, for example, is a popular drug that stimulates the release of norepinephrine and dopamine and also prevents the reuptake of norepinephrine and dopamine. The result is to flood the synapse with those neurotransmitters, resulting in increased activation of their receptors. Thus, it is a strong agonist. Cocaine acts through similar mechanisms to amphetamine, although the psychological effects of the two drugs differ somewhat because of subtle distinctions in where and how they act on the brain. Norepinephrine and dopamine play a critical role in mood control, such that increases in either neurotransmitter result in euphoria, wakefulness, and a burst of energy. However, norepinephrine also increases heart rate. An overdose of amphetamine or cocaine can cause the heart to contract so rapidly that heartbeats do not last long enough to pump blood effectively, leading to fainting and sometimes to death.

Prozac, a drug commonly used to treat depression, is another example of a neurotransmitter agonist. Prozac blocks the reuptake of the neurotransmitter serotonin, making it part of a category of drugs called *selective serotonin reuptake inhibitors*, or *SSRIs* (Wong, Bymaster, & Engelman, 1995). Patients suffering from clinical depression typically have reduced levels of serotonin in their brains. By blocking reuptake, more of the neurotransmitter remains in the synapse longer and produces greater activation of serotonin receptors. Serotonin elevates mood, which can help relieve depression.

As you've read, many drugs alter the actions of neurotransmitters. Think back to David, whom you met at the beginning of this chapter: His paranoid hallucinations were induced by his crystal meth habit. The actions of methamphetamine involve a complex interaction at the neuron's synapses—it affects pathways for dopamine, serotonin, and norepinephrine—making it difficult to interpret exactly how it works. But the combination of its agonist and antagonist effects alters the functions of neurotransmitters that help us perceive and interpret visual images. In David's case, it led to hallucinations that called his eyesight, and his sanity, into question.

summary quiz [3.1]

1. The gap between the axon of one neuron and the dendrites of another is called the
   a. glial cell.
   b. interneuron.
   c. myelin sheath.
   d. synapse.

2. The neurons that receive information from the external world and convey this information to the brain are called
   a. sensory neurons.
   b. motor neurons.
   c. interneurons.
   d. glial cells.

3. An action potential occurs when an electric charge causes
   a. potassium ions to flow into the neuron.
   b. potassium ions to flow out of the neuron.
   c. sodium ions to flow into the neuron.
   d. sodium ions to flow out of the neuron.

4. One way to clear up an overflow of neurotransmitters in the synapse is reabsortion of the excess by the terminal buttons of the presynaptic neuron's axon. This process is called
   a. enzyme deactivation.
   b. uptake.
   c. autoreceptor action.
   d. agonistic action.

5. Depression is often treated by a class of drugs that inhibits the reuptake of which neurotransmitter?
   a. serotonin
   b. endorphins
   c. glutamate
   d. GABA

The Organization of the Nervous System

nervous system An interacting network of neurons that conveys electrochemical information throughout the body.

central nervous system (CNS) The part of the nervous system that is composed of the brain and spinal cord.

peripheral nervous system (PNS) The part of the nervous system that connects the central nervous system to the body's organs and muscles.

somatic nervous system A set of nerves that conveys information into and out of the central nervous system.

autonomic nervous system (ANS) A set of nerves that carries involuntary and automatic commands that control blood vessels, body organs, and glands.

sympathetic nervous system A set of nerves that prepares the body for action in threatening situations.

parasympathetic nervous system A set of nerves that helps the body return to a normal resting state.

Neurons work by forming circuits and pathways in the brain, which in turn influence circuits and pathways in other areas of the body. Without this kind of organization and delegation, neurons would be churning away with little purpose. Neurons are the building blocks that form *nerves*, or bundles of axons and the glial cells that support them. The **nervous system** *is an interacting network of neurons that conveys electrochemical information throughout the body*. In this section, we'll look at the major divisions of the nervous system, focusing particularly on structures in the brain and their specific functions.

Divisions of the Nervous System

There are two major divisions of the nervous system: the central nervous system and the peripheral nervous system (see **FIGURE 3.6** on the following page). The **central nervous system (CNS)** is *composed of the brain and spinal cord*. The central nervous system receives sensory information from the external world, processes and coordinates this information, and sends commands to the skeletal and muscular systems for action.

The **peripheral nervous system (PNS)** *connects the central nervous system to the body's organs and muscles*. The peripheral nervous system is itself composed of two major subdivisions, the somatic nervous system and the autonomic nervous system. The **somatic nervous system** is *a set of nerves that conveys information into and out of the central nervous system*. Humans have conscious control over this system and use it to perceive, think, and coordinate their behaviors. For example, directing your hand to reach out and pick

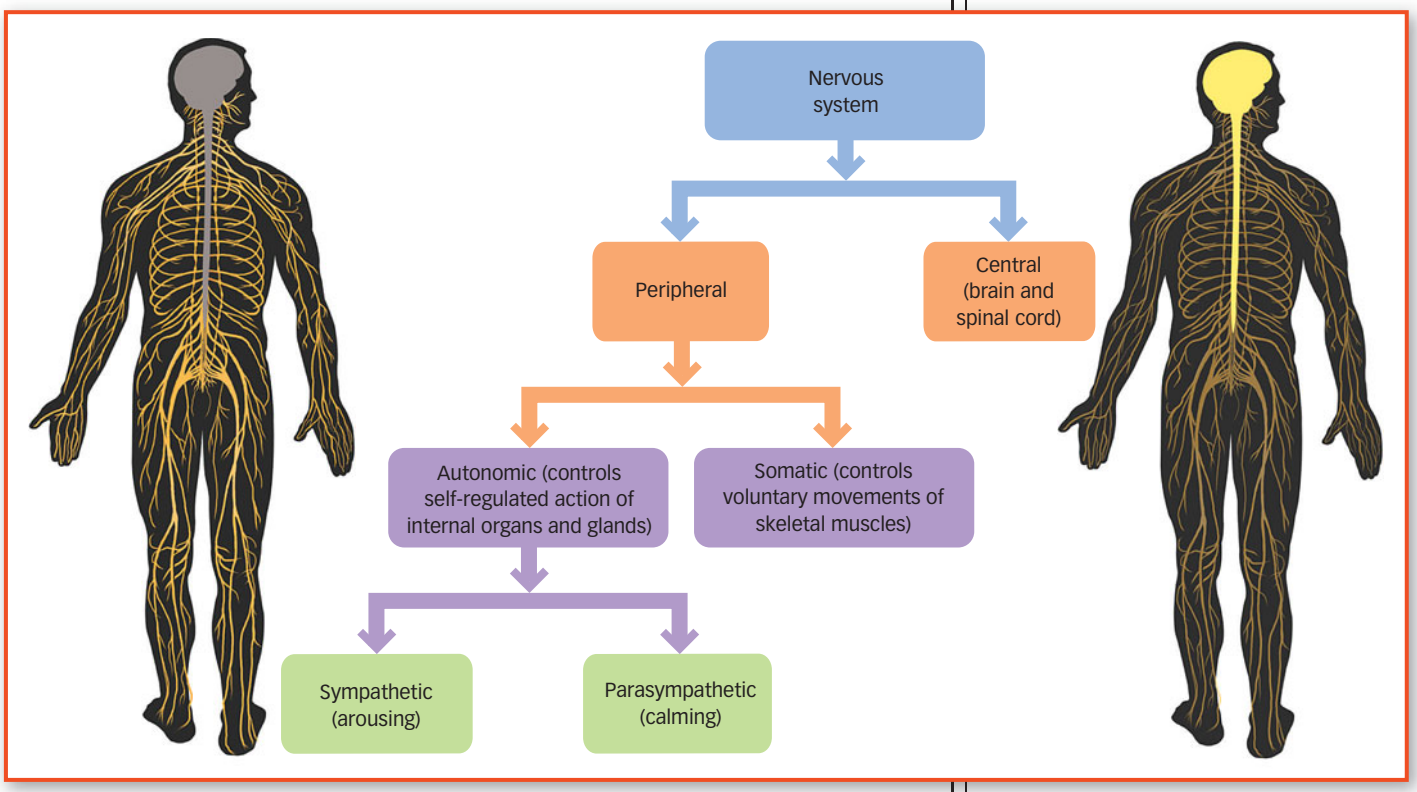


FIGURE 3.6
The Human Nervous System *The nervous system is organized into the peripheral and central nervous systems. The peripheral nervous system is further divided into the automatic and somatic nervous systems.*

up a coffee cup involves the elegantly orchestrated activities of the somatic nervous system: Information from the receptors in your eyes travels to your brain, registering that a cup is on the table; signals from your brain travel to the muscles in your arm and hand; feedback from those muscles tells your brain that the cup has been grasped; and so on.

In contrast, the **autonomic nervous system (ANS)** is *a set of nerves that carries involuntary and automatic commands that control blood vessels, body organs, and glands*. As suggested by its name, this system works on its own to regulate bodily systems, largely outside conscious control. The ANS has two major subdivisions, which each exerts a different type of control on the body. The **sympathetic nervous system** is *a set of nerves that prepares the body for action in threatening situations* (see **FIGURE 3.7** on the next page).

When danger threatens, your sympathetic nervous system kicks into action: It dilates your pupils to let in more light, increases your heart rate and respiration to pump more oxygen to muscles, diverts blood flow to your brain and muscles, and activates sweat glands to cool your body. To conserve energy, the sympathetic nervous system inhibits salivation and bowel movements, suppresses the body's immune responses, and suppresses responses to pain and injury. The sum total of these fast, automatic responses is that they increase the likelihood that you can escape from or fight off the threat.

What triggers the increase in your heart rate when you feel threatened?

The **parasympathetic nervous system** *helps the body return to a normal resting state*. Once the threat has been eliminated or avoided, your body doesn't need to remain on red alert. Now the parasympathetic nervous system kicks in to reverse the effects of the sympathetic nervous system and return your body to its normal state. The parasympathetic nervous system generally mirrors the connections of the sympathetic nervous system. For example, the parasympathetic nervous system constricts your pupils, slows your heart rate and respiration, diverts blood flow to your digestive system, and decreases activity in your sweat glands.

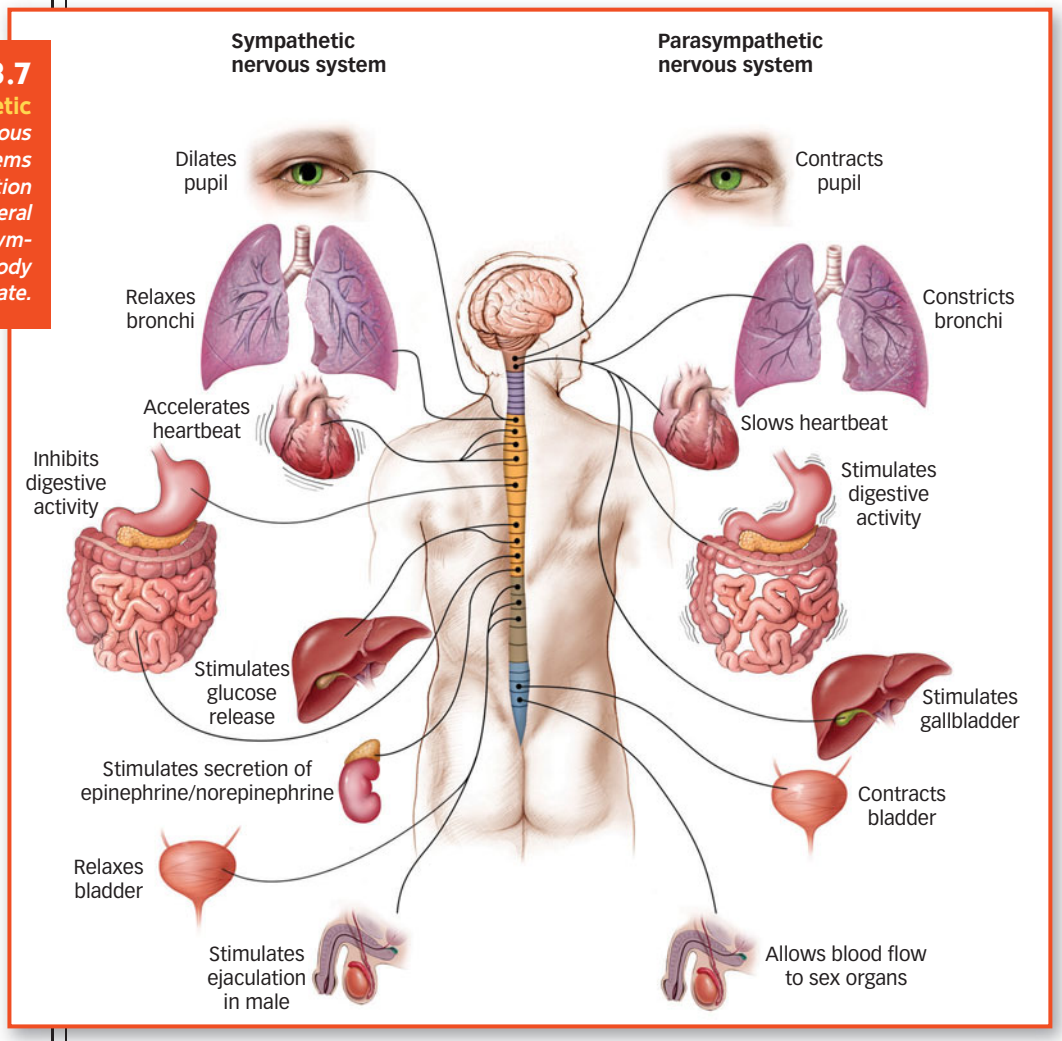


FIGURE 3.7
Sympathetic and Parasympathetic Systems *The autonomic nervous system is composed of two subsystems that complement each other. Activation of the sympathetic system serves several aspects of arousal, whereas the parasympathetic nervous system returns the body to its normal resting state.*

As you might imagine, the sympathetic and parasympathetic nervous systems coordinate to control many bodily functions. One example is sexual behavior. In men, the parasympathetic nervous system engorges the blood vessels of the penis to produce an erection, but the sympathetic nervous system is responsible for ejaculation. In women, the parasympathetic nervous system produces vaginal lubrication, but the sympathetic nervous system underlies orgasm. In both men and women, a successful sexual experience depends on a delicate balance of these two systems; in fact, anxiety about sexual performance can disrupt this balance. For example, sympathetic nervous system activation caused by anxiety can lead to premature ejaculation in males and lack of lubrication in females.

Components of the Central Nervous System

Compared to the many divisions of the peripheral nervous system, the central nervous system may seem simple. After all, it has only two elements: The brain and the spinal cord. But those two elements are ultimately responsible for most of what we do as humans.

The spinal cord often seems like the brain's poor relation: The brain gets all the glory, and the spinal cord just hangs around, doing relatively simple tasks. Those tasks, however, are pretty important: keeping you breathing, responding to pain, moving your muscles, allowing you to walk. What's more, without the spinal cord, the brain would not be able to put any of its higher processing into action.

For some very basic behaviors, the spinal cord doesn't need input from the brain at all. Connections between the sensory inputs and motor neurons in the spinal cord mediate

spinal reflexes Simple pathways in the nervous system that rapidly generate muscle contractions.

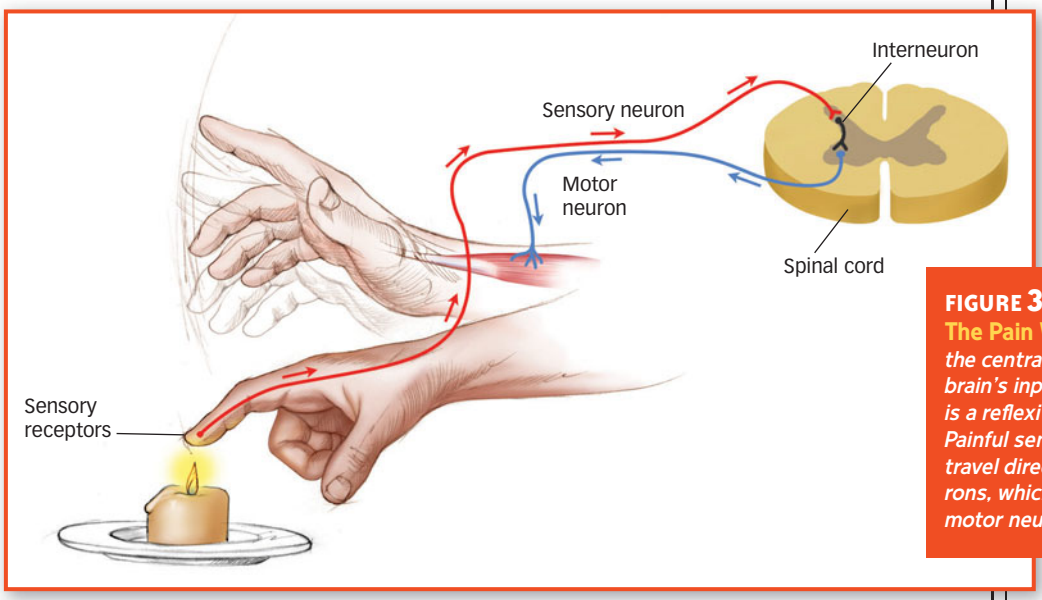
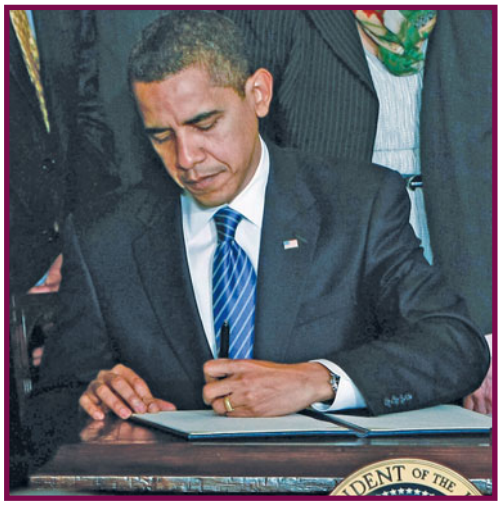


FIGURE 3.8 **The Pain Withdrawal Reflex** *Many actions of the central nervous system don't require the brain's input. For example, withdrawing from pain is a reflexive activity controlled by the spinal cord. Painful sensations (e.g., a pin jabbing your finger) travel directly to the spinal cord via sensory neurons, which then issue an immediate command to motor neurons to retract the hand.*

spinal reflexes, *simple pathways in the nervous system that rapidly generate muscle contractions*. For example, if you touch a hot stove, the sensory neurons that register pain send inputs directly into the spinal cord (see **FIGURE 3.8**, above). Through just a few synaptic connections within the spinal cord, interneurons relay these sensory inputs to motor neurons that connect to your arm muscles and direct you to quickly retract your hand. In other words, you don't need a whole lot of brainpower to rapidly pull your hand off a hot stove!

More elaborate tasks require the collaboration of the spinal cord and the brain. The peripheral nervous system communicates with the central nervous system through nerves that conduct sensory information into the brain, carry commands out of the brain, or both. Damage to the spinal cord severs the connection from the brain to sensory and motor neurons that are essential to sensory perception and movement. The location of the spinal injury often determines the extent of the abilities that are lost. Patients with damage at a particular level of the spinal cord lose sensation of touch and pain in body parts below the level of the injury as well as a loss of motor control of the muscles in the same areas. A spinal injury higher up the cord usually predicts a much poorer prognosis, such as quadriplegia (the loss of sensation and motor control over all limbs), breathing through a respirator, and lifelong immobility.

What important functions does the spinal cord perform on its own?



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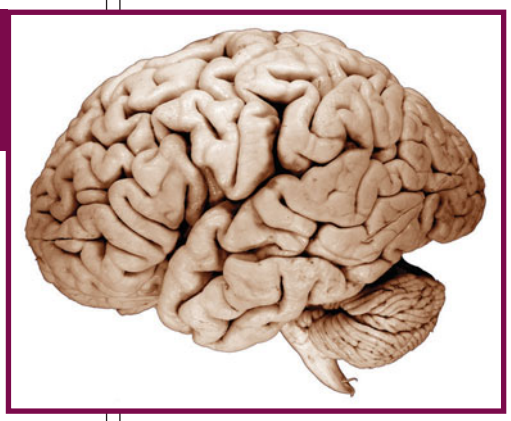
Research using embryonic stem cells, which has the potential to advance understanding and treatment of serious brain diseases, should be enhanced by President Obama's executive order in early 2009 lifting previous restrictions on this research.

The human brain weighs only three pounds and isn't much to look at, but its accomplishments are staggering.



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Exploring the Brain

The human brain is really not much to look at. It's about three pounds of slightly slimy, pinkish grayish stuff that sits there like a lump. You already know, of course, that the neurons and glial cells that make up that lump are busy humming away, giving you consciousness, feelings, and potentially brilliant ideas. But to find out which neurons in which parts of the brain control which functions, scientists first had to divide and conquer—that is, find a way of describing the brain that allows researchers to communicate with one another.

Neuroscientists divide up the brain in several ways. Although these divisions make it easier to understand areas of the brain and their functions, keep in mind that none of these structures or areas in the brain can act alone: They are all part of one big, interacting, interdependent whole. Often, it's convenient to divide the brain into three parts: the hindbrain, the midbrain, and the forebrain (see FIGURE 3.9).

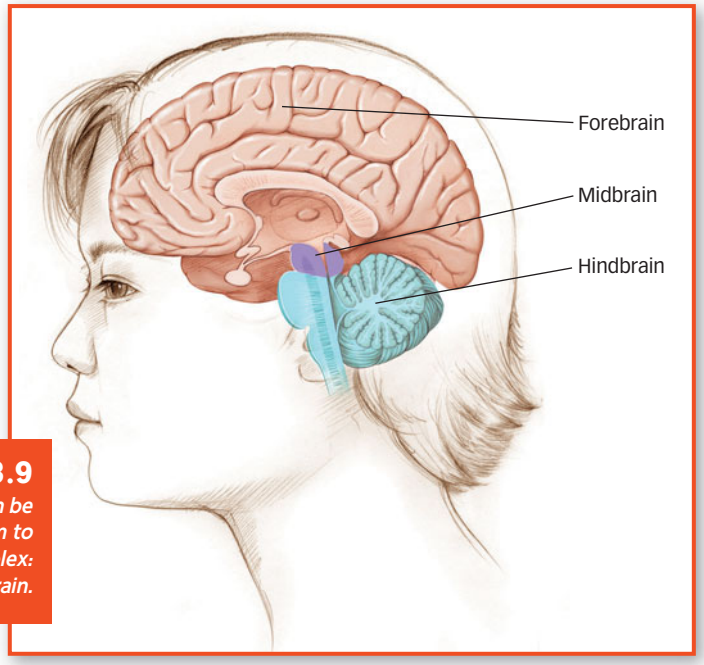


FIGURE 3.9
The Major Divisions of the Brain *The brain can be organized into three parts moving from the bottom to the top, from simpler functions to the more complex: the hindbrain, the midbrain, and the forebrain.*

The Hindbrain

If you follow the spinal cord from your tailbone to where it enters your skull, you'll find it difficult to determine where your spinal cord ends and your brain begins. That's because the spinal cord is continuous with the **hindbrain**, *an area of the brain that coordinates information coming into and out of the spinal cord*. The hindbrain is sometimes called the *brain stem*; indeed, it looks like a stalk on which the rest of the brain sits. The hindbrain controls the most basic functions of life: respiration, alertness, and motor skills (see FIGURE 3.10 on the next page). The **medulla** is *an extension of the spinal cord into the skull that coordinates heart rate, circulation, and respiration.* Inside the medulla is a small cluster of neurons called the **reticular formation**, *which regulates sleep, wakefulness, and levels of arousal.*

Which part of the brain helps to orchestrate movements that keep you steady on your bike?

hindbrain An area of the brain that coordinates information coming into and out of the spinal cord.

medulla An extension of the spinal cord into the skull that coordinates heart rate, circulation, and respiration.

reticular formation A brain structure that regulates sleep, wakefulness, and levels of arousal.

Behind the medulla is the **cerebellum**, *a large structure of the hindbrain that controls fine motor skills*. The cerebellum orchestrates the proper sequence of movements when we ride a bike, play the piano, or maintain balance while walking and running. It is important for "fine-tuning" or smoothing our actions, rather than initiating them; accordingly, damage to the cerebellum produces impairments in coordination and balance, although not paralysis or immobility.

The last major area of the hindbrain is the **pons**, *a structure that relays information from the cerebellum to the rest of the brain*. *Pons* means "bridge" in Latin. Although the detailed functions of the pons remain poorly understood, it essentially acts as a "relay station" or bridge between the cerebellum and other structures in the brain.

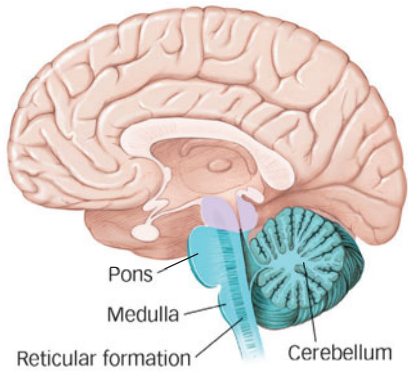
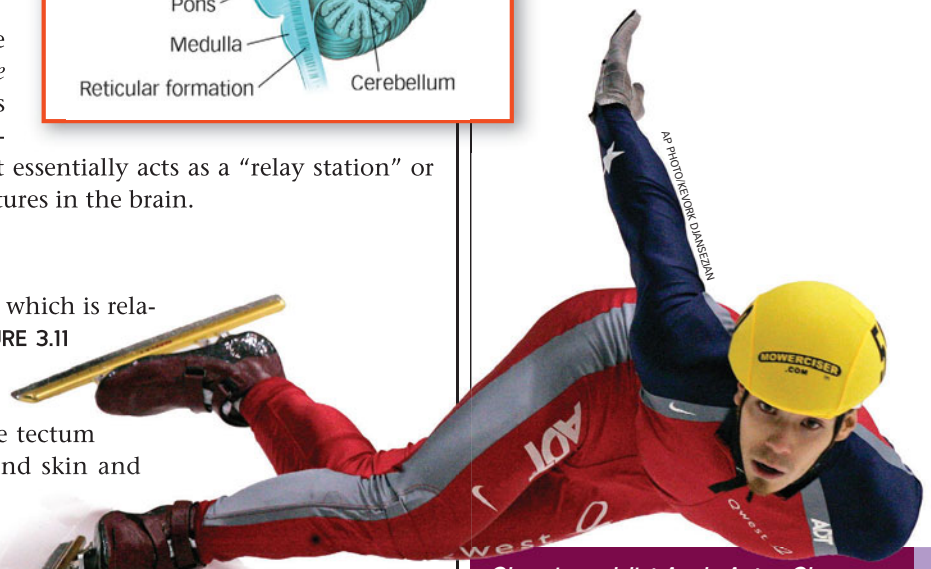


FIGURE 3.10
The Hindbrain *The hindbrain coordinates information coming into and out of the spinal cord and controls the basic functions of life. It includes the medulla, the reticular formation, the cerebellum, and the pons.*



Olympic medalist Apolo Anton Ohno relies on his cerebellum to execute graceful, coordinated motions on the ice. The cerebellum, part of the hindbrain, helps direct the smooth action of a variety of motor behaviors.

The Midbrain

Sitting on top of the hindbrain is the *midbrain*, which is relatively small in humans. As you can see in FIGURE 3.11 (below), the midbrain contains two main structures: the tectum and the tegmentum. The **tectum** *orients an organism in the environment*. The tectum receives stimulus input from the eyes, ears, and skin and moves the organism in a coordinated way toward the stimulus. The **tegmentum** *is involved in movement and arousal; it also helps orient an organism toward sensory stimuli*. The midbrain may be relatively small, but it is a central location of neurotransmitters such as *dopamine* and *serotonin* that are involved in arousal, mood, and motivation and the brain structures that rely on them (White, 1996).

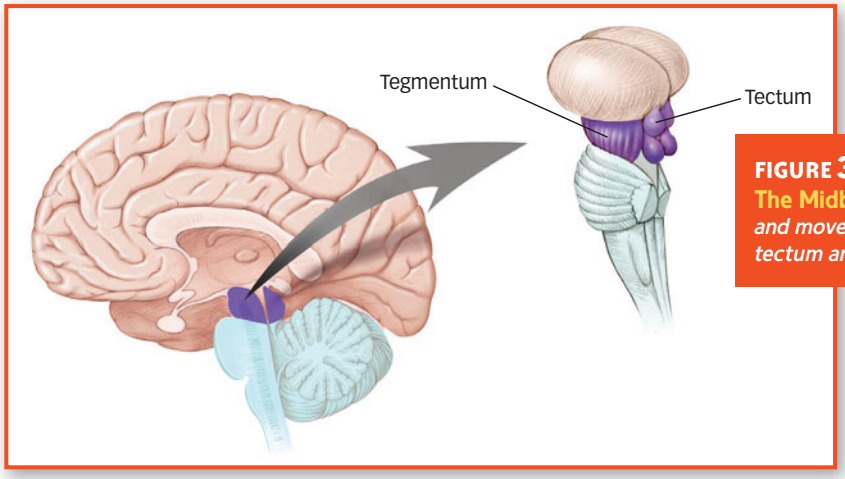


FIGURE 3.11
The Midbrain *The midbrain is important for orientation and movement. It includes structures such as the tectum and tegmentum.*

The Forebrain

You could survive if you had only a hindbrain and a midbrain. The structures in the hindbrain would take care of all the bodily functions necessary to sustain life, and the structures in the midbrain would orient you toward or away from pleasurable or threatening stimuli in the environment. But this wouldn't be much of a life. To understand

cerebellum A large structure of the hindbrain that controls fine motor skills.

pons A brain structure that relays information from the cerebellum to the rest of the brain.

tectum A part of the midbrain that orients an organism in the environment.

tegmentum A part of the midbrain that is involved in movement and arousal.

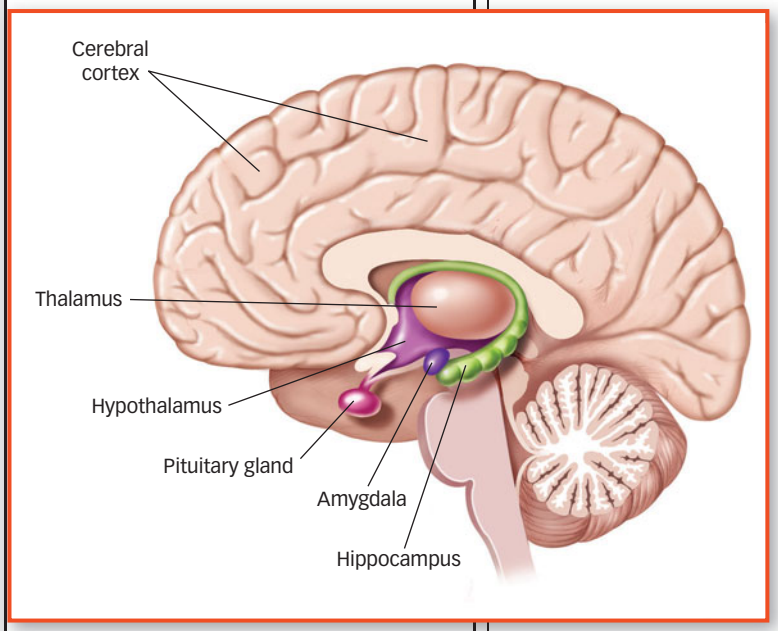


FIGURE 3.12
The Forebrain *The forebrain, the highest level of the brain, is critical for complex cognitive, emotional, sensory, and motor functions. The forebrain is divided into two parts: the cerebral cortex and the underlying subcortical structures. These include the thalamus, hypothalamus, pituitary gland, amygdala, and hippocampus.*

where the abilities that make us fully human come from, you need a forebrain. The *forebrain* is the highest level of the brain—literally and figuratively—and controls complex cognitive, emotional, sensory, and motor functions (see **FIGURE 3.12**). The forebrain itself is divided into two main sections: the cerebral cortex and the subcortical structures. The **cerebral cortex** is *the outermost layer of the brain*; the **subcortical structures** are *areas of the forebrain housed under the cerebral cortex near the very center of the brain*. You'll meet many key subcortical structures in later chapters, but for now, let's just review a few of the most critical.

The **thalamus** *relays and filters information from the senses and transmits the information to the cerebral cortex*. The thalamus receives inputs from all the major senses except smell, which has direct connections to the cerebral cortex. More than just a relay station, the thalamus actively filters incoming sensory information, giving more weight to some inputs and less weight to others. The thalamus also closes the pathways of incoming sensations during sleep, providing a valuable function in *not* allowing information to pass to the rest of the brain.

The **hypothalamus**, located below the thalamus (*hypo-* is Greek for "under"), *regulates body temperature, hunger, thirst, and sexual behavior*. For example, the hypothalamus makes sure that body temperature, blood sugar levels, and metabolism are kept within an optimal range for normal human functioning. Also, when you think about sex, messages from your cerebral cortex are sent to the hypothalamus to trigger the release of hormones. It's been suggested, then, that the hypothalamus is in charge of the "four Fs" of behavior: (a) fighting, (b) fleeing, (c) feeding, and (d) mating.

Other important subcortical structures, shown in Figure 3.12 and covered in more depth in later chapters, are the **pituitary gland**, *which releases hormones that direct the functions of many other glands* (such as the hypothalamus); the **hippocampus**, *which is critical for the creation and storage of new memories;* the **amygdala**, *which plays a central role in many emotional processes*; and the *basal ganglia*, a set of structures that direct intentional movement.

The Cerebral Cortex

Perched atop all these subcortical areas in the forebrain lies the cerebral cortex. The cortex is responsible for the most complex aspects of perception, emotion, movement, and thought (Fuster, 2003). It sits over the rest of the brain, like a mushroom cap shielding the underside and stem, and it is the wrinkled surface you see when looking at the brain with the naked eye. The cerebral cortex can be divided down the middle into two halves, the left hemisphere and the right hemisphere. The two hemispheres are more or less symmetrical in their appearance and, to some extent, in their functions. However, each hemisphere controls the functions of the opposite side of the body: Your right cerebral hemisphere perceives stimuli from and controls movements on the left side of your body, whereas your left cerebral hemisphere perceives stimuli from and controls movement on the right side of your body. The cerebral hemispheres are connected to each other by *commissures,* bundles of axons that make possible communication between parallel areas of the cortex in each half. The largest of these commissures is the **corpus callosum**, which *connects large areas of the cerebral cortex on each side of the brain and supports communication of information across the hemispheres* (see **FIGURE 3.13**). This means that

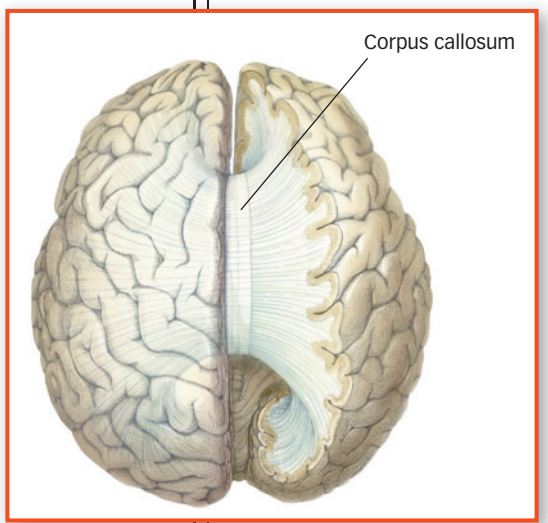


FIGURE 3.13
Cerebral Hemispheres *Top view of the brain with part of the right cerebral hemisphere pulled away to expose the corpus callosum.*

information received in the right hemisphere, for example, can pass across the corpus callosum and be registered, virtually instantaneously, in the left hemisphere.

The hemispheres themselves can be subdivided into four areas or *lobes*. From back to front, these are the occipital lobe, the parietal lobe, the temporal lobe, and the frontal lobe, as shown in **FIGURE 3.14**. We'll examine the functions of these lobes in more detail later; for now, here's a quick review. The **occipital lobe**, located at the back of the cerebral cortex, *processes visual information*. The **parietal lobe**, located in front of the occipital lobe, carries out functions that include *processing information about touch*. The parietal lobe contains the *somatosensory cortex,* a strip of brain tissue running from the top of the brain down to the sides (see Figure 3.14). Each part of the somatosensory cortex maps onto a particular part of the body. If a body area is more sensitive, a larger part of the somatosensory cortex is devoted to it. For example, the part of the somatosensory cortex that corresponds to the lips and tongue is larger than the area corresponding to the feet. The **temporal lobe**, located on the lower side of each hemisphere, is *responsible for hearing and language*. The *primary auditory cortex* in the temporal lobe is analogous to the somatosensory cortex in the parietal lobe and the primary visual areas of the occipital lobe; it receives sensory information from the ears based on the frequencies of sounds. Secondary areas of the temporal lobe then process the information into meaningful units, such as speech and words. The temporal lobe also houses the visual association areas that interpret the meaning of visual stimuli and help us recognize common objects in the environment (Martin, 2007).

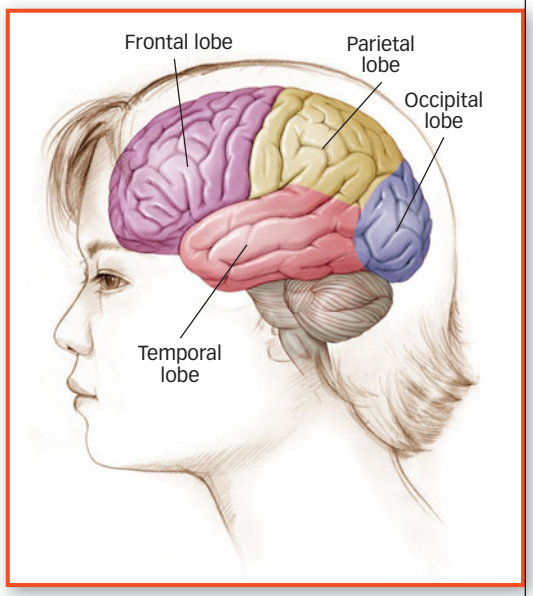


FIGURE 3.14
Cerebral Cortex and Lobes *The four major lobes of the cerebral cortex are the occipital lobe, the parietal lobe, the temporal lobe, and the frontal lobe.*

What types of thinking occur in the frontal lobe?

The **frontal lobe**, which sits behind the forehead, has *specialized areas for movement, abstract thinking, planning, memory, and judgment*. Lying just in front of the somatosensory cortex, at the back of the frontal lobe, is a parallel strip of brain tissue called the *motor cortex* (see **FIGURE 3.15** on the next page). Like the somatosensory cortex, different parts of the motor cortex correspond to different body parts. The motor cortex initiates voluntary movements and sends messages to the basal ganglia, cerebellum, and spinal cord. Other areas in the frontal lobe coordinate thought processes that help us manipulate information and retrieve memories, which we can use to plan our behaviors and interact socially with others. In short, the frontal cortex allows us to do the kind of thinking, imagining, planning, and anticipating that sets humans apart from most other species (Stuss & Benson, 1986).

Within each of the cortical lobes are areas specialized for processing particular types of information. Other areas, called **association areas**, *help provide sense and meaning to information registered in the cortex*. For example, neurons in the primary visual cortex are highly specialized; some detect features of the environment that are in a horizontal orientation, others detect movement, and still others process information about human versus nonhuman forms. The association areas of the occipital lobe interpret the information extracted by these primary areas—shape, motion, and so on—to help stitch together the threads of information in the various parts of the cortex to produce a meaningful understanding of what's being registered in the brain. Neurons in the association areas are usually less specialized and more flexible than neurons in the primary areas. As such, they can be shaped by

cerebral cortex The outermost layer of the brain, visible to the naked eye and divided into two hemispheres.

subcortical structures Areas of the forebrain housed under the cerebral cortex near the very center of the brain.

thalamus A subcortical structure that relays and filters information from the senses and transmits the information to the cerebral cortex.

hypothalamus A subcortical structure that regulates body temperature, hunger, thirst, and sexual behavior.

pituitary gland The "master gland" of the body's hormone-producing system, which releases hormones that direct the functions of many other glands in the body.

hippocampus A structure critical for creating new memories and integrating them into a network of knowledge so that they can be stored indefinitely in other parts of the cerebral cortex.

amygdala A part of the subcortical system that plays a central role in many emotional processes, particularly the formation of emotional memories.

corpus callosum A thick band of nerve fibers that connects large areas of the cerebral cortex on each side of the brain and supports communication of information across the hemispheres.

occipital lobe A region of the cerebral cortex that processes visual information.

parietal lobe A region of the cerebral cortex whose functions include processing information about touch.

temporal lobe A region of the cerebral cortex responsible for hearing and language.

frontal lobe A region of the cerebral cortex that has specialized areas for movement, abstract thinking, planning, memory, and judgment.

association areas Areas of the cerebral cortex that are composed of neurons that help provide sense and meaning to information registered in the cortex.

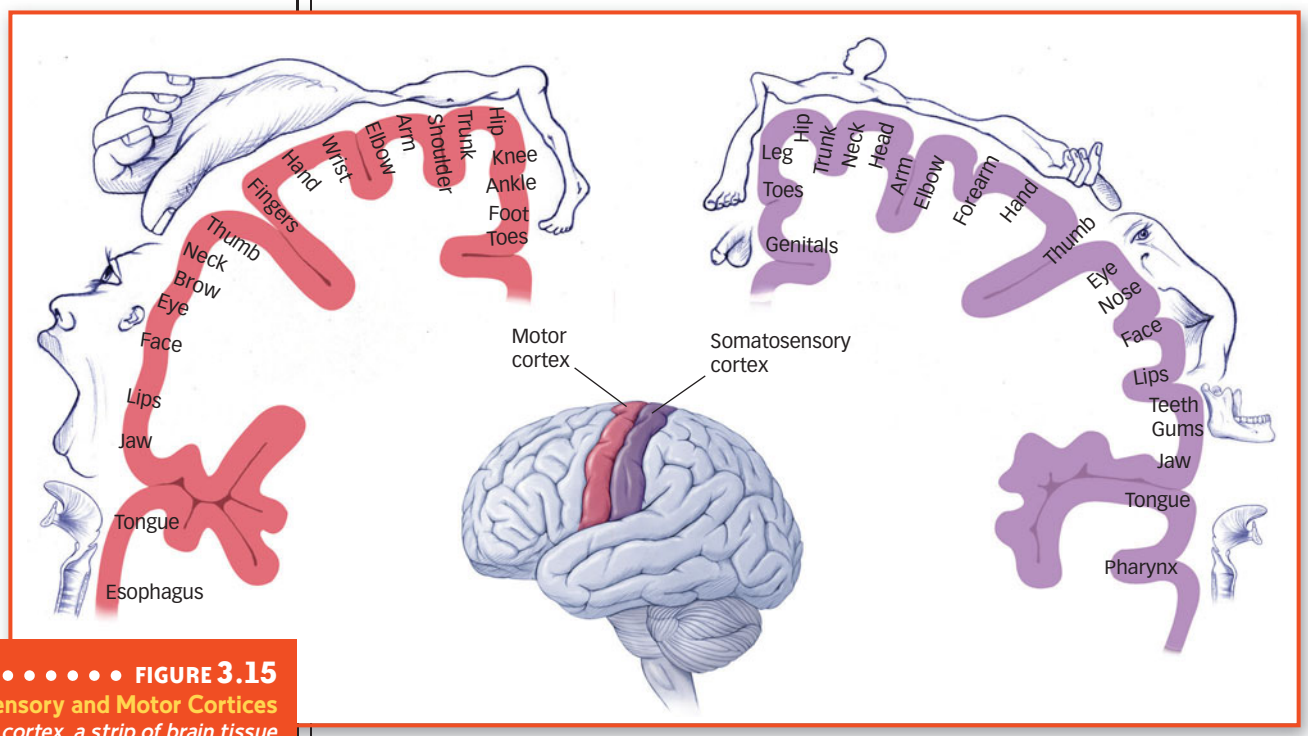
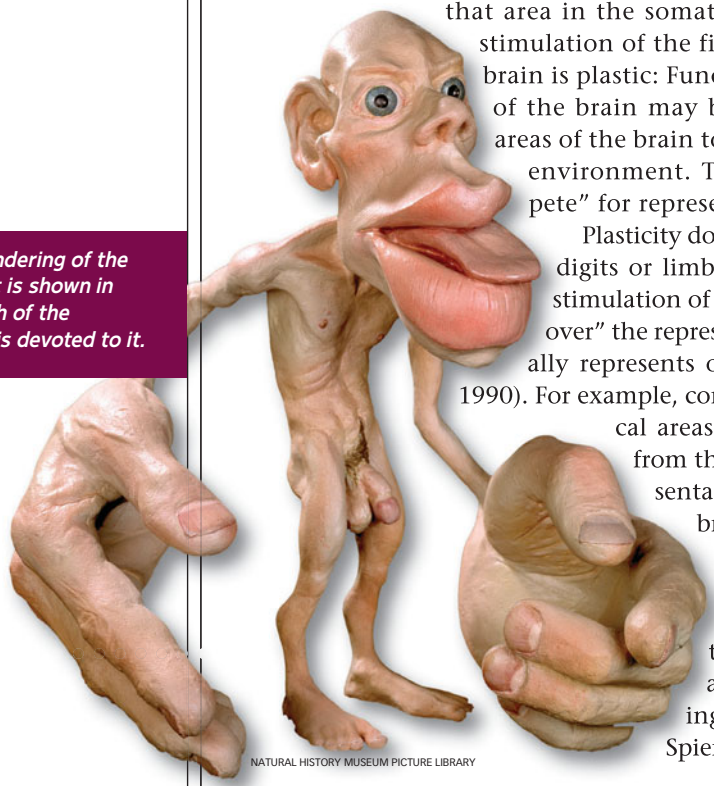


FIGURE 3.15
Somatosensory and Motor Cortices
The motor cortex, a strip of brain tissue in the frontal lobe, represents and controls different skin and body areas on the contralateral side of the body. Directly behind the motor cortex, in the parietal lobe, lies the somatosensory cortex. Like the motor cortex, the somatosensory cortex represents skin areas of particular parts on the contralateral side of the body.

learning and experience to do their job more effectively, a quality researchers call *plasticity* (i.e., "the ability to be molded"). As an example, if you lose your middle finger in an accident, the part of the somatosensory area that represents that finger is initially unresponsive (Kaas, 1991). After all, there's no longer any sensory input going from that location to that part of the brain. You might expect the "left middle finger neurons" of the somatosensory cortex to wither away. However, over time, that area in the somatosensory cortex becomes responsive to stimulation of the fingers *adjacent* to the missing finger. The brain is plastic: Functions that were assigned to certain areas of the brain may be capable of being reassigned to other areas of the brain to accommodate changing input from the environment. This suggests that sensory inputs "compete" for representation in each cortical area.



The homunculus is a rendering of the body in which each part is shown in proportion to how much of the somatosensory cortex is devoted to it.

Plasticity doesn't only occur to compensate for missing digits or limbs, however. An extraordinary amount of stimulation of one finger can result in that finger "taking over" the representation of the part of the cortex that usually represents other, adjacent fingers (Merzenich et al., 1990). For example, concert pianists have highly developed cortical areas for finger control: The continued input from the fingers commands a larger area of representation in the somatosensory cortices in the brain. Similar findings have been obtained with quilters (who may have highly developed areas for the thumb and forefinger, which are critical to their profession) and taxi drivers (who have overdeveloped brain areas in the hippocampus that are used during spatial navigation; Maguire, Woollett, & Spiers, 2006).

summary quiz [3.2]

6. When you feel threatened, your _____ nervous system prepares you to either fight or run away.
   a. central
   b. somatic
   c. sympathetic
   d. parasympathetic

7. The proper sequence of movements when we walk, run, ride a bike, or play the piano is controlled by the
   a. medulla.
   b. cerebellum.
   c. pons.
   d. thalamus.

8. Jim was in a bad car accident, and his occipital lobe was severely damaged. After that, he had difficulty recognizing
   a. faces.
   b. odors.
   c. familiar melodies.
   d. tastes.

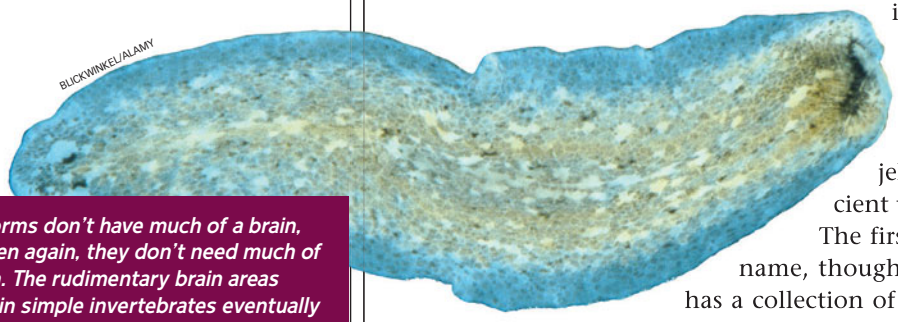
9. According to the textbook, which part of the cerebral cortex sets humans apart from most other species?
   a. occipital lobe
   b. parietal lobe
   c. temporal lobe
   d. frontal lobe

The Evolution of Nervous Systems

Another way to understand the organization of the nervous system is to consider its evolution over time. This approach reveals how the nervous system in humans evolved and adapted from other species to be the way it is, which is surprisingly imperfect. Far from being a single, elegant machine—the enchanted loom philosophers wrote so poetically about—the human brain is instead a system composed of many distinct components that have been added at different times during the course of evolution. The human species has retained what worked best in earlier versions of the brain, then added bits and pieces to get us to our present state through evolution.

Evolutionary Development of the Central Nervous System

The nervous system evolved from the very simple one found in simple animals to the elaborate one in humans today. Even the simplest animals have sensory neurons and motor neurons for responding to the environment (Shepherd, 1988). For example, single-celled protozoa have molecules in their cell membrane that are sensitive to food in the water. These molecules trigger the movement of tiny threads called *cilia*, which help propel the protozoa toward the food source. The first neurons appeared in simple



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Flatworms don't have much of a brain, but then again, they don't need much of a brain. The rudimentary brain areas found in simple invertebrates eventually evolved into the complex brain structures found in humans.

invertebrates, such as jellyfish; the sensory neurons in the jellyfish's tentacles can feel the touch of a potentially dangerous predator, which prompts the jellyfish to swim to safety. If you're a jellyfish, this simple neural system is sufficient to keep you alive.

The first central nervous system worthy of the name, though, appeared in flatworms. The flatworm has a collection of neurons in the head—a simple kind of brain—that includes sensory neurons for vision and taste and motor neurons that control feeding behavior. Emerging from the brain are a pair of tracts that form a spinal cord. The tracts are also connected by smaller collections of neurons called *ganglia*, which integrate information and coordinate motor behavior in the body region near each ganglion.

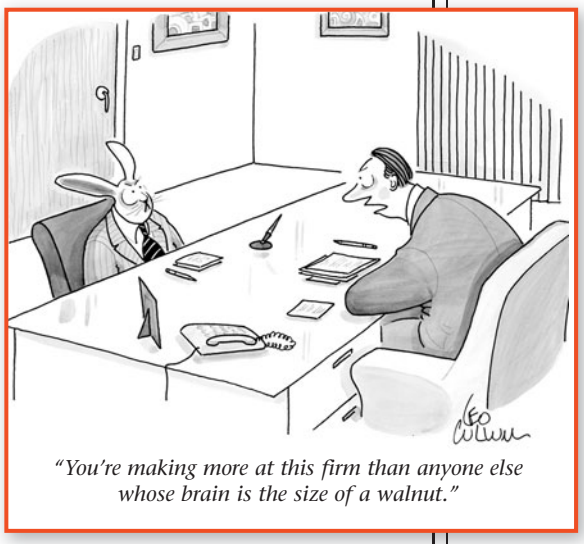
During the course of evolution, a major split in the organization of the nervous system occurred between invertebrate animals (those without a spinal column) and vertebrate animals (those with a spinal column). In all vertebrates, the central nervous system is a organized into a hierarchy: The lower levels of the brain and spinal cord execute simpler functions, while the higher levels of the nervous system perform more complex functions. As you saw earlier, in humans, reflexes are accomplished in the spinal cord. At the next level, the midbrain executes the more complex task of orienting toward an important stimulus in the environment. Finally, a more complex task, such as imagining what your life will be like 20 years from now, is performed in the forebrain (Addis, Wong, & Schacter, 2007; Szpunar, Watson, & McDermott, 2007).

The forebrain undergoes further evolutionary advances in vertebrates. In lower vertebrate species such as amphibians (frogs and newts), the forebrain consists only of small clusters of neurons. In higher vertebrates, including reptiles, birds, and mammals, the forebrain is much larger, and it evolves in two different patterns. Reptiles and birds have almost no cerebral cortex. By contrast, mammals have highly developed cerebral cortex, which develops multiple areas that serve a broad range of higher mental functions. This forebrain development has reached its peak—so far—in humans; the human forebrain allows for some remarkable, uniquely human abilities: self-awareness, sophisticated language use, social interaction, abstract reasoning, imagining, and empathy, among others.

Are our brains still evolving?

Intriguing evidence indicates that the human brain evolved more quickly than the brains of other species (Dorus et al., 2004). Researchers compared the sequences of 200 brain-related genes in mice, rats, monkeys, and humans and discovered a collection of genes that evolved more rapidly among primates. What's more, they found that this evolutionary process was more rapid along the lineage that led to humans. That is, primate brains evolved quickly compared to those of other species, but the brains of the primates who eventually became humans evolved even more rapidly. These results suggest that in addition to the normal adaptations that occur over the process of evolution, the genes for human brains took particular advantage of a variety of mutations (changes in a gene's DNA) along the evolutionary pathway. These results also suggest that the human brain is still evolving—becoming bigger and more adapted to the demands of the environment (Evans et al., 2005; Mekel-Bobrov et al., 2005).

Genes may direct the development of the brain on a large, evolutionary scale, but they also guide the development of an individual and, generally, the development of a species. Let's take a brief look at how genes and the environment contribute to the biological bases of behavior.



"You're making more at this firm than anyone else whose brain is the size of a walnut."

Genes and the Environment

gene The unit of hereditary transmission.

chromosomes Strands of DNA wound around each other in a double-helix configuration.

A **gene** is *the unit of hereditary transmission*. Genes are built from strands of DNA (deoxyribonucleic acid) and are organized into large threads called **chromosomes**, which are *strands of DNA wound around each other in a double-helix configuration* (see **FIGURE 3.16**). Chromosomes come in pairs, and humans have 23 pairs each. These pairs of chromosomes are similar but not identical: You inherit one of each pair from your father and one from your mother. For example, the 23rd pair of chromosomes determine an individual's biological sex. Each chromosome in the 23rd pair can be either an X chromosome or a Y chromosome. Females have two X chromosomes, whereas males have one X and one Y chromosome. You inherited an X chromosome from your mother since she has only X chromosomes to give. Your biological sex, therefore, was determined by whether you received an additional X chromosome or a Y chromosome from your father.

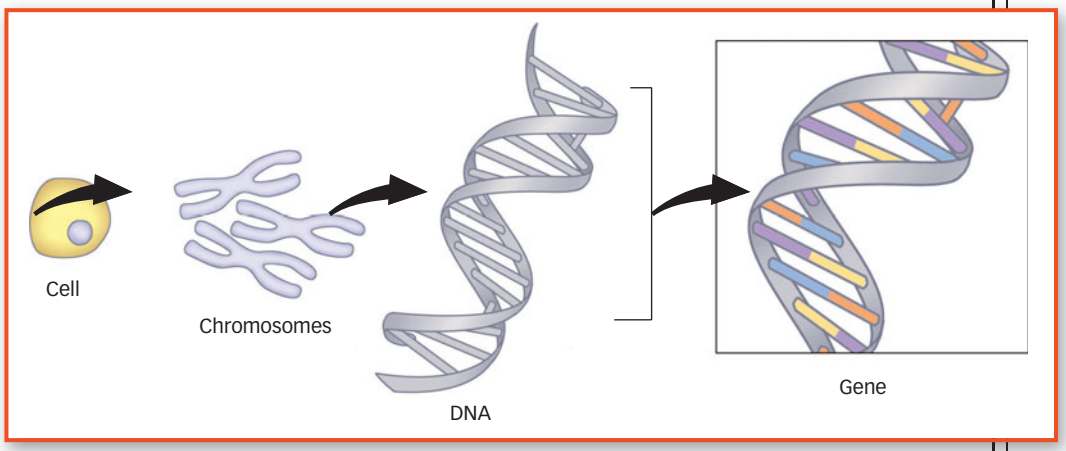


FIGURE 3.16 Genes, Chromosomes, and Their Recombination *The cell nucleus houses chromosomes, which are made up of double-helix strands of DNA. Every cell in our bodies has 23 pairs of chromosomes. Genes are segments on a strand of DNA with codes that make us who we are.*

There is considerable variability in the genes that individual offspring receive. Nonetheless, children share a higher proportion of their genes with their parents than with more distant relatives or with nonrelatives. Children share half their genes with each parent, a quarter of their genes with their grandparents, an eighth of their genes with cousins, and so on. The probability of sharing genes is called *degree of relatedness*. The most genetically related people are *monozygotic twins* (also called *identical twins*), who develop from the splitting of a single fertilized egg and therefore share 100% of their genes. *Dizygotic twins* (*fraternal twins*) develop from two separate fertilized eggs and share 50% of their genes, the same as any two siblings born separately.

Monozygotic twins (left) share 100% of their genes in common, while dizygotic twins (right) share 50% of their genes, the same as other siblings. Studies of monozygotic and dizygotic twins help researchers estimate the relative contributions of genes and environmental influences on behavior.

THOMAS WANSTALL/THE IMAGE WORKS

COURTESY OF TRANG BLACK

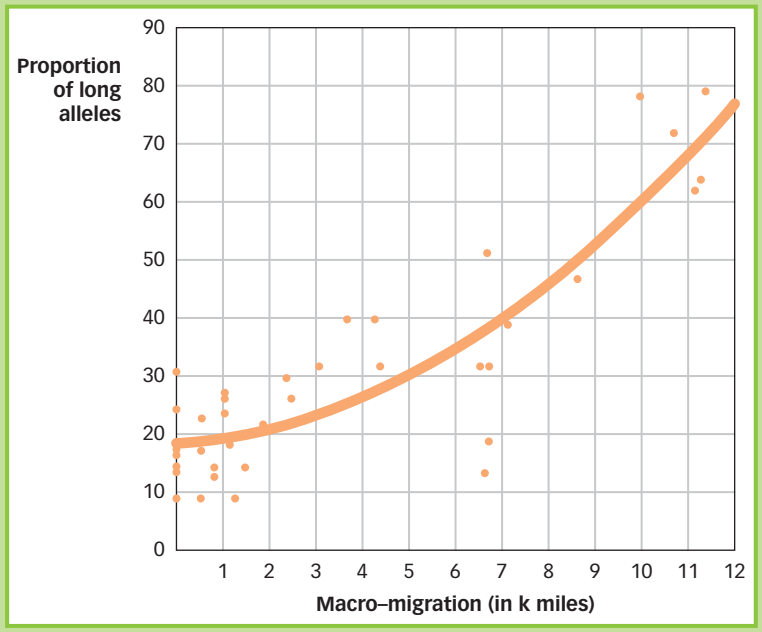
Culture & Community

Is the Desire to Explore New Lands in the Genes?

Psychologists have found an intriguing correlation between the migratory patterns of various populations of people and the dopamine D4 receptor gene (DRD4) (Chen et al., 1999). They found that (a) the DRD4 genotype varies considerably across populations and (b) that the distance each group moved from their original place of settlement was associated with the frequency of the long allele of DRD4 (see the graph).

For example, Native Americans in the United States, whose ancestors traveled from northern Asia, have a higher proportion of long allele of DRD4, which has been associated with novelty seeking, whereas Han Chinese have traveled little and have very few long allele DRD4.

Although it's tempting to want to reach conclusions based on this relationship, causal links have not been demonstrated. Still, it has potentially interesting implications for our understanding of the link between biology and culture.



Many researchers have tried to determine the relative influence of genetics on behavior. One way to do this is to compare a trait shown by monozygotic twins with that same trait among dizygotic twins. This type of research usually enlists twins who were raised in the same household, so that the impact of their environment—their socioeconomic status, access to education, parental child-rearing practices, environmental stressors, and so forth—remains relatively constant. Finding that monozygotic twins have a higher prevalence of a specific trait suggests a genetic influence (Boomsma, Busjahn, & Peltonen, 2002).

As an example, the likelihood that the dizygotic twin of a person who has schizophrenia (a mental disorder we'll discuss in greater detail in Chapter 13) will *also* develop schizophrenia is 27%. However, this statistic rises to 50% for monozygotic twins. This

observation suggests a substantial genetic influence on the likelihood of developing schizophrenia. Monozygotic twins share 100% of their genes, and if one assumes environmental influences are relatively consistent for both members of the twin pair, the 50% likelihood can be traced to genetic factors. That sounds scarily high . . . until you realize that the remaining 50% probability must be due to environmental influences. In short, genetics can contribute to the development, likelihood, or onset of a variety of traits. But a more complete picture of genetic influences on behavior must always take the environmental context into consideration. Genes express themselves within an environment, not in isolation.

"The title of my science project is My Little Brother: Nature or Nurture.'"

With these parameters in mind, behavioral geneticists use calculations based on relatedness to compute the heritability of behaviors (Plomin et al., 2001a). *Heritability* is a measure of the variability of behavioral traits among individuals that can be accounted for by genetic factors. It's calculated as a proportion, and its numerical value (index) ranges from 0 to 1.00. A heritability of 0 means that genes do not contribute to individual differences in the behavioral trait; a heritability of 1.00 means that genes are the *only* reason for the individual differences. As you might guess, scores of 0 or 1.00 occur so infrequently that they serve more as theoretical limits than realistic values; almost nothing in human behavior is completely due to the environment or *completely* to genetic inheritance. Scores between 0 and 1.00, then, indicate that individual differences are caused by varying degrees of genetic and environmental contributions—a little stronger influence of genetics here, a little stronger influence of the environment there, but each always within the context of the other.

For human behavior, almost all estimates of heritability are in the moderate range, between 0.30 and 0.60. For example, a heritability index of 0.50 for intelligence indicates that half of the variability in intelligence test scores is attributable to genetic influences, and the remaining half is due to environmental influences. Smart parents often (but not always) produce smart children; genetics certainly plays a role. But smart and not-so-smart children attend good or not-so-good schools, practice their piano lessons with more or less regularity, study or not study as hard as they might, have good and not-so-good teachers and role models, and so on. Genetics is only half the story in intelligence. Environmental influences also play a significant role in predicting the basis of intelligence (see Chapter 7).

Are abilities, such as intelligence and memory, inherited through our genes?

Heritability has proven to be a theoretically useful and statistically sound concept in helping scientists understand the relative genetic and environmental influences on behavior. However, there are four important points about heritability to bear in mind.

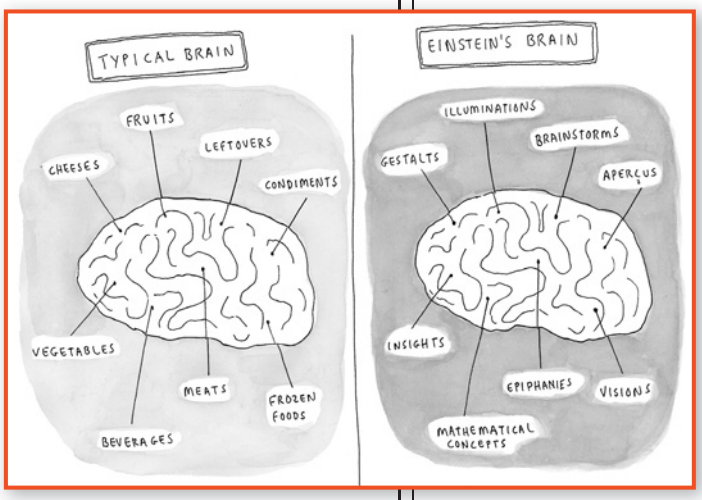
First, *heritability is an abstract concept*: It tells us nothing about the *specific* genes that contribute to a trait. Second, *heritability is a population concept*: It tells us nothing about an individual. For example, a 0.50 heritability of intelligence means that, on average, about 50% of the differences in intellectual performance are attributable to genetic differences among individuals in the population. It does *not* mean that 50% of any given person's intelligence is due to her or his genetic makeup. Third, *heritability is dependent on the environment*. Just as behavior occurs within certain contexts, so do genetic influences. For example, intelligence isn't an unchanging quality: People are intelligent within a particular learning context, a social setting, a family environment, a socioeconomic class, and so on. Heritability, therefore, is meaningful only for the environmental conditions in which it was computed, and heritability estimates may change dramatically under other environmental conditions. Finally, *heritability is not fate*. It tells us nothing about the degree to which interventions can change a behavioral trait. Heritability is useful for identifying behavioral traits that are influenced by genes, but it is not useful for determining how individuals will respond to particular environmental conditions or treatments.

summary quiz [3.3]

10. The first central nervous system appeared in
- a. protozoa.
- b. jellyfish.
- c. flatworms.
- d. frogs.

11. Which is true of forebrain development in vertebrates?
- a. Amphibians have no forebrain at all.
- b. Reptiles have a large cerebral cortex.
- c. The cerebral cortex of mammals is smaller than that of birds.
- d. Birds have almost no cerebral cortex

12. A heritability index of 0.50 for intelligence indicates that
- a. half of each person's intelligence is due to her or his genetic makeup, and half is due to environment.
- b. among individuals in the population, half of the variability in intellectual performance is attributable to genetic influence, and half is due to environment.
- c. no matter how the environment changes, heritability of intelligence will remain at 0.50.
- d. half of the specific genes that cause intelligence have been identified.



Investigating the Brain

So far, you've read a great deal about the nervous system: how it's organized, how it works, what its components are, and what those components do. But one question remains largely unanswered: *How* do we know all of this? Anatomists can dissect a human brain and identify its structures, but this cannot tell us which structures play a role in producing which behaviors. To study function, scientists use a variety of methods to understand how the brain affects behavior. Let's consider three of the main ones: testing people with brain damage and observing their deficits, studying electrical activity in the brain during behavior, and conducting brain scans while people perform various tasks.

Learning about Brain Organization by Studying the Damaged Brain

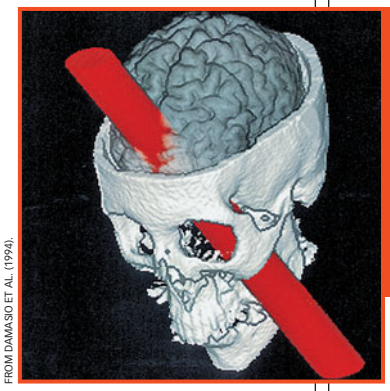
Remember Betty, the 75-year-old woman admitted to the emergency room because she couldn't recognize her own husband? She had suffered a stroke from a blood clot that deprived her brain of oxygen and caused the death of neurons in the afflicted area. Betty's stroke affected part of the association area in her temporal lobe, where complex visual objects are identified. Betty's occipital lobe, the main area where visual processing takes place, was unaffected, so Betty could see her husband and two sons, but because of the damage to her temporal lobe, she could not recognize them.

Much research in neuroscience correlates the loss of specific perceptual, motor, emotional, or cognitive functions with specific areas of brain damage (Andrewes, 2001; Kolb & Whishaw, 2003). By studying these mindbugs, neuroscientists can theorize about the functions those brain areas normally perform. The modern history of neuroscience can be dated to the work of Paul Broca (see Chapter 1). In 1861, Broca described a patient who had lost the capacity to produce spoken language (but not the ability to understand language) due to damage in a small area in the left frontal lobe. In 1874, Carl Wernicke (1848–1905) described a patient with an impairment in language comprehension (but not the ability to produce speech) associated with damage to an area in the upper-left temporal lobe. These areas were named, respectively, *Broca's area* and *Wernicke's area,* and they provided the earliest evidence that the brain locations for speech production and speech comprehension are separate and that for most people, the left hemisphere is critical to producing and understanding language (Young, 1990).

How have brain disorders been central to our study of specific areas of the brain?

The Emotional Functions of the Frontal Lobes

Individuals with brain damage have also given us important insight into the functions of the frontal lobes. One famous case was Phineas Gage, a muscular 25-year-old railroad worker who, in 1848, was packing an explosive charge into a crevice in a rock when the powder exploded, driving a 3-foot, 13-pound iron rod through his head at high speed. As **FIGURE 3.17** shows, the rod entered through his lower left jaw and exited through the middle top of his head. Incredibly, Gage lived to tell the tale. But his personality underwent a significant change.



FROM DAMASIO ET AL. (1994).

FIGURE 3.17 Phineas Gage *Phineas Gage's traumatic accident allowed researchers to investigate the functions of the frontal lobe and its connections with emotion centers in the subcortical structures. The likely path of the metal rod through Gage's skull is reconstructed here.*

Before the accident, Gage had been mild mannered, quiet, conscientious, and a hard worker. After the accident, he became irritable, irresponsible, indecisive, and given to profanity. The sad decline of Gage's personality and emotional life nonetheless provided an unexpected benefit to psychology. His case study was the first to allow researchers to investigate the hypothesis that the frontal lobe is involved in emotion regulation, planning, and decision making. Furthermore, because the connections between the frontal lobe and subcortical structures concerned with emotion and motivation were affected, scientists were able to better understand how the amygdala, hippocampus, and related subcortical structures interacted with the cerebral cortex (Damasio, 2005).

The Distinct Roles of the Left and Right Hemispheres

The study of patients with brain damage has even yielded clues about the different functions of the left and right hemispheres of the cerebral cortex. Some of these studies focus on patients who suffer from severe, intractable epilepsy. Seizures that begin in one hemisphere cross the corpus callosum (the thick band of nerve fibers that allows the two hemispheres to communicate) to the opposite hemisphere and start a feedback loop that results in a kind of firestorm in the brain. To alleviate the severity of the seizures, surgeons can sever the corpus callosum in a procedure called a *split-brain procedure*. This meant that a seizure that starts in one hemisphere is isolated in that hemisphere since there is no longer a connection to the other side. This procedure helps the patients with epilepsy but also produces some unusual, if not unpredictable, behaviors. Normally, any information that initially enters the left hemisphere is also registered in the right hemisphere and vice versa. The information comes in and

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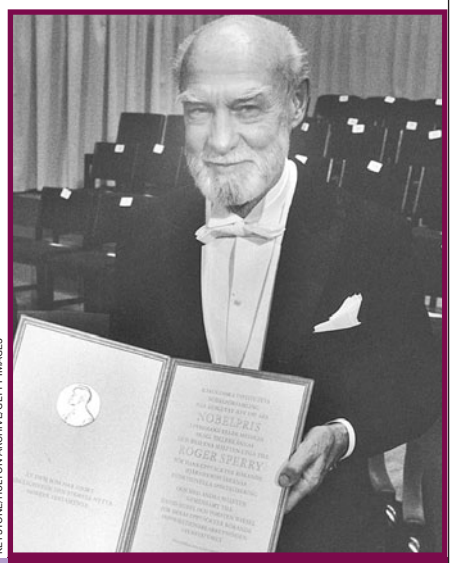


KEYSTONE/HULTON ARCHIVE/GETTY IMAGES

Roger Wolcott Sperry (1913–1994) received the Nobel Prize in Physiology in 1981 for his pioneering work investigating the independent functions of the cerebral hemisphere.

travels across the corpus callosum, and both hemispheres understand what's going on. But in a split-brain patient, information entering one hemisphere stays there. Without an intact corpus callosum, there's no way for that information to reach the other hemisphere.

To investigate this phenomenon, Roger Sperry and his colleagues had split-brain patients look at a spot in the center of a screen and then projected a stimulus on one side of the screen, isolating the stimulus to one hemisphere (Sperry et al. 1964). For example, they could project a picture of an object to the left hemisphere of a split-brain patient and ask her to verbally describe what it was. Typically, the left hemisphere is specialized for language processing, and so the patient would have no difficulty verbally describing what she saw. But suppose the patient was instead asked to reach behind a screen with her left hand and pick up the object she just saw. Remember that the hemispheres exert contralateral control over the body, meaning that the left hand is controlled by the right hemisphere. But this patient's right hemisphere has no clue what the object was because that information was received in the left hemisphere and was unable to travel to the right hemisphere! So, even though the split-brain patient saw the object and could verbally describe it, she would be unable to use the right hemisphere to perform other tasks regarding that object, such as correctly selecting it from a group with her left hand (see **FIGURE 3.18**).

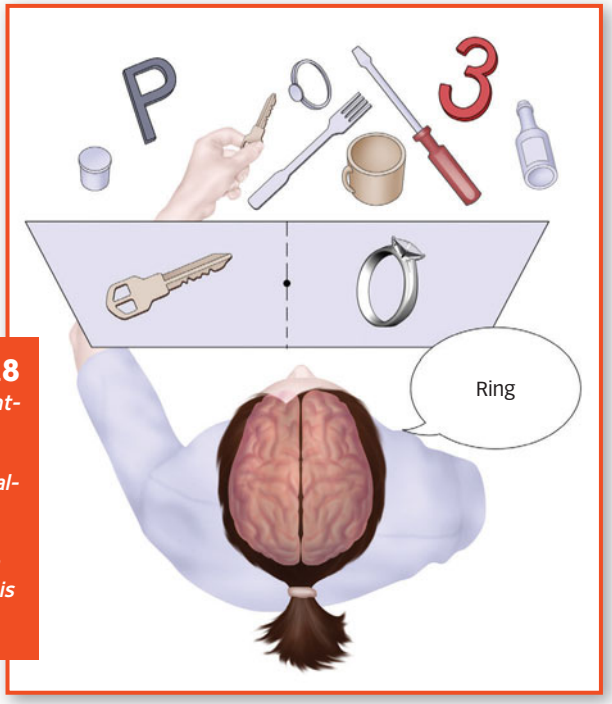


FIGURE 3.18

Split-Brain Experiment *When a split-brain patient is presented with the picture of a ring on the right and that of a key on the left side of a screen, she can verbalize ring but not key because the left hemisphere "sees" the ring, and language is usually located in the left hemisphere. This patient would be able to choose a key with her left hand from a set of objects behind a screen. She would not, however, be able to pick out a ring with her right hand since what the left hemisphere "sees" is not communicated to the right side of her body.*

Such split-brain studies reveal that the two hemispheres perform different functions and can work together seamlessly as long as the corpus callosum is intact. Without a way to transmit information from one hemisphere to the other, information gets "stuck" in the hemisphere it initially entered, and we become acutely aware of the different functions of each hemisphere. Of course, a split-brain patient can adapt to this by simply moving her eyes a little so that the same information independently enters both hemispheres. Split-brain studies have continued over the past few decades and play an important role in shaping our understanding of how the brain works (Gazzaniga, 2006).

Listening to the Brain: Single Neurons and the EEG

A second approach to studying the link between brain structures and behavior involves recording the pattern of electrical activity of neurons. An *electroencephalogram (EEG)* is a device used to record electrical activity in the brain. Typically, electrodes are placed

on the outside of the head, and even though the source of electrical activity in synapses and action potentials is far removed from these wires, the electric signals can be amplified several thousand times by the EEG to provide a visual record of the underlying electrical activity, as shown in **FIGURE 3.19**. Using this technique, researchers can determine the amount of brain activity when individuals engage in a variety of psychological functions, such as perceiving, learning, and remembering.

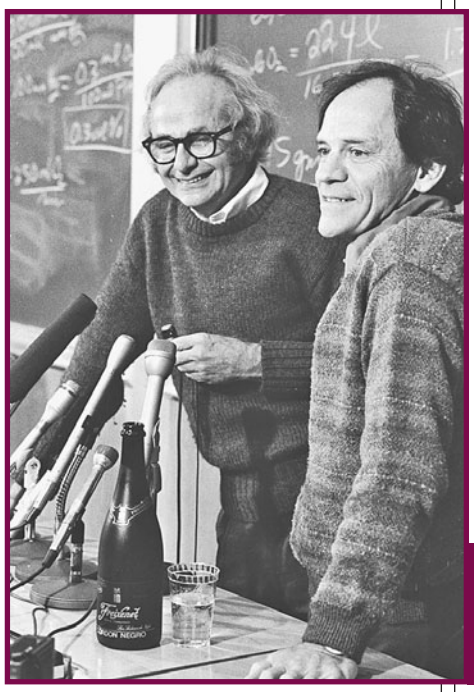
A different approach to recording electrical activity resulted in a more refined understanding of the brain's division of responsibilities, even at a cellular level. Nobel laureates David Hubel and Torsten Wiesel used a technique that inserted electrodes into the occipital lobes of anesthetized cats and observed the patterns of action potentials of individual neurons (Hubel, 1988). Hubel and Wiesel amplified the action potential signals through a loudspeaker so that the signals could be heard as clicks as well as seen on an oscilloscope. While flashing lights in front of the animal's eye, Hubel and Wiesel recorded the resulting activity of neurons in the occipital cortex. They discovered that neurons in the primary visual cortex are activated whenever a contrast between light and dark occurs in part of the visual field, seen particularly well when the visual stimulus was a thick line of light against a dark background. They then found that each neuron responded vigorously only when presented with a contrasting edge at a particular orientation. Since then, many studies have shown that neurons in the primary visual cortex represent particular features of visual stimuli, such as contrast, shape, and color (Zeki, 1993). These dimensions can then be combined during a later stage of processing to allow recognition and perception of a stimulus.

How does the EEG record electrical activity in the brain?

AJPHOTO/PHOTO RESEARCHERS

FIGURE 3.19
EEG *The electroencephalogram (EEG) records electrical activity in the brain. Many states of consciousness, such as wakefulness and stages of sleep, are characterized by particular types of brainwaves.*

Other studies have identified a variety of features that are detected by sensory neurons. For example, some visual processing neurons in the temporal lobe are activated only when detecting faces (Kanwisher, 2000; Perrett, Rolls, & Caan, 1982). These neurons lie in the same area of the temporal cortex that was damaged in Betty's stroke. Neurons in this area are specialized for processing faces; damage to this area results in an inability to perceive faces. These complementary observations—showing that the type of function that is lost or altered when a brain area is damaged corresponds to the kind of information processed by neurons in that cortical area—provide the most compelling evidence linking the brain to behavior. (See the Hot Science box on the next page.)



AP PHOTO

David Hubel (left, b. 1926) and Torsten Wiesel (right, b. 1924) received the Nobel Prize in Physiology in 1981 for their work on mapping the visual cortex.

Brain Imaging: Watching the Brain in Action

The third major way that neuroscientists can peer into the workings of the human brain has only become possible within the past several decades. *Neuroimaging techniques* use advanced technology to create images of the living, healthy brain (Posner & Raichle, 1994; Raichle & Mintun, 2006).

[HOT SCIENCE]

Mirror, Mirror, in My Brain

You've no doubt heard the expression "Monkey see, monkey do." In fact, you may have taunted a sibling or playmate with that line more than once in your life. You probably didn't realize that you were *that close* to making one of the major discoveries in neuroscience when you uttered those prophetic words!

One of the most exciting recent advances in neuroscience is the discovery of the mirror-neuron system. Mirror neurons are found in the frontal lobe (near the motor cortex) and in the parietal lobe (Rizzolatti & Craighero, 2004). They have been identified in birds, monkeys, and humans, and their name reflects the function they serve. Mirror neurons are active when an animal performs a behavior, such as reaching for or manipulating an object. However, mirror neurons are also activated whenever another animal *observes* this animal performing the behavior. In other words, mirror neurons are active both in the animal reaching for the food and in the animal observing this behavior. This kind of mirroring—one monkey sees, one monkey does, but both monkeys' mirror neurons fire—holds intriguing implications for understanding the brain's role in complex social behavior.

A recent study on mirror neurons used fMRI, a technique discussed later in the chapter, to monitor the brains of humans as they watched each of three presentations (Iacoboni et al., 2005). Sometimes participants saw a hand making grasping motions in midair with no "props" or background. Sometimes they saw only the context: coffee cups or scrubbing sponges but no hands making motions to go with them. Other times they saw hand motions in two different contexts, either grasping and moving a coffee cup to drink, or cleaning dishes with a sponge.

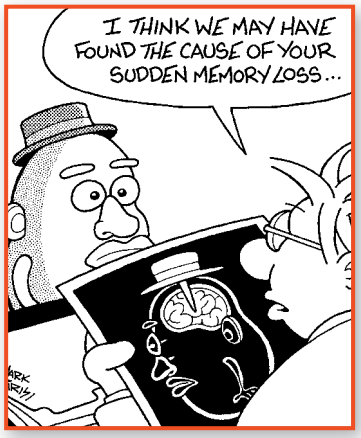
When actions were embedded in a context, such as in the last set of presentations, the participants' mirror neurons responded more strongly than in either of the other two conditions. This suggests that the same set of neurons involved in action recognition are also involved in understanding the intentions of others. Recognizing another person's intentions means that the observer has inferred something about that person's goals, wants, or wishes ("Oh, she must be thirsty"). These fMRI results suggest that this kind of recognition occurs effortlessly at a neural level.

Why is this interesting? For one thing, these results suggest a possible inborn neural basis for empathy. Grasping the intentions of another person—indeed, having your brain respond in kind as another person acts—is critical to smooth social interaction. It allows us to understand other people's possible motivations and anticipate their future actions. In fact, these are the kinds of skills that people suffering from autism severely lack. Autism is a developmental disorder characterized by impoverished social interactions and communication skills (Frith, 2001). Psychologists who study autism focus on trying to understand the nature of the disorder and devise ways to help people with autism cope with and function in human society. Research on mirror neurons may offer one avenue for better understanding the origin and prognosis of this disorder (Iacoboni & Dapretto, 2006).

PHOTO/DAVID LONGSTREATH

When one animal observes another engaging in a particular behavior, some of the same neurons become active in the observer as well as in the animal exhibiting the behavior. These mirror neurons, documented in monkeys, birds, and humans, seem to play an important role in the social behavior.

Off The Mark



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One of the first neuroimaging techniques developed was the *computerized axial tomography* (*CT*) *scan*. In a CT scan, a scanner rotates a device around a person's head and takes a series of x-ray photographs from different angles. Computer programs then combine these images to provide views from any angle. CT scans show different densities of tissue in the brain. For example, the higher-density skull looks white on a CT scan, the cortex shows up as gray, and the least dense fissures and ventricles in the brain look dark (see **FIGURE 3.20** on the next page). CT scans are used to locate lesions or tumors, which typically appear darker because they are less dense than the cortex.

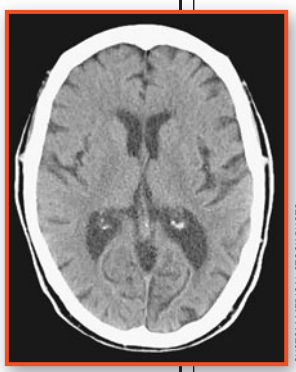
Magnetic resonance imaging (*MRI*) involves applying brief but powerful magnetic pulses to the head and recording how these pulses are absorbed throughout the brain. For very short periods, these magnetic pulses cause molecules in the brain tissue to twist slightly and then relax, which releases a small amount of energy. Differently charged molecules respond differently to the magnetic pulses, so the energy signals reveal brain structures with different molecular compositions. Magnetic

resonance imaging produces pictures of soft tissue at a better resolution than a CT scan, as you can see in Figure 3.20. These techniques give psychologists a clearer picture of the structure of the brain and can help localize brain damage (as when someone suffers a stroke), but they reveal nothing about the functions of the brain.

Two newer techniques show researchers much more than just the structure of the brain. *Functional-brain-imaging* techniques allow us to actually watch the brain in action. These techniques rely on the fact that activated brain areas demand more energy for their neurons to work. This energy is supplied through increased blood flow to the activated areas. Functional-imaging techniques can detect such changes in blood flow. In *positron emission tomography* (*PET*), a harmless radioactive substance is injected into a person's bloodstream. Then the brain is scanned by radiation detectors as the person performs perceptual or cognitive tasks, such as reading or speaking. Areas of the brain that are activated during these tasks demand more energy and greater blood flow, resulting in a higher amount of the radioactivity in that region. The radiation detectors record the level of radioactivity in each region, producing a computerized image of the activated areas (see **FIGURE 3.21**, below).

For psychologists, the most widely used functional-brain-imaging technique nowadays is *functional magnetic resonance imaging* (*fMRI*), which detects the twisting of oxygen-carrying hemoglobin molecules in the blood when they are exposed to magnetic pulses. When active neurons demand more energy and blood flow, oxygenated hemoglobin concentrates in the active areas. fMRI detects the oxygenated hemoglobin and provides a picture of the level of activation in each brain area. Both fMRI and PET allow researchers to localize changes in the brain very accurately. However, fMRI has a couple of advantages over PET. First, fMRI does not require any exposure to a radioactive substance. Second, fMRI can localize changes in brain activity across briefer periods than PET, which makes it more useful for analyzing psychological processes that occur extremely quickly, such as reading a word or recognizing a face.

What does an fMRI track in an active brain?



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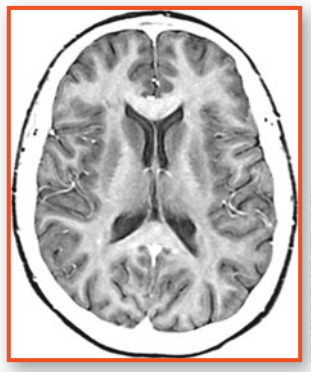
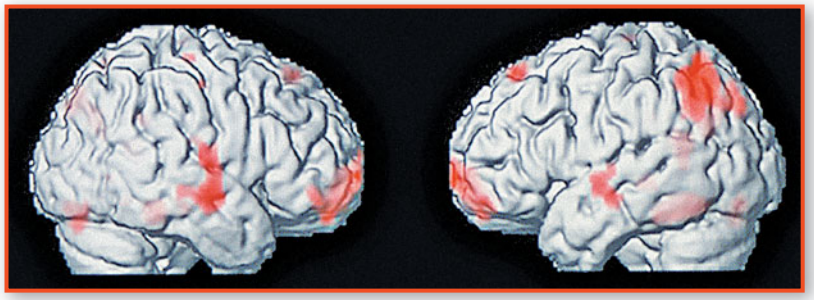


NEIL BORDEN/PHOTO RESEARCHERS

FIGURE 3.20 **Structural Imaging Techniques (CT and MRI)** *CT (left) and MRI (right) scans are used to provide information about the structure of the brain and can help spot tumors and other kinds of damage. Each scan shown here provides a snapshot of a single slice in the brain. Note that the MRI scan provides a clearer, higher-resolution image than the CT scan (see the text for further discussion of how these images are constructed and what they depict).*



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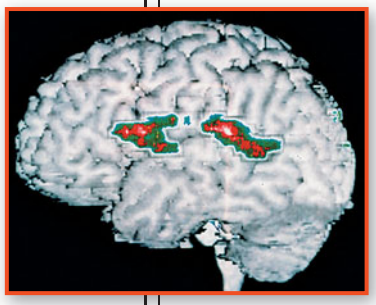
Gesture preparation



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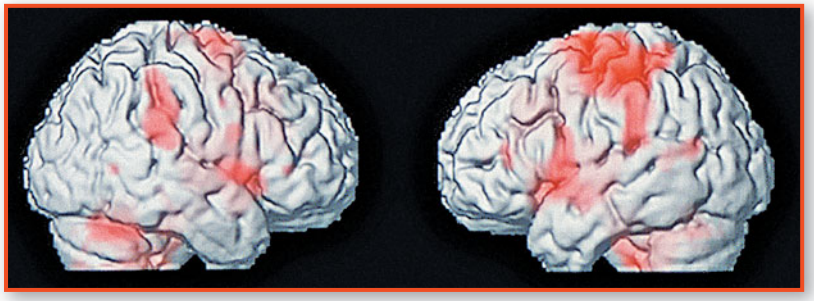

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Gesture production

FIGURE 3.21 **Functional-Imaging Techniques (PET fMRI)** *PET and fMRI scans provide information about the functions of the brain by revealing which brain areas become more or less active in different conditions. The PET scan (directly above) shows areas in the left hemisphere (Broca's area, left; lower parietal-upper temporal area, right) that become active when people hold in mind a string of letters for a few seconds. The fMRI scans (all views to the left) show several different regions in both hemispheres that become active when someone is thinking about a gesture (top) and when performing a gesture (bottom).*

PET and fMRI provide remarkable insights into the types of information processing that take place in specific areas of the brain. For example, when a person performs a simple perceptual task, such as looking at a circular checkerboard, the primary visual areas are activated. But when people perform a task that engages emotional processing, such as looking at sad pictures, researchers observe significant activation in the amygdala, which is linked with emotional arousal (Phelps, 2006). There is also increased activation in parts of the frontal lobe that are involved in emotional regulation—in fact, in the same areas that were most likely damaged in the case of Phineas Gage (Wang et al., 2005). It's always nice when independent methods—in these instances, very old case studies and very recent technology—arrive at the same conclusions. As you'll also see at various points in the text, brain-imaging techniques such as fMRI are also revealing new and surprising findings, such as the insights described in the Where Do You Stand? box (on the next page). Although the human brain still holds many mysteries, researchers are developing increasingly sophisticated ways of unraveling them.

summary quiz [3.4]

13. The earliest evidence that separate brain locations control speech comprehension and speech production was provided by
- a. Phineas Gage.
- b. David Hubel and Torsten Wiesel.
- c. Roger Sperry and his colleagues.
- d. Paul Broca and Carl Wernicke.

14. Split-brain studies have revealed that
- a. neurons in the primary visual cortex represent features of visual stimuli such as contrast, shape, and color.
- b. the two hemispheres perform different functions but can work together by means of the corpus callosum.
- c. when people perform a task that involves emotional processing, the amygdala is activated.
- d. brain locations for vision, touch, and hearing are separate.

15. The activity of specific neurons in the brain can best be detected by means of
- a. brain-imaging techniques.
- b. split-brain procedures.
- c. inserting electrodes into brain cells.
- d. studying the behaviors of individuals with brain damage.

16. Researchers can observe relationships between energy consumption in certain brain areas and specific cognitive and behavioral events using which technique?
- a. functional brain imaging
- b. electroencephalographs
- c. inserting electrodes into individual cells
- d. CT scans

WhereDoYouStand?

Brain Death

A story shrouded in mystery follows the memory of Andreas Vesalius (1514–1564), a Belgian physician regarded as one of the founders of modern anatomy. According to the story, Vesalius conducted an autopsy in 1564 in front of a large crowd in Madrid, Spain. When the cadaver's chest was opened, the audience saw that the man's heart was still beating! The possibility that the patient was still alive created a scandal that forced Vesalius to leave Spain, where he was serving as the imperial physician at the time. He died during his exodus in a shipwreck.

We may never know whether this story is accurate. However, it raises a question related to the brain and behavior that is still fiercely debated today. In Vesalius's time, if a patient didn't appear to be breathing, was generally unresponsive, or gave no strong evidence of a heartbeat, the person could safely be considered dead (despite the occasional misdiagnosis). Modern resuscitative techniques can keep the heart, lungs, and other organs functioning for days, months, or even years, so physicians have identified measures of brain function that allow them to decide more definitively when someone is dead.

In 1981, the President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research defined brain death as the *irreversible loss of all functions of the brain.* Contrary to what you may think, brain death is not the same as being in a coma or being unresponsive to stimulation. Respiration is controlled by structures in the hindbrain, such as the medulla, and will continue as long as this area is intact. A heartbeat does not require input from any area of the brain, so the heart will continue to beat as long it continues to receive oxygen, either by intact respiration or if the patient is artificially ventilated. Also, a patient who is brain dead may continue to have muscle spasms, twitches, or even sit up. This so-called L*azarus reflex* is coordinated solely by the spinal cord.

Brain death came to the forefront of national attention during March 2005 in the case of Terri Schiavo, a woman who had been kept alive on a respirator for nearly 15 years in a Florida nursing home. A person like Schiavo is commonly referred to as brain dead, but such an individual is more accurately described as being in a *persistent vegetative state*. In fact, some people consider patients in a persistent vegetative state to still be alive.

Terri Schiavo's parents thought she had a substantial level of voluntary consciousness; they felt that she appeared to smile, cry, and turn toward the source of a voice. Terri's parents hired physicians who claimed that she had a primitive type of consciousness. However, neurologists who specialize in these cases emphasized that these responses could be automatic reflexes supported by circuits in the thalamus and midbrain. These neurologists failed to see conclusive evidence of consciousness or voluntary behavior.

Terri's husband, Michael, agreed with the neurologists and asked the courts to remove the feeding tube that kept her alive, a decision a Florida court accepted. Nonetheless, Florida governor Jeb Bush decreed in 2003 that doctors retain Terri's feeding tube and continue to provide medical care. Eventually, in 2005, the court again ordered her feeding tube removed, and this time it was not replaced, resulting in her death.

Where do you stand on this issue? Should Terri Schiavo have been kept alive indefinitely? The definition of brain death includes the term *irreversible,* suggesting that as long as *any* component of the brain can still function—with or without the aid of a machine—the person should be considered alive. But does a persistent vegetative state qualify as "life"? Is a simple consensus of qualified professionals–doctors, nurses, social workers, specialists–sufficient to decide whether someone is "still living" or at least "still living enough" to maintain whatever treatments may be in place? How should the wishes of family members be considered? What is your position on these questions of the brain and the ultimate behavior: staying alive?

After you've thought about your answers to these questions, consider this: A recent study found evidence that a person diagnosed as being in a vegetative state showed intentional mental activity (Owen et al., 2006). Researchers used fMRI to observe the patterns of brain activity in a 25-year-old woman with severe brain injuries as the result of a traffic accident. When the researchers spoke ambiguous sentences ("The creak came from a beam in the ceiling") and unambiguous sentences ("There was milk and sugar in his coffee"), fMRI revealed that the activated areas in the woman's brain were comparable to those areas activated in the brains of normal volunteers. What's more, when the woman was instructed to imagine playing a game of tennis and then imagine walking through the rooms of her house, the areas of her brain that showed activity were again indistinguishable from those brain areas in normal, healthy volunteers.

The researchers suggest that these findings are evidence for, at least, conscious understanding of spoken commands and, at best, a degree of intentionality in an otherwise vegetative person. The patient's brain activity while "playing tennis" and "walking through her house" revealed that she could both understand the researchers' instructions and willfully complete them. Unfortunately, it's too early to tell how these and other research findings may impact decisions regarding the brain and when life ends (Laureys et., 2006).

CHAPTER REVIEW

Summary

Neurons: The Origin of Behavior

- Neurons process information, communicate with each other, and send messages to the body's muscles and organs. They contain three major parts: cell body, dendrites, and axon.
- Action potentials occur when sodium channels in the axon membrane open, allowing sodium ions to rush inside, changing the cell's electrical potential.
- When it reaches the end of the axon, the action potential triggers a release of neurotransmitters into the synapse, where they may bind to receptors on the receiving neuron's dendrite, completing transmission of the message.
- Some major neurotransmitters are acetylcholine, dopamine, glutamate, GABA, norepinephrine, serotonin, and the endorphins.
- Drugs can affect behavior by facilitating or increasing, or by blocking, the actions of neurotransmitters.

The Organization of the Nervous System

- The nervous system can be divided into the central nervous system (brain and spinal cord) and the peripheral nervous system (somatic nervous system and autonomic nervous system). The autonomic nervous system can be further divided into the sympathetic nervous system, which oversees arousal to prepare the body to fight or run away, and the parasympathetic nervous system, which helps calm the body after the threat has passed.
- The brain can be divided into the hindbrain (medulla, cerebellum, and pons), the midbrain (tectum and tegmentum), and the forebrain, which includes the cerebral cortex and subcortical structures such as the thalamus, hypothalamus, pituitary gland, hippocampus, and amygdala.
- The cerebral cortex contains two symmetrical hemispheres. Each can be divided into four major lobes: the occipital lobe, which processes visual information; the parietal lobe, which processes sensory (touch) information; the temporal lobe, which is responsible for hearing and language; and the frontal lobe, which has specialized areas for movement, abstract thinking, planning, memory, and judgment. Each lobe also has association areas, which help integrate information across different modalities.

The Evolution of Nervous Systems

- Even the simplest animals have sensory neurons and motor neurons for responding to the environment. The first central nervous system appeared in flatworms.
- Animals can be divided into vertebrates (those with a spinal column) and invertebrates (those without a spinal column). Among vertebrates, reptiles, birds, and mammals have large forebrains; and in mammals, the cerebral cortex is particularly large.
- An individual's behavior is determined by both genetics ("nature") and environment ("nurture"). Heritability is a measure of the degree to which variations in behavior across individuals can be accounted for by genetic factors, but it tells us nothing about specific individuals, about what specific genes cause the behavior, or about how interventions might alter a trait.

Investigating the Brain

- There are three major approaches to studying the link between brain and behavior.
- By studying how perceptual, intellectual, motor, and emotional capabilities are altered in patients with damage to particular areas of the brain, researchers can better understand how those brain areas normally play a role in producing those behaviors.
- Global activity in the brain can be observed from outside the skull (using electroencephalographs), and activity of specific neurons can be recorded to determine whether they respond to particular kinds of stimuli or control particular aspects of behavior.
- With brain imaging, researchers can see the structure of the living brain; with functional brain imaging, researchers can observe correlations energy consumption in particular brain areas with specific cognitive and behavioral events, suggesting that those brain areas are involved in those events.

Key Terms

neurons (p. 56)
cell body (p. 57)
dendrites (p. 57)
axon (p. 57)
glial cell (p. 57)
myelin sheath (p. 57)
synapse (p. 57)
sensory neurons (p. 57)
motor neurons (p. 57)
interneurons (p. 57)
resting potential (p. 59)
action potential (p. 59)
refractory period (p. 60)
terminal buttons (p. 60)
neurotransmitters (p. 60)
receptors (p. 60)
nervous system (p. 64)
central nervous system (CNS) (p. 64)
peripheral nervous system (PNS) (p. 64)
somatic nervous system (p. 64)
autonomic nervous system (p. 65)
sympathetic nervous system (p. 65)
parasympathetic nervous system (p. 65)
spinal reflexes (p. 67)
hindbrain (p. 68)
medulla (p. 68)
reticular formation (p. 68)
cerebellum (p. 69)

pons (p. 69)
tectum (p. 69)
tegmentum (p. 69)
cerebral cortex (p. 70)
subcortical structures (p. 70)
thalamus (p. 70)
hypothalamus (p. 70)
pituitary gland (p. 70)
hippocampus (p. 70)
amygdala (p. 70)
corpus callosum (p. 70)
occipital lobe (p. 71)
parietal lobe (p. 71)
temporal lobe (p. 71)
frontal lobe (p. 71)
association areas (p. 71)
gene (p. 75)
chromosomes, (p. 75)

Critical Thinking Questions

1. In this chapter, you read about the various functions of different areas of the human cerebral cortex. Reptiles and birds have almost no cerebral cortex, while mammals such as rats and cats do have a cerebral cortex, but their frontal lobes are proportionately much smaller than the frontal lobes of humans and other primates.

   How might this explain the fact that only humans have developed complex language, computer technology, and calculus?
2. Different parts of the human cerebral cortex specialize in processing different types of information: The occipital lobe processes visual information, the parietal lobe processes information about touch, the temporal lobe is responsible for hearing and language, and the frontal lobe is involved in planning and judgment.

   Suppose a toddler is playing with the remote control and accidentally pushes the big red button, at which point her favorite cartoon disappears from the television screen. How would the different parts of her cortex encode information about this event so that she may learn not to make the same mistake twice?
3. In Chapter 2, you learned about the difference between correlation and causation, and that even if two events are correlated, it does not necessarily mean that one causes the other. In this chapter, you read about techniques such as fMRI and PET, which researchers can use to measure blood flow or activity in different regions while people perform particular tasks.

   Suppose a researcher designs an experiment in which participants view words on a screen and are asked to pronounce each word aloud, while the researcher uses fMRI to examine brain activity. First, what areas of the brain would you expect to show activity on fMRI while participants complete this task? Second, can the researcher now safely conclude that those brain areas are required for humans to perform word pronunciation?

Answers to Summary Quizzes

Summary Quiz 3.1
1. d; 2. a; 3. c; 4. b; 5. a

Summary Quiz 3.2
6. c; 7. b; 8. a; 9. d

Summary Quiz 3.3
10. c; 11. d; 12. b

Summary Quiz 3.4
13. d; 14. b; 15. c; 16. a