Psychology in the News

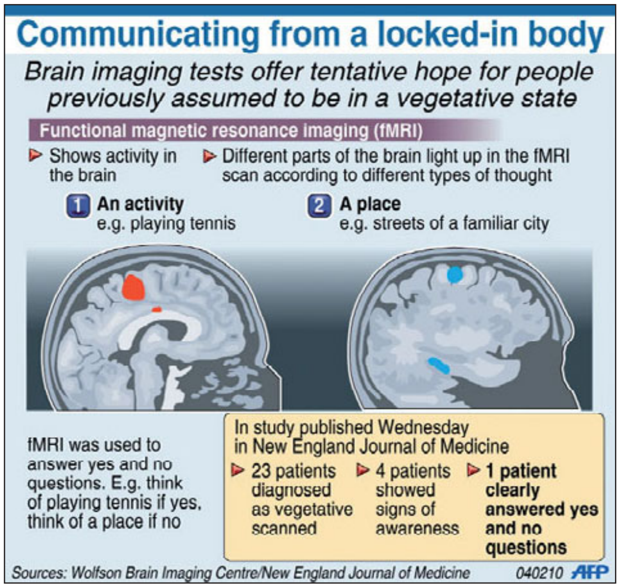
Traces of Consciousness Found in Some Patients Diagnosed as "Vegetative"

LIEGE, BELGIUM, February 4, 2010. A 29-year-old man thought to have been in a persistent vegetative state for five years following a car accident has shown signs of brain activity in response to questions from doctors. Most patients who are in a vegetative state can open and move their eyes and may make sounds and facial expressions, but they have no conscious awareness of themselves or their environment and cannot think or reason.

The man is one of 54 patients with severe brain damage, resulting in their being either in a vegetative or minimally conscious state, who are being studied by an international team of scientists in England and Belgium. Researchers prompted them to imagine themselves playing tennis or walking through the house they grew up in, as their brains were being scanned by functional magnetic resonance imaging (MRI). Five of the 54 were able to intentionally modulate their brain activity in response to these prompts, just as healthy people in a control group could. The researchers then instructed these five patients to respond to yes–no questions by using one type of mental imagery (either playing tennis or walking through the house) for "yes" and the other for "no." Only the man who had been injured in the car accident was able to do this successfully. He responded accurately to simple questions, such as whether his father's name was Paul (yes) or Alexander (no), and whether he had ever been to the United States. Yet, at a bedside evaluation by a skilled clinical team, he showed no consciousness or ability to communicate.

Experts continue to debate just what these findings mean for a patient's state of cognition and consciousness. In 2009, Rom Houben, another victim of a car crash who apparently was unconscious for 23 years, made headlines when neurological tests indicated that he too had some possible awareness, and a brain scan revealed nearly normal activity in his brain. Therapists provided Houben with a computer touch screen that seemed to allow him to communicate by spelling out words. But skeptics pointed out that all of Houben's messages were typed with the help of an aide who supported and guided his hand. Scientific research has discredited such "facilitated communication" and has found that the typed messages come from the facilitator, not the patient. After watching a video of Houben supposedly communicating as a facilitator guided his hand, bioethics expert Arthur Caplan commented, "That is Ouija board stuff."

Nonetheless, these studies suggest that, in rare cases, patients with brain injury may have a greater degree of consciousness than previously believed possible. "With further development," the researchers conclude, "this technique could be used by some patients to express their thoughts, control their environment, and increase their quality of life."



Communicating from a locked-in body

Brain imaging tests offer tentative hope for people previously assumed to be in a vegetative state

Functional magnetic resonance imaging (fMRI)

- Shows activity in the brain
- Different parts of the brain light up in the fMRI scan according to different types of thought

fMRI was used to answer yes and no questions. E.g. think of playing tennis if yes, think of a place if no

In study published Wednesday in New England Journal of Medicine

- 23 patients diagnosed as vegetative scanned
- 4 patients showed signs of awareness
- **1 patient clearly answered yes and no questions**

Sources: Wolfson Brain Imaging Centre/New England Journal of Medicine 040210 AFP

CHAPTER

4

The Nervous System: A Basic Blueprint

Communication in the Nervous System

Mapping the Brain

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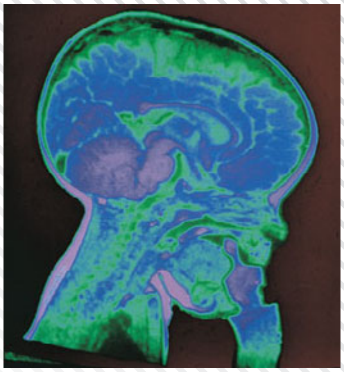
Neurons, Hormones, and the Brain

There is almost nothing that human beings fear more than having a conscious brain in a paralyzed head and body—with a brain that is alive and functioning yet with no way to communicate to the outside world. So it is no wonder that stories of people who seem to recover from comas or vegetative states after many years, or who show signs of brain activity when they were previously thought to be brain dead, are both exciting and terrifying.

Incidents of apparent consciousness in vegetative patients raise all sorts of difficult medical, psychological, and ethical issues. How can we know for sure whether a person has become incapable of higher mental function? Does brain-scan technology offer an answer, or merely a possible clue? Will rare cases of awareness give families false hope that their loved one is "really in there" when the person actually lacks all cognitive function? Should a patient's apparent responses to yes–no questions be used to draw conclusions about whether the person is in pain—or wants to live or die?

Cases of brain injury and disease vividly remind us that the 3-pound organ inside our skulls provides the bedrock for everything we do, feel, and think. *Neuropsychologists*, along with neuroscientists from other disciplines, study the brain and the rest of the nervous system in hopes of gaining a better understanding of normal behavior and of the outer reaches of what is possible for this organ. They are concerned with the biological foundations of consciousness, perception, memory, emotion, stress, and mental disorders—of everything, in fact, that human beings feel and do. In this chapter, we will examine the structure of the brain and the rest of the nervous system as background for our later discussions of these and other topics.

At this very moment, your own brain, assisted by other parts of your nervous system, is busily taking in these words. Whether you are excited, curious, or bored, your brain is registering some sort of emotional reaction. As you continue reading, your brain will (we hope) store away much of the information in this chapter. Later on, your brain may enable you to smell a flower, climb the stairs,



The study of this mysterious 3-pound organ raises many challenging questions. Why can a small glitch in the brain's circuits be devastating to some people, whereas others can function with major damage? How do experiences alter our brains? And where in this collection of cells and circuits are the mind and our sense of self to be found?

greet a friend, solve a problem, or chuckle at a joke. But the brain's most startling accomplishment is its knowledge that it is doing all these things. This self-awareness makes brain research different from the study of anything else in the universe. Scientists must use the cells, biochemistry, and circuitry of their own brains to understand the cells, biochemistry, and circuitry of brains in general.

William Shakespeare called the brain "the soul's frail dwelling house." Actually, this miraculous organ is more like the main room in a house filled with many alcoves and passageways—the "house" being the nervous system as a whole. Before we can understand the windows, walls, and furniture of this house, we need to become acquainted with the overall floor plan.

YOU are about to learn...

- **why you automatically pull your hand away from something hot, without thinking.**
- **the major parts of the nervous system and their primary functions.**

The Nervous System: A Basic Blueprint

The function of a nervous system is to gather and process information, produce responses to stimuli, and coordinate the workings of different cells. Even the lowly jellyfish and the humble earthworm have the beginnings of such a system. In very simple organisms that do little more than move, eat, and eliminate wastes, the "system" may be no more than one or two nerve cells. In human beings, who do such complex things as dance, cook, and take psychology courses, the nervous system contains billions of cells. Scientists divide this intricate network into two main parts: the central nervous system and the peripheral (outlying) nervous system (see Figure 4.1).

The Central Nervous System

central nervous system (CNS) The portion of the nervous system consisting of the brain and spinal cord.

spinal cord A collection of neurons and supportive tissue running from the base of the brain down the center of the back, protected by a column of bones (the spinal column).

The **central nervous system (CNS)** receives, processes, interprets, and stores incoming sensory information—information about tastes, sounds, smells, color, pressure on the skin, the state of internal organs, and so forth. It also sends out messages destined for muscles, glands, and internal organs. The CNS is usually conceptualized as having two components: the brain, which we will consider in detail later, and the **spinal cord**, which is actually an extension of the brain. The spinal cord runs from the base of the brain down the center of the back, protected by a column of bones (the spinal column), and it acts as a bridge between the brain and the parts of the body below the neck.

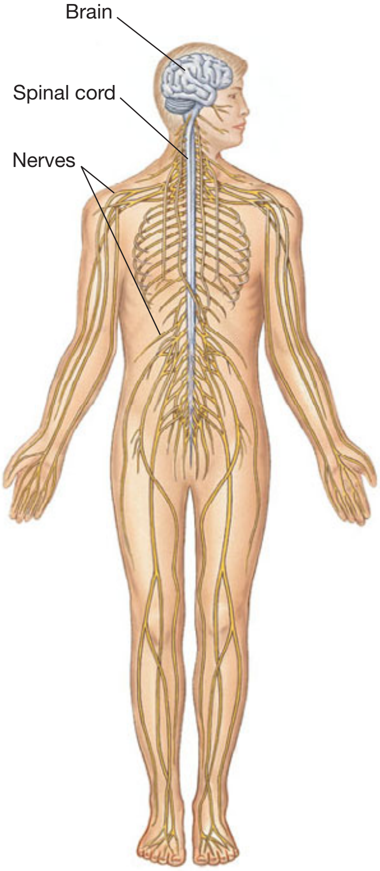


FIGURE 4.1
The Central and Peripheral Nervous Systems
The central nervous system includes the brain and the spinal cord. The peripheral nervous system consists of 43 pairs of nerves that transmit information to and from the central nervous system. Twelve pairs of cranial nerves in the head enter the brain directly; 31 pairs of spinal nerves enter the spinal cord at the spaces between the vertebrae.

The spinal cord produces some behaviors on its own without any help from the brain. These *spinal reflexes* are automatic, requiring no conscious effort. If you accidentally touch a hot iron, you will immediately pull your hand away, even before your brain has had a chance to register what has happened. Nerve impulses bring a message to the spinal cord (hot!), and the spinal cord immediately sends out a command via other nerve impulses, telling muscles in your arm to contract and to pull your hand away from the iron. (Reflexes above the neck, such as sneezing and blinking, involve the lower part of the brain rather than the spinal cord.)

The neural circuits underlying many spinal reflexes are linked to neural pathways that run up and down the spinal cord, to and from the brain.

Because of these connections, reflexes can sometimes be influenced by thoughts and emotions. An example is erection in men, a spinal reflex that can be inhibited by anxiety or distracting thoughts and initiated by erotic thoughts. Moreover, some reflexes can be brought under conscious control. If you concentrate, you may be able to keep your knee from jerking when it is tapped, as it normally would. Similarly, most men can learn to voluntarily delay ejaculation, another spinal reflex. (Yes, they can.)

The Peripheral Nervous System

The **peripheral nervous system (PNS)** handles the central nervous system's input and output. It contains all portions of the nervous system outside the brain and spinal cord, right down to the nerves in the tips of the fingers and toes. If your brain could not collect information about the world by means of a peripheral nervous system, it would be like a radio without a receiver. In the peripheral nervous system, *sensory nerves* carry messages from special receptors in the skin, muscles, and other internal and external sense organs to the spinal cord, which sends them along to the brain. These nerves put us in touch with both the outside world and the activities of our own bodies. *Motor nerves* carry orders from the central nervous system to muscles, glands, and internal organs. They enable us to move, and they cause glands to contract and to secrete substances, including chemical messengers called *hormones*.

Scientists further divide the peripheral nervous system into two parts: the somatic (bodily) nervous system and the autonomic (self-governing) nervous system. The **somatic nervous system**, sometimes called the *skeletal nervous system*, consists of nerves that are connected to sensory receptors—cells that enable you to sense the world—and also to the skeletal muscles that permit voluntary action. When you feel a bug on your arm, or when you turn off a light or write your name, your somatic system is active. The **autonomic nervous system** regulates the functioning of blood vessels, glands, and internal (visceral) organs such as the bladder, stomach, and heart. When you see someone you have a crush on and your heart pounds, your hands get sweaty, and your cheeks feel hot, you can blame your autonomic nervous system.

The autonomic nervous system is itself divided into two parts: the **sympathetic nervous system** and the **parasympathetic nervous system**. These two parts work together, but in opposing ways, to adjust the body to changing circumstances (see Figure 4.2).

peripheral nervous system (PNS) All portions of the nervous system outside the brain and spinal cord; it includes sensory and motor nerves.

somatic nervous system The subdivision of the peripheral nervous system that connects to sensory receptors and to skeletal muscles; sometimes called the *skeletal nervous system*.

autonomic nervous system The subdivision of the peripheral nervous system that regulates the internal organs and glands.

sympathetic nervous system The subdivision of the autonomic nervous system that mobilizes bodily resources and increases the output of energy during emotion and stress.

parasympathetic nervous system The subdivision of the autonomic nervous system that operates during relaxed states and that conserves energy.

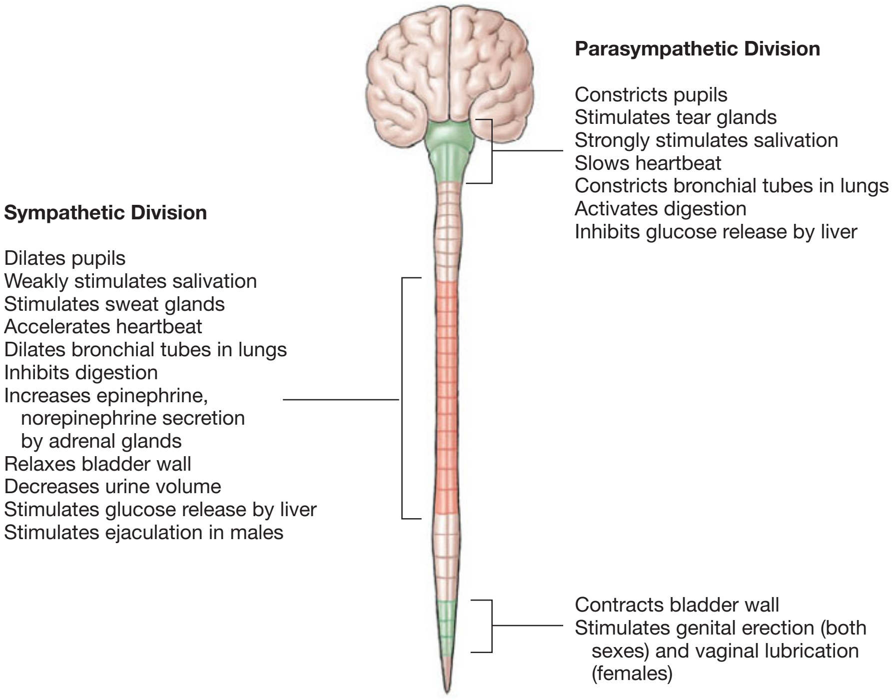


FIGURE 4.2

The Autonomic Nervous System

In general, the sympathetic division of the autonomic nervous system prepares the body to expend energy and the parasympathetic division restores and conserves energy. Sympathetic nerve fibers exit from areas of the spinal cord (shown in red); parasympathetic fibers exit from the base of the brain and from spinal cord areas (shown in green).

Explore **Autonomic Nervous System** on **mypsychlab.com**

The sympathetic system acts like the accelerator of a car, mobilizing the body for action and an output of energy. It makes you blush, sweat, and breathe more deeply, and it pushes up your heart rate and blood pressure. As we discuss in Chapter 13, when you are in a situation that requires you to fight, flee, or cope, the sympathetic nervous system whirls into action. The parasympathetic system is more like a brake: It does not stop the body, of course, but it does tend to slow things down and keep them running smoothly. It enables the body to conserve and store energy. In everyday life, the two systems work in harmony. If you have to jump out of the way of a speeding motorcyclist, sympathetic nerves increase your heart rate. Afterward, parasympathetic nerves slow it down again and keep its rhythm regular.

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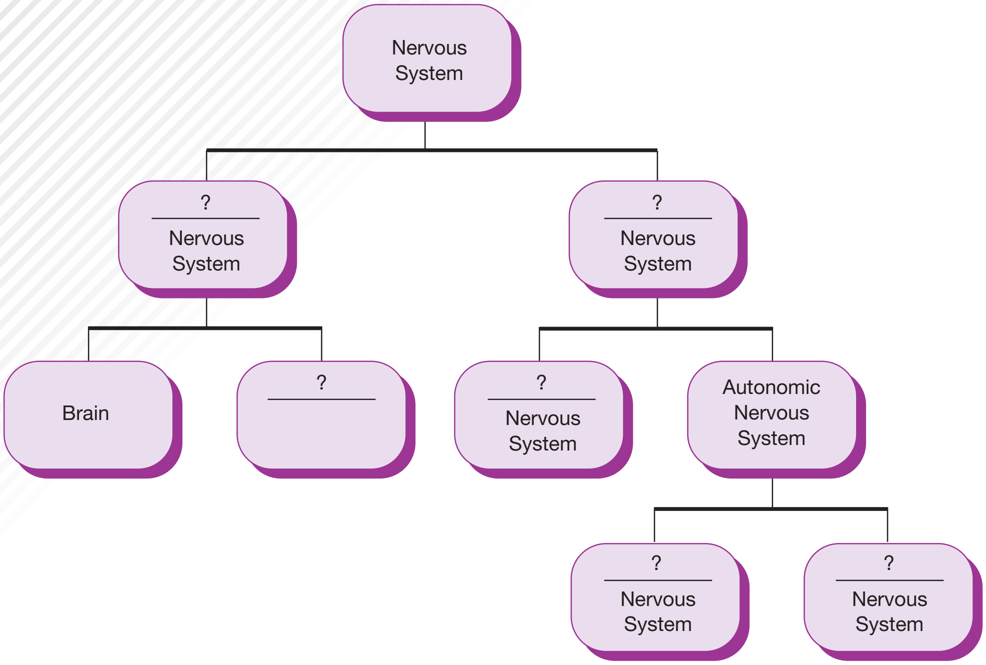
Quick Quiz

Pause now to mentally fill in the missing parts of the nervous system "house." Then see whether you can briefly describe what each part of the system does.



Answers:

1. central: processes, interprets, and stores information and issues orders to muscles, glands, and organs **2.** peripheral: transmits information to and from the CNS **3.** spinal cord: serves as a bridge between the brain and the peripheral nervous system, produces reflexes **4.** somatic: controls the skeletal muscles **5.** sympathetic: mobilizes the body for action, energy output **6.** parasympathetic: conserves energy, maintains the body in a quiet state

YOU are about to learn...

- which cells function as the nervous system's communication specialists, and how they "talk" to each other.
- the functions of glial cells, the most numerous cells in the brain.
- why researchers are excited about the discovery of stem cells in the brain.
- how learning and experience alter the brain's circuits.
- what happens when levels of neurotransmitters are too low or too high.
- which brain chemicals mimic the effects of morphine by dulling pain and promoting pleasure.
- which hormones are of special interest to psychologists, and why.

Communication in the Nervous System

The blueprint we just described provides only a general idea of the nervous system's structure. Now let's turn to the details.

The nervous system is made up in part of **neurons**, or *nerve cells*. They are the brain's communication specialists, transmitting information to, from, and within the central nervous system. Neurons are held in place by **glia**, or *glial cells* (from the Greek word for "glue"), which make up 90 percent of the brain's cells.

Glial cells are more than just glue, however. They provide the neurons with nutrients, insulate them, protect the brain from toxic agents, and remove cellular debris when neurons die. They also communicate chemically with each other and with neurons, and without them, neurons could not function effectively. One kind of glial cell appears to give neurons the go-ahead to form connections and to start "talking" to each other (Ullian, Christopherson, & Barres, 2004). And over time, glia help determine which neural connections get stronger or weaker, suggesting that they play a vital role in learning and memory (Fields, 2004).

It's neurons, however, that are considered the building blocks of the nervous system, though in structure they are more like snowflakes than blocks, exquisitely delicate and differing from one another greatly in size and shape (see Figure 4.3). In the giraffe, a neuron that runs from the spinal cord down the animal's hind leg may be 9 feet long! In the human brain, neurons are microscopic. No one is sure how many neurons the human brain contains, but a typical estimate is 100 billion, about the same number as there are stars in our galaxy, and some estimates go much higher.

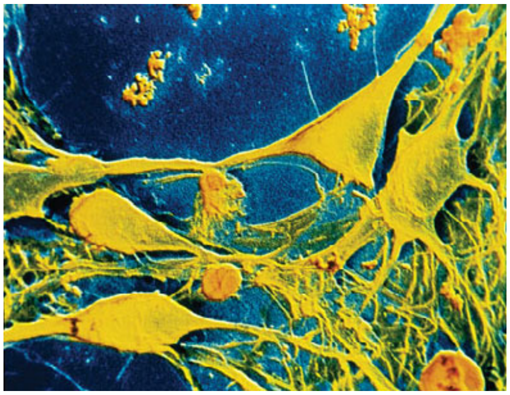
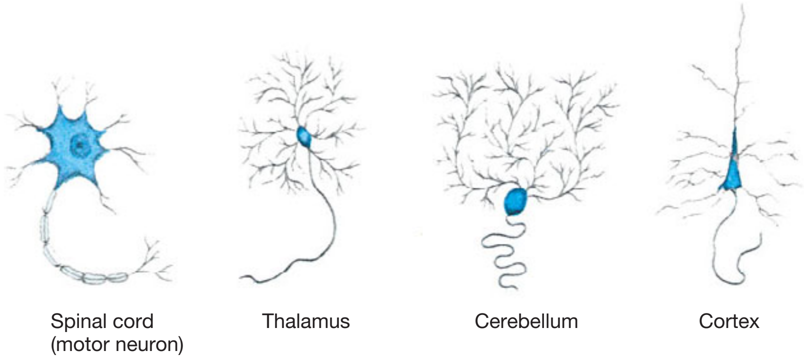


FIGURE 4.3

Different Kinds of Neurons

Neurons vary in size and shape, depending on their location and function. More than 200 types of neurons have been identified in mammals. This photo shows neurons in the outer layers of the brain.



The Structure of the Neuron

As you can see in Figure 4.4, a neuron has three main parts: *dendrites*, a *cell body*, and an *axon*. The **dendrites** look like the branches of a tree; indeed, the word *dendrite* means "little tree" in Greek. Dendrites act like antennas, receiving messages from as many as 10,000 other nerve cells and transmitting these messages toward the cell body. They also do some preliminary processing of those messages. The **cell body**, which is shaped roughly like a sphere or a pyramid, contains the biochemical machinery for keeping the neuron alive. It also plays the key role in determining whether the neuron should fire—transmit a message to other neurons—depending on inputs from other neurons. The **axon** (from the Greek for "axle") transmits messages away from the cell body

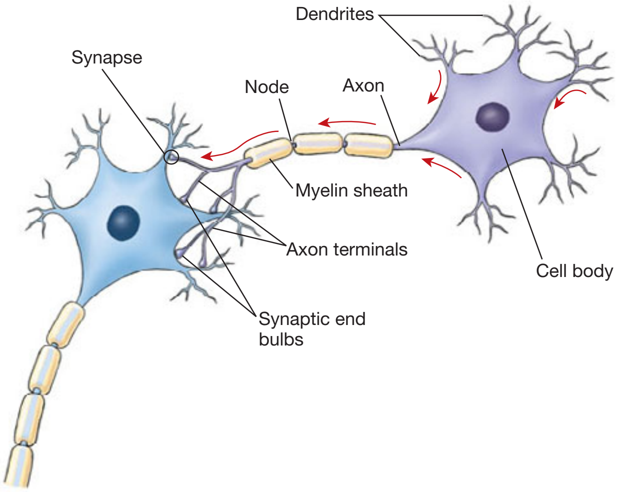


FIGURE 4.4

The Structure of a Neuron

Incoming neural impulses are received by the dendrites of a neuron and are transmitted to the cell body. Outgoing signals pass along the axon to terminal branches.

neuron A cell that conducts electrochemical signals; the basic unit of the nervous system; also called a *nerve cell*.

glia [GLY-uh or GLEE-uh] Cells that support, nurture, and insulate neurons, remove debris when neurons die, enhance the formation and maintenance of neural connections, and modify neuronal functioning.

dendrites A neuron's branches that receive information from other neurons and transmit it toward the cell body.

cell body The part of the neuron that keeps it alive and determines whether it will fire.

axon A neuron's extending fiber that conducts impulses away from the cell body and transmits them to other neurons or to muscle or gland cells.

myelin sheath A fatty insulation that may surround the axon of a neuron.

nerves A bundle of nerve fibers (axons and sometimes dendrites) in the peripheral nervous system.

neurogenesis The production of new neurons from immature stem cells.

stem cells Immature cells that renew themselves and have the potential to develop into mature cells; given encouraging environments, stem cells from early embryos can develop into any cell type.

to other neurons or to muscle or gland cells. Axons commonly divide at the end into branches called *axon terminals*. In adult human beings, axons vary from only four-thousandths of an inch to a few feet in length. Dendrites and axons give each neuron a double role: As one researcher put it, a neuron is first a catcher, then a batter (Gazzaniga, 1988).

Many axons, especially the larger ones, are insulated by a surrounding layer of fatty material called the **myelin sheath**, which in the central nervous system is made up of glial cells. Constrictions in this covering, called *nodes*, divide it into segments, which make it look a little like a string of link sausages (see Figure 4.4 again). One purpose of the myelin sheath is to prevent signals in adjacent cells from interfering with each other. Another, as we will see shortly, is to speed up the conduction of neural impulses. In individuals with multiple sclerosis, loss of myelin causes erratic nerve signals, leading to loss of sensation, weakness or paralysis, lack of coordination, or vision problems.

In the peripheral nervous system, the fibers of individual neurons (axons and sometimes dendrites) are collected together in bundles called **nerves**, rather like the lines in a telephone cable. The human body has 43 pairs of peripheral nerves; one nerve from each pair is on the left side of the body and the other is on the right. Most of these nerves enter or leave the spinal cord, but 12 pairs in the head, the *cranial nerves*, connect directly to the brain. In Chapter 6, we will discuss cranial nerves that are involved in the senses of smell, hearing, and vision.

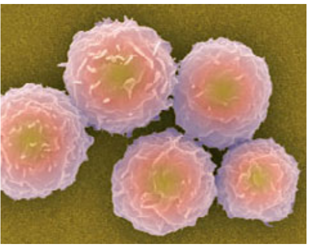
Neurons in the News

For most of the twentieth century, scientists assumed that if neurons in the central nervous system were injured or damaged, they could never grow back (regenerate). But then the conventional wisdom got turned upside down. Animal studies showed that severed axons in the spinal cord *can* regrow if you treat them with particular nervous system chemicals (Schnell & Schwab, 1990). Researchers are hopeful that regenerated axons will eventually enable people with spinal cord injuries to use their limbs again.

In the past two decades, scientists have also had to rethink another entrenched assumption: that mammals produce no new CNS cells after infancy. In the early 1990s, Canadian neuroscientists, working with mice, immersed immature cells from the animals' brains in a growth-promoting protein and showed that these cells could give birth to new neurons in a process called **neurogenesis**. Even more astonishing, the new neurons continued to divide and multiply (Reynolds & Weiss, 1992). Since then, scientists have discovered that the human brain and other body organs also contain such cells, which are now known as **stem cells**. Stem cells involved in learning and memory seem to divide and mature throughout adulthood. Animal studies find that physical exercise, effortful mental activity, and an enriched environment promote the production and survival of new cells, whereas aging and stress can inhibit their production and nicotine can kill them (Berger, Gage, & Vijayaraghavan, 1998; Kempermann, 2006; Shors, 2009).

Stem-cell research is one of the hottest areas in biology and neuroscience. But in the United States, federal funding for basic stem-cell research has faced strong resistance by antiabortion activists who are opposed to taking cells from embryos that are a few days old, which consist of just a few cells. (Fertility clinics store many such embryos because several test-tube fertilizations are created for every patient who hopes to become pregnant; eventually, the extra embryos are destroyed.) Embryonic stem (ES) cells are especially useful because they can differentiate into any type of cell, from neurons to kidney cells, whereas those from adults are more limited and are harder to keep alive. Scientists have also been able to reprogram cells from adult organs, most notably skin cells, to become stem cells (e.g., Takahashi et al., 2007; Yu et al., 2007). Like ES cells, these "induced pluripotent stem (iPS) cells" seem capable of giving rise to all types of cells, although it is still unclear whether they will prove to be equally versatile; in one comparison test, the embryonic stem cells made more than 1,000 times more of the desired cells than did the iPS cell lines (Feng et al., 2010). Some scientists have directly turned skin cells taken from the tails of mice into neurons without first turning the cells into iPS cells (Vierbuchen et al., 2010). The next step will be to see if the same can be done with human cells.

Advocacy groups hope that transplanted stem cells will eventually help people recover from diseases of the brain (such as Parkinson's) and from damage to the spinal cord and other parts of the body. Scientists have already had some success in animals. In one study, mice with recent spinal cord injuries regained much of their ability to walk normally after being injected with stem cells derived from human fetal brain tissue. Microscopic analysis showed that most of the cells had turned into either neurons or a particular type of glial cell (Cummings et al., 2005). In 2009, the FDA approved the first



Tiny stem cells like these (magnified 1,200 times in this photo) have provoked both excitement and controversy.

In an area associated with learning and memory, immature stem cells give rise to new neurons, and physical and mental stimulation promotes the production and survival of these neurons. These mice have toys to play with, tunnels to explore, wheels to run on, and other mice to share their cage with. They will grow more cells than mice living alone in standard cages.

small U.S. trial with human patients with spinal cord injuries (Couzin, 2009).

A long road lies ahead, and many daunting technical hurdles remain to be overcome before stem-cell research yields practical benefits for human patients. Increasing the rate of neurogenesis may alleviate or improve some medical conditions but have negative or no effects on others (Scharfman & Hen, 2007). We live in exciting times. Each year brings more incredible findings about neurons, findings that only a short time ago would have seemed like science fiction.

How Neurons Communicate

Neurons do not directly touch each other, end to end. Instead, they are separated by a minuscule space called the *synaptic cleft*, where the axon terminal of one neuron nearly touches a dendrite or the cell body of another. The entire site—the axon terminal, the cleft, and the covering membrane of the receiving dendrite or cell body—is called a **synapse**. Because a neuron's axon may have hundreds or even thousands of terminals, a single neuron may have synaptic connections with a great many others. As a result, the number of communication links in the nervous system runs into the trillions or perhaps even the quadrillions.

Neurons speak to one another, or in some cases to muscles or glands, in an electrical and chemical language. When a nerve cell is stimulated, a change in electrical potential occurs between the inside and the outside of the cell. The physics of this process involves the sudden, momentary inflow of positively charged sodium ions across the cell's membrane, followed by the outflow of positively charged potassium ions. The result is a brief change in electrical voltage, called an **action potential**, which produces an electric current, or impulse.

If an axon is unmyelinated, the action potential at each point in the axon gives rise to a new action potential at the next point; thus, the impulse travels down the axon somewhat as fire travels along the fuse of a firecracker. But in myelinated axons, the process is a little different. Conduction of a neural impulse beneath the sheath is impossible, in part because sodium and potassium ions cannot cross the cell's membrane except at the breaks (nodes) between the myelin's "sausages." Instead, the action potential "hops" from one node to the next. (More precisely, the action potential regenerates at each node.) This arrangement allows the impulse to travel faster than it could if the action potential had to be regenerated at every point along the axon. Nerve impulses travel more slowly in babies than in older children and adults, because when babies are born, the myelin sheaths on their axons are not yet fully developed.

When a neural impulse reaches the axon terminal's buttonlike tip, it must get its message across the synaptic cleft to another cell. At this point, *synaptic vesicles*, tiny sacs in the tip of the axon terminal, open and release a few thousand molecules of a chemical substance called a **neurotransmitter**. Like sailors carrying a message from one island to another, these molecules then diffuse across the synaptic cleft (see Figure 4.5 on the next page).

When they reach the other side, the neurotransmitter molecules bind briefly with *receptor sites*, special molecules in the membrane of the receiving neuron's dendrites (or sometimes cell body), fitting these sites much as a key fits a lock. Changes occur in the receiving neuron's membrane, and the ultimate effect is either *excitatory* (a voltage shift in a positive direction) or *inhibitory* (a voltage shift in a negative direction), depending on which receptor sites have been activated. If the effect is excitatory, the probability that the receiving neuron will fire increases; if it is inhibitory, the probability decreases. Inhibition in the nervous system is extremely important. Without it, we could not sleep or coordinate our movements. Excitation of the nervous system would be overwhelming, producing convulsions.

What any given neuron does at any given moment depends on the net effect of all the messages being received from other neurons. Only when the

synapse The site where transmission of a nerve impulse from one nerve cell to another occurs; it includes the axon terminal, the synaptic cleft, and receptor sites in the membrane of the receiving cell.

action potential A brief change in electrical voltage that occurs between the inside and the outside of an axon when a neuron is stimulated; it serves to produce an electrical impulse.

neurotransmitter A chemical substance that is released by a transmitting neuron at the synapse and that alters the activity of a receiving neuron.

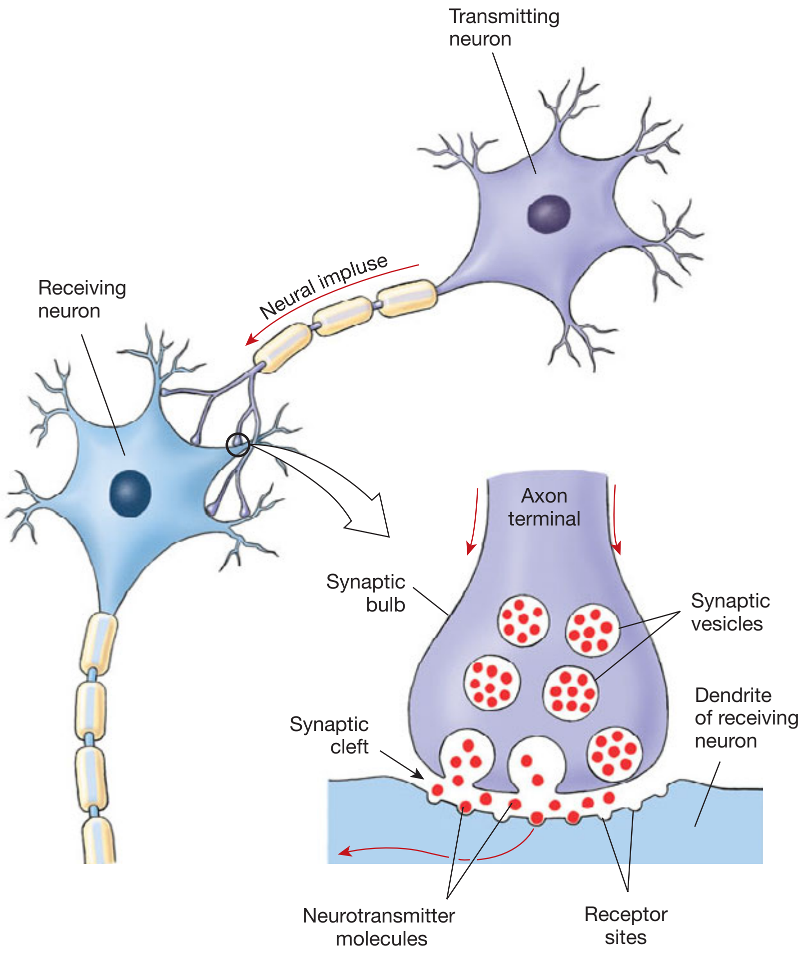


FIGURE 4.5

Neurotransmitter Crossing a Synapse

Neurotransmitter molecules are released into the synaptic cleft between two neurons from vesicles (chambers) in the transmitting neuron's axon terminal. The molecules then bind to receptor sites on the receiving neuron. As a result, the electrical state of the receiving neuron changes and the neuron becomes either more likely to fire an impulse or less so, depending on the type of neurotransmitter.

cell's voltage reaches a certain threshold will it fire. Thousands of messages, both excitatory and inhibitory, may be coming into the cell, and the receiving neuron must essentially average them. The message that reaches a final destination depends on the rate at which individual neurons are firing, how many are firing, what types of neurons are firing, where the neurons are located, and the degree of synchrony among different neurons. It does *not* depend on how strongly the individual neurons are firing, however, because a neuron always either fires or doesn't. Like the turning on of a light switch, the firing of a neuron is an all-or-none event.

plasticity The brain's ability to change and adapt in response to experience, by reorganizing or growing new neural connections.

The Plastic Brain

When we are born, most of our synapses have not yet formed, but new synapses proliferate at a great rate during infancy (see Figure 4.6). Axons and dendrites continue to grow, and tiny projections on dendrites, called *spines*, increase in size and number, producing more complex connections among the brain's nerve cells. Just as new learning and stimulating environments promote the production of new neurons, they also produce increases in synaptic complexity (Diamond, 1993; Greenough & Anderson, 1991; Greenough & Black, 1992; Rosenzweig, 1984). During childhood, unused synaptic connections are also pruned away as cells or their branches die and are not replaced, leaving behind a more efficient neural network. These changes may help explain why critical or sensitive periods for the development of some sensory and cognitive abilities occur early in life. During these periods, acquisition of these skills is amazingly rapid, but when the period ends, learning slows and may even become irreversible (Thomas & Johnson, 2008). (We discuss critical periods in language development in Chapter 3 and in visual development in Chapter 6.) Pruning and increases in synaptic density, however, are not confined to childhood. They have another important developmental phase in adolescence and may continue all through life. For the most part, the brain retains flexibility in adapting to new experiences, an adaptability neuroscientists call **plasticity**.

Plasticity is vividly demonstrated in cases of people with brain damage who have experienced

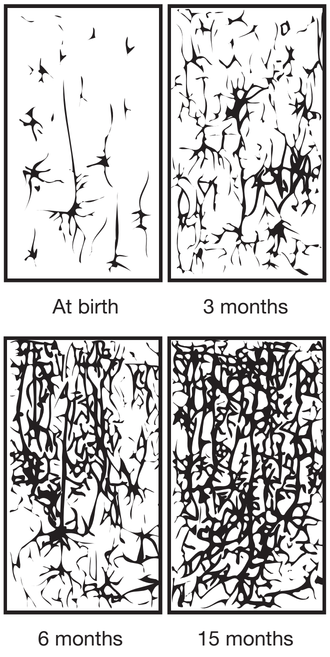


FIGURE 4.6

Getting Connected

Neurons in a newborn's brain are widely spaced, but they immediately begin to form new connections. These drawings show the marked increase in the number of connections from birth to age 15 months.

remarkable recoveries—such as individuals who cannot recall simple words after a stroke but are speaking normally within months, or who cannot move an arm after a head injury but regain full use of the limb after physical therapy. Their brains have apparently rewired themselves to adapt to the damage (Liepert et al., 2000).

When people who have been blind from birth or early childhood try to determine where a sound is coming from, what happens in the part of the brain that, in sighted people, processes visual information? In some blind people, might regions normally devoted to vision begin to process input from other senses instead? Using brain-scan technology, a team of researchers examined the brains of people as they localized sounds heard through speakers (Gougoux et al., 2005). Some participants were sighted and others had been blind from early in life. When the participants heard sounds through both ears, activity in the occipital cortex, an area associated with vision, decreased in the sighted people but *not* in the blind ones. When one ear was plugged, blind participants who did especially well at localizing sounds showed activation in two areas of the occipital cortex; neither sighted people nor blind people with ordinary ability showed such activation. The degree of activation in these regions was correlated with the blind people's accuracy on the task, suggesting that their brains had adapted to blindness by recruiting visual areas to take part in activities involving hearing—a dramatic example of plasticity.

Building on this research, the researchers wondered what would happen if sighted people were blindfolded for five days and had to adapt to their temporary inability to see. Before donning the blindfolds, the volunteers' brain scans showed that the visual areas in their brains were quiet during tasks requiring hearing or touch. By the fifth day, however, these areas were lighting up during the tasks. Then, after the blindfolds were removed, the visual centers once again quieted down (Pascual-Leone et al., 2005). The visual areas of the brain apparently possess the computational machinery necessary for processing nonvisual information, but this machinery remains dormant until circumstances require its activation (Amedi et al., 2005). When people have been blind for most of their lives, new connections may form, permitting lasting structural changes in the brain's wiring.

This research teaches us that the brain is a dynamic organ: Its circuits are continually being modified in response to information, challenges, and changes in the environment. As scientists come to understand this process better, they may be able to apply their knowledge by designing improved rehabilitation programs for people with sensory impairments, developmental disabilities, and brain injuries.

Chemical Messengers in the Nervous System

The nervous system "house" would remain forever dark and lifeless without chemical couriers such as the neurotransmitters. Let's look more closely now at these substances and at two other types of chemical messengers: endorphins and hormones.

Neurotransmitters: Versatile Couriers

As we have seen, neurotransmitters make it possible for one neuron to excite or inhibit another. Neurotransmitters exist not only in the brain but also in the spinal cord, the peripheral nerves, and certain glands. Through their effects on specific nerve circuits, these substances can affect mood, memory, and well-being. The nature of the effect depends on the level of the neurotransmitter, its location, and the type of receptor it binds with. Here are a few of the better-understood neurotransmitters and some of their known or suspected effects: **Explore**

Explore Neuronal Transmission on **mypsychlab.com**

- *Serotonin* affects neurons involved in sleep, appetite, sensory perception, temperature regulation, pain suppression, and mood.
- *Dopamine* affects neurons involved in voluntary movement, learning, memory, emotion, pleasure or reward, and, possibly, response to novelty.
- *Acetylcholine* affects neurons involved in muscle action, cognitive functioning, memory, and emotion.
- *Norepinephrine* affects neurons involved in increased heart rate and the slowing of intestinal activity during stress, and neurons involved in learning, memory, dreaming, waking from sleep, and emotion.
- *GABA (gamma-aminobutyric acid)* is the major inhibitory neurotransmitter in the brain.
- *Glutamate* is the major excitatory neurotransmitter in the brain; it is released by about 90 percent of the brain's neurons.

Harmful effects can occur when neurotransmitter levels are too high or too low. Abnormal GABA levels have been implicated in sleep and eating disorders and in convulsive disorders, including epilepsy. People with Alzheimer's disease lose brain cells responsible for producing acetylcholine and other neurotransmitters, and these deficits help account for their devastating memory problems. A loss of cells that produce dopamine is responsible for the tremors and rigidity of Parkinson's disease. In multiple sclerosis, immune cells overproduce

Former heavyweight champion Muhammad Ali and actor Michael J. Fox both have Parkinson's disease, which involves a loss of dopamine-producing cells. They have used their fame to draw public attention to the disorder.

glutamate, which damages or kills glial cells that normally make myelin.

We want to warn you, however, that pinning down the relationship between neurotransmitter abnormalities and behavioral or physical abnormalities is extremely tricky. Each neurotransmitter plays multiple roles, and the functions of different substances often overlap. Further, it is always possible that something about a disorder leads to abnormal neurotransmitter levels instead of the other way around. For example, although drugs that boost or decrease levels of particular neurotransmitters are sometimes effective in treating some mental disorders, such as depression, this fact does not necessarily mean that abnormal neurotransmitter levels *cause* the disorders. After all, aspirin can relieve a headache, but headaches are not caused by a lack of aspirin!

Many of us regularly ingest things that affect our own neurotransmitters. Even ordinary foods can influence the availability of neurotransmitters in the brain. Most recreational drugs produce their effects by blocking or enhancing the actions of neurotransmitters. So do some herbal remedies. St. John's wort, which is often taken for depression, prevents the cells that release serotonin from reabsorbing excess molecules that have remained in the synaptic cleft; as a result, serotonin levels rise. Many people do not realize that such remedies, because they affect the nervous system's biochemistry, can interact with other medications and can be harmful in high doses.

endorphins [en-DOR-fins] Chemical substances in the nervous system that are similar in structure and action to opiates; they are involved in pain reduction, pleasure, and memory and are known technically as *endogenous opioid peptides*.

hormones Chemical substances, secreted by organs called *glands*, that affect the functioning of other organs.

endocrine glands Internal organs that produce hormones and release them into the bloodstream.

Endorphins: The Brain's Natural Opiates

Another intriguing group of chemical messengers is known collectively as *endogenous opioid peptides*, or more popularly as **endorphins**. Endorphins have effects similar to those of natural opiates; that is, they reduce pain and promote pleasure. They are also thought to play a role in appetite, sexual activity, blood pressure, mood, learning, and memory. Some endorphins function as neurotransmitters, but most of them act primarily by limiting, prolonging, or altering the effects of neurotransmitters.

Endorphin levels seem to shoot up when an animal or a person is afraid or under stress. This is no accident; by making pain bearable in such situations, endorphins give a species an evolutionary advantage. When an organism is threatened, it needs to do something fast. Pain, however, can interfere with action: A mouse that pauses to lick a wounded paw may become a cat's dinner; a soldier who is overcome by an injury may never get off the battlefield. But, of course, the body's built-in system of counteracting pain is only partly successful, especially when painful stimulation is prolonged.

In Chapter 14, we will see that a link also exists between endorphins and human attachment. Research with animals suggests that, in infancy, contact with the mother stimulates the flow of endorphins, which strengthens the infant's bond with her. Some researchers now think that this endorphin rush also occurs in the early stages of passionate love between adults, accounting for the feeling of euphoria that "falling" for someone creates (Diamond, 2004).

Hormones: Long-Distance Messengers

Hormones, which make up the third class of chemical messengers, are produced primarily in **endocrine glands**. They are released directly into the bloodstream, which carries them to organs and cells that may be far from their point of origin. Hormones have dozens of jobs, from promoting bodily growth to aiding digestion to regulating metabolism. Neurotransmitters and hormones are not always chemically distinct; the two classifications are like social clubs that admit some of the same members. A particular chemical, such as norepinephrine, may belong to more than one classification, depending on where it is located and what function it is performing. Nature has been efficient, giving some substances more than one task.

"PSST—ENDORPHINS. AND THEY'RE PERFECTLY LEGAL."

The following hormones, among others, are of particular interest to psychologists:

1. **Melatonin**, which is secreted by the *pineal gland* deep within the brain, helps to regulate daily biological rhythms and promotes sleep, as we discuss in Chapter 5.

2. **Oxytocin**, which is secreted by another small gland in the brain, the *pituitary gland*, enhances uterine contractions during childbirth and facilitates the ejection of milk during nursing. Psychologists are interested in this hormone because, along with another hormone called *vasopressin*, it also contributes to relationships in both sexes by promoting attachment and trust (see Chapter 14).

3. **Adrenal hormones**, which are produced by the *adrenal glands* (organs that are perched right above the kidneys), are involved in emotion and stress (see Chapter 13). These hormones also rise in response to other conditions, such as heat, cold, pain, injury, burns, and physical exercise, and in response to some drugs, such as caffeine and nicotine. The outer part of each adrenal gland produces *cortisol*, which increases blood-sugar levels and boosts energy. The inner part produces *epinephrine* (commonly known as adrenaline) and *norepinephrine*. When adrenal hormones are released in your body, activated by the sympathetic nervous system, they increase your arousal level and prepare you for action. Adrenal hormones also enhance memory, as we discuss in Chapter 8.

4. **Sex hormones**, which are secreted by tissue in the gonads (testes in men, ovaries in women) and also by the adrenal glands, include three main types, all occurring in both sexes but in differing amounts and proportions in males and females after puberty. *Androgens* (the most important of which is *testosterone*) are masculinizing hormones produced mainly in the testes but also in the ovaries and the adrenal glands. Androgens set in motion the physical changes males experience at puberty—notably a deepened voice and facial and chest hair—and cause pubic and underarm hair to develop in both sexes. Testosterone also influences sexual arousal in both sexes. *Estrogens* are feminizing hormones that bring on physical changes in females at puberty, such as breast development and the onset of menstruation, and that influence the course of the menstrual cycle. *Progesterone* contributes to the growth and maintenance of the uterine lining in preparation for a fertilized egg, among other functions. Estrogens and progesterone are produced mainly in the ovaries but also in the testes and the adrenal glands.

Researchers are studying the possible involvement of sex hormones in behavior not linked to sex or reproduction. The body's natural estrogen may contribute to learning and memory in both sexes by promoting the formation of synaptic connections in areas of the brain (Lee & McEwen, 2001; Maki & Resnick, 2000; Sherwin, 1998a). But the common belief that fluctuating levels of estrogen and progesterone make most women "emotional" before menstruation has not been supported by research, as we discuss in Chapter 5.

melatonin A hormone, secreted by the pineal gland, that is involved in the regulation of daily biological rhythms.

oxytocin A hormone, secreted by the pituitary gland, that stimulates uterine contractions during childbirth, facilitates the ejection of milk during nursing, and seems to promote, in both sexes, attachment and trust in relationships.

adrenal hormones Hormones that are produced by the adrenal glands and that are involved in emotion and stress.

sex hormones Hormones that regulate the development and functioning of reproductive organs and that stimulate the development of male and female sexual characteristics; they include androgens, estrogens, and progesterone.

Quick Quiz

Get your glutamate going by taking this quiz.

A. Which word in parentheses better fits each of the following definitions?

1. Basic building blocks of the nervous system (*nerves, neurons*)
2. Cell parts that receive nerve impulses (*axons, dendrites*)
3. Site of communication between neurons (*synapse, myelin sheath*)
4. Opiatelike substance in the brain (*dopamine, endorphin*)
5. Chemicals that make it possible for neurons to communicate (*neurotransmitters, hormones*)
6. Hormone closely associated with emotional excitement (*epinephrine, estrogen*)

B. Imagine that you are depressed, and you hear about a treatment for depression that affects the levels of several neurotransmitters thought to be involved in the disorder. Based on what you have learned, what questions would you want to ask before deciding whether to try the treatment?

Answers:

A. 1. neurons **2.** dendrites **3.** synapse **4.** endorphin **5.** neurotransmitters **6.** epinephrine **B.** You might want to ask, among other things, about side effects (each neurotransmitter has several functions, all of which might be affected by the treatment); evidence that the treatment works; whether there is any reason to believe that your own neurotransmitter levels are abnormal; and whether there may be other reasons for your depression.

Study and **Review** on **mypsychlab.com**

YOU are about to learn…

- why patterns of electrical activity in the brain are called "brain waves."
- how scanning techniques reveal changes in brain activity while people listen to music, solve math problems, or do other activities.
- the limitations of brain scans as a way of understanding the brain.

Mapping the Brain

electroencephalogram (EEG) A recording of neural activity detected by electrodes.

transcranial magnetic stimulation (TMS) A method of stimulating brain cells, using a powerful magnetic field produced by a wire coil placed on a person's head; it can be used by researchers to temporarily inactivate neural circuits and is also being used therapeutically.

We come now to the main room of the nervous system house: the brain. A disembodied brain stored in a formaldehyde-filled container is a putty-colored, wrinkled glob of tissue that looks a little like an oversized walnut. It takes an act of imagination to envision this modest-looking organ writing *Hamlet*, discovering radium, or inventing the paper clip.

In a living person, of course, the brain is encased in a thick protective vault of bone. How, then, can scientists study it? One approach is to study patients who have had a part of the brain damaged or removed because of disease or injury. Another, the *lesion method*, involves damaging or removing sections of brain in animals and then observing the effects.

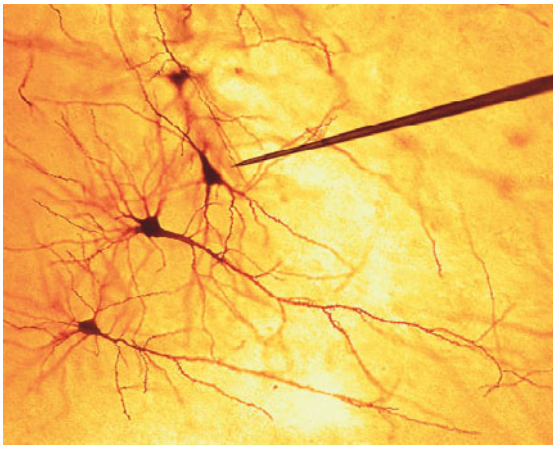
Electrical and Magnetic Detection The brain can also be probed with devices called *electrodes*. Some electrodes are coin-shaped and are simply pasted or taped onto the scalp. They detect the electrical activity of millions of neurons in particular regions of the brain and are widely used in research and medical diagnosis. The electrodes are connected by wires to a machine that translates the electrical energy from the brain into wavy lines on a moving piece of paper or visual patterns on a screen. That is why electrical patterns in the brain are known as "brain waves." Different wave patterns are associated with sleep, relaxation, and mental concentration (see Chapter 5).

A brain-wave recording is called an **electroencephalogram (EEG)**. A standard EEG is useful but not very precise because it reflects the activities of many cells at once. "Listening" to the brain with an EEG machine is like standing outside a sports stadium: You know when something is happening, but you can't be sure what it is or who is doing it. Fortunately, computer technology can be combined with EEG technology to get a clearer picture of brain activity patterns associated with specific events and mental processes. The computer suppresses all the background noise, leaving only the pattern of electrical response to the event being studied.

Electrodes are used to produce an overall picture of electrical activity in different areas of the brain.

For even more precise information, researchers use *needle electrodes*, very thin wires or hollow glass tubes that can be inserted into the brain, either directly in an exposed brain or through tiny holes in the skull. Only the skull and the membranes covering the brain need to be anesthetized; the brain itself, which processes all sensation and feeling, paradoxically feels nothing when touched. Therefore, a human patient or an animal can be awake and not feel pain during the procedure. Needle electrodes can be used both to record electrical activity from the brain and to stimulate the brain with weak electrical currents. Stimulating a given area often results in a specific sensation or movement. *Microelectrodes* are so fine that they can be inserted into single cells.

A newer method of stimulating the brain, **transcranial magnetic stimulation (TMS)**, delivers a large current through a wire coil placed on a person's head. The current produces a magnetic field about 40,000 times greater than the earth's natural magnetic field. This procedure causes neurons under the coil to fire. It can be used to produce motor responses (say, a twitch in the thumb or a knee jerk) and can also be used by researchers to briefly inactivate an area and observe the effects on behavior—functioning, in effect, as a virtual (and temporary) lesion method. The drawback is that when neurons fire, they cause many other neurons to become active too, so it is often hard to tell which neurons are critical for a particular task. TMS has also been used to treat depression (see Chapter 12), but there is little reliable evidence of its effectiveness so far.



This microelectrode is being used to record the electrical impulses generated by a single cell in the brain of a monkey.

Scanning the Brain Since the mid-1970s, many other amazing doors to the brain have opened. The **PET scan (positron-emission tomography)** goes beyond anatomy to record biochemical changes in the brain as they are happening. One type of PET scan takes advantage of the fact that nerve cells convert glucose, the body's main fuel, into energy. A researcher can inject a person with a glucoselike substance that contains a harmless radioactive element. This substance accumulates in brain areas that are particularly active and are therefore consuming glucose rapidly. The substance emits radiation, which is detected by a scanning device, and the result is a computer-processed picture of biochemical activity on a display screen, with different colors indicating different activity levels. Other kinds of PET scans measure blood flow or oxygen consumption, which also reflect brain activity.

PET scans, which were originally designed to diagnose abnormalities, have produced evidence that some brain areas in people with emotional disorders are either unusually quiet or unusually active. But PET technology can also show which parts of the brain are active during ordinary activities and emotions. It lets researchers see which areas are busiest when a person hears a song, recalls a sad memory, works on a math problem, or shifts attention from one task to another. The PET scans in Figure 4.7a show what an average brain looks like when a person is doing various tasks.

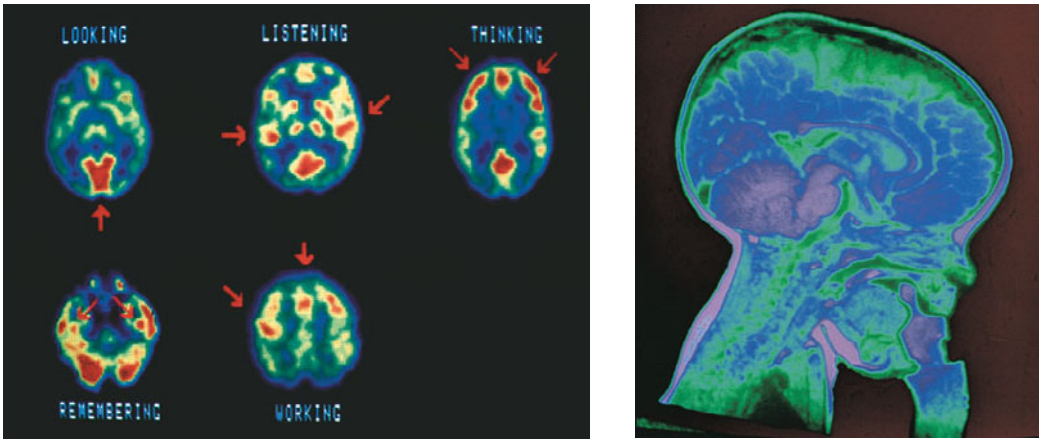
Another technique, **MRI (magnetic resonance imaging)**, allows the exploration of inner space without injecting chemicals. Powerful magnetic fields and radio frequencies are used to produce vibrations in the nuclei of atoms making up body organs. The vibrations are then picked up as signals by special receivers. A computer analyzes the signals, taking into account their strength and duration, and converts them into a high-contrast picture of the organ (see Figure 4.7b). An ultrafast version of MRI, called *functional MRI* (fMRI), can capture brain changes many times a second as a person performs a task, such as reading a sentence or solving a puzzle. Today, thousands of facilities across the United States are using MRIs for research and assessment.

Other methods are becoming available with each passing year. Researchers are using fMRI scans, in particular, to correlate activity in specific brain areas with everything from racial attitudes to moral reasoning to spiritual meditation. Researchers in an applied field called "neuromarketing" are even using them to study which parts of the brain are activated while people watch TV commercials or political ads.

Controversies and Cautions Exciting though these developments and technologies are, we need to understand that technology cannot replace critical thinking (Wade, 2006). Because brain-scan images seem so "real" and scientific, many people fail to realize that these images can convey oversimplified and sometimes misleading impressions. By manipulating the color scales used in PET scans, researchers can either accentuate or minimize contrasts between two brains. Small contrasts can be made to look dramatic, larger ones to look insignificant. An individual's brain can even be made to

PET scan (positron-emission tomography) A method for analyzing biochemical activity in the brain, using injections of a glucoselike substance containing a radioactive element.

MRI (magnetic resonance imaging) A method for studying body and brain tissue, using magnetic fields and special radio receivers; *functional MRI* (fMRI) is a faster form often used in psychological research.



(a) (b)

FIGURE 4.7

Scanning the Brain

In the PET scans on the left, arrows and the color red indicate areas of highest activity, and violet indicates areas of lowest activity, as a person does different things. On the right, an MRI shows a child's brain, along with the bottle he was drinking from while the image was obtained.

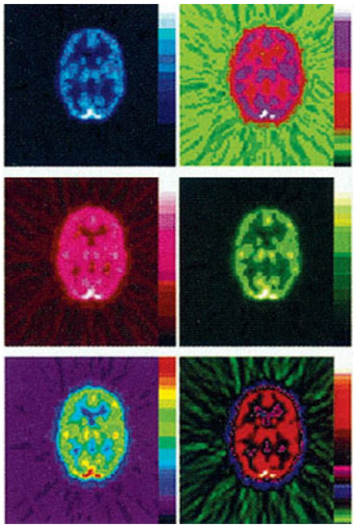


FIGURE 4.8
Coloring the Brain
By altering the colors used in a PET scan, researchers can create the appearance of dramatic brain differences. These scans are actually images of the same brain.

appear completely different depending on the colors used, as the photographs in Figure 4.8 show (Dumit, 2004).

Further, in fMRI studies, questionable statistical procedures have often produced highly inflated correlations between brain activity and measures of personality and emotion (Vul et al., 2009). Yet the press usually reports these findings uncritically, giving the impression that neuroscientists know more about the relationship between the brain and psychological processes than they really do.

There is a final reason for caution about these methods: As of yet, brain scans do not tell us precisely what is happening inside a person's head, either mentally or physiologically. They tell us *where* things happen, but not *why* or *how* they happen—how different circuits connect to produce behavior. Enthusiasm for technology has produced a mountain of findings, but it has also resulted in some unwarranted conclusions about "brain centers" or "critical circuits" for this or that behavior. If you know that one part of the brain is activated when you are thinking hot thoughts of your beloved, what exactly do you know about love? Does that part also light up when you are watching a hot love scene in a movie, looking at a luscious hot fudge sundae, or thinking about happily riding your horse Horace through the hills?

Thinking Critically about Brain Technology

For these reasons, one neuroscientist has called the search for brain centers and circuits "the new phrenology" (Uttal, 2001). Another drew this analogy (cited in Wheeler, 1998): A researcher scans the brains of gum-chewing volunteers, finds out which parts of their brains are active, and concludes that she has found the brain's "gum-chewing center"!

Even if there were a gum-chewing center, yours might not be in the same place as someone else's. Each brain is unique for two reasons: First, a unique genetic package is present in each of us at birth; second, a lifetime of experiences and sensations is constantly altering the brain's biochemistry and neural networks. Thus, if you are a string musician, the area in your brain associated with music production is likely to be larger than that of nonmusicians; the earlier in life you started to play, the larger it becomes (Jancke, Schlaug, & Steinmetz, 1997). And if you are a cab driver, the area in your hippocampus responsible for visual representations of the environment is likely to be larger than average (Maguire et al., 2000). Technological measurements often promote the incorrect view that all brains are alike—if we scan a few, we understand them all.

Nonetheless, scans do provide an exciting look at the brain at work and play, and we will be reporting many findings from PET scan and fMRI research throughout this book. The brain can no longer hide from researchers behind the fortress of the skull.

YOU are about to learn...

- **the major parts of the brain and some of their major functions.**
- **why it is a good thing that the outer covering of the human brain is so wrinkled.**
- **how a bizarre nineteenth-century accident illuminated the role of the frontal lobes.**

A Tour through the Brain

Most modern brain theories assume that different brain parts perform different (though greatly overlapping) tasks. This concept, known as **localization of function**, goes back at least to Joseph Gall (1758–1828), the Austrian anatomist who thought that personality traits were reflected in the development of specific areas of the brain. Gall's theory of phrenology was completely wrong-headed (so to speak), but his general notion of specialization in the brain had merit.

To learn about what the major brain structures do, let's take an imaginary stroll through the brain. Pretend that you have shrunk to a microscopic size and that you are wending your way through the "soul's frail dwelling house," starting at the lower part, just above the spine. Figure 4.9 shows the major structures we will encounter along our tour; you may want to refer to it as we proceed. But keep in mind that any activity—feeling an emotion, having a thought, performing a task—involves many different structures. Our description, therefore, is a simplification.

The Brain Stem

We begin at the base of the skull with the **brain stem**, which began to evolve some 500 million years ago in segmented worms. The brain stem looks like a stalk rising out of the spinal cord. Pathways to and from upper areas of the brain pass through its two main structures: the medulla and the pons. The **pons** is involved in (among other things) sleeping, waking, and dreaming. The **medulla** is responsible

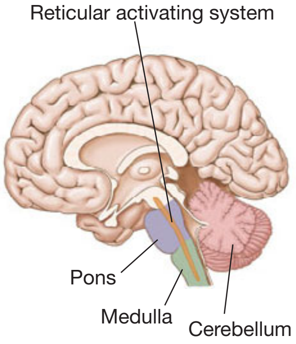
localization of function Specialization of particular brain areas for particular functions.

brain stem The part of the brain at the top of the spinal cord, consisting of the medulla and the pons.

pons A structure in the brain stem involved in, among other things, sleeping, waking, and dreaming.

medulla [muh-DUL-uh] A structure in the brain stem responsible for certain automatic functions, such as breathing and heart rate.

for bodily functions that do not have to be consciously willed, such as breathing and heart rate. Hanging has long been used as a method of execution because when it breaks the neck, nerve pathways from the medulla are severed, stopping respiration.



Extending upward from the core of the brain stem is the **reticular activating system (RAS)**. This dense network of neurons, which extends above the brain stem into the center of the brain and has connections with areas that are higher up, screens incoming information and arouses the higher centers when something happens that demands their attention. Without the RAS, we could not be alert or perhaps even conscious.

The Cerebellum

Standing atop the brain stem and looking toward the back part of the brain, we see a structure about the size of a small fist. It is the **cerebellum**, or "lesser brain," which contributes to a sense of balance and coordinates the muscles so that movement is smooth and precise. If your cerebellum were damaged, you would probably become exceedingly clumsy and uncoordinated. You might have trouble using a pencil, threading a needle, or even walking. In addition, this structure is involved in remembering simple skills and acquired reflexes. But the cerebellum, which was once considered just a motor center, is not as "lesser" as its name implies: It plays a part in such complex cognitive tasks as analyzing sensory information, solving problems, and understanding words.

The Thalamus

Deep in the brain's interior, roughly at its center, we can see the **thalamus**, the busy traffic officer of the brain. As sensory messages come into the brain, the thalamus directs them to higher areas: The sight of a sunset sends signals that the thalamus directs to a vision area, and the sound of an oboe sends signals that the thalamus sends on to an auditory area. The only sense that completely bypasses the thalamus is the sense of smell, which has its own private switching station, the *olfactory bulb*. The olfactory bulb lies near areas involved in emotion. Perhaps that is why particular odors—the smell of fresh laundry, gardenias, a steak sizzling on the grill—often rekindle vivid memories.

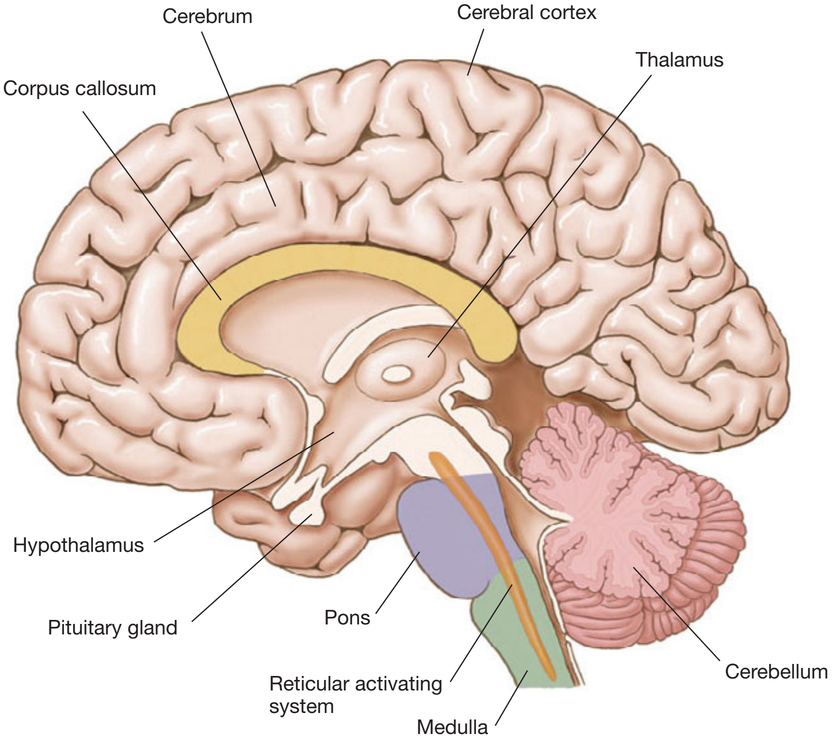
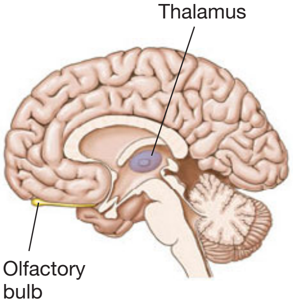


FIGURE 4.9

Major Structures of the Human Brain

This cross section depicts the brain as if it were split in half. The view is of the inside surface of the right half, and it shows the structures described in the text.



The Hypothalamus and the Pituitary Gland

Beneath the thalamus sits a structure called the **hypothalamus** (*hypo* means "under"). It is involved in

reticular activating system (RAS) A dense network of neurons found in the core of the brain stem; it arouses the cortex and screens incoming information.

cerebellum A brain structure that regulates movement and balance and is involved in some cognitive tasks.

thalamus A brain structure that relays sensory messages to the cerebral cortex.

hypothalamus A brain structure involved in emotions and drives vital to survival, such as fear, hunger, thirst, and reproduction; it regulates the autonomic nervous system.

drives associated with the survival of both the individual and the species—hunger, thirst, emotion, sex, and reproduction. It regulates body temperature by triggering sweating or shivering, and it controls the complex operations of the autonomic nervous system. It also contains the biological clock that controls the body's daily rhythms (see Chapter 5).

Hanging down from the hypothalamus, connected to it by a short stalk, is a cherry-sized endocrine gland called the **pituitary gland**, mentioned earlier in our discussion of hormones. The pituitary is often called the body's "master gland" because the hormones it secretes affect many other endocrine glands. The master, however, is really only a supervisor. The true boss is the hypothalamus, which sends chemicals to the pituitary that tell it when to "talk" to the other endocrine glands. The pituitary, in turn, sends hormonal messages out to these glands.

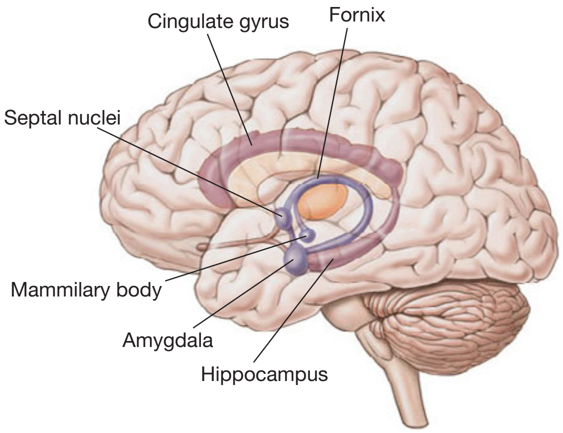
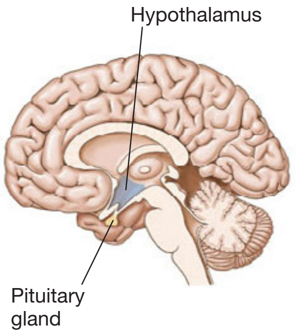


FIGURE 4.10
The Limbic System
Structures of the limbic system play an important role in memory and emotion. The text describes two of these structures, the amygdala and the hippocampus. The hypothalamus is also often included as part of the limbic system.



The hypothalamus, along with the two structures we will come to next, has often been considered part of a loosely interconnected set of structures called the **limbic system**, shown in Figure 4.10. (*Limbic* comes from the Latin word for "border": These structures form a sort of border between the higher and lower parts of the brain.) Some anatomists also include parts of the thalamus in this system. Structures in this region are heavily involved in emotions that we share with other animals, such as rage and fear (MacLean, 1993). The usefulness of speaking of the limbic system as an integrated set of structures is now in dispute, because these structures also have other functions, and because parts of the brain outside of the limbic system are involved in emotion. However, the term *limbic system* is still in wide use among researchers, so we thought you should know it.

The Amygdala

The **amygdala** (from the ancient Greek word for "almond") is responsible for evaluating sensory information, quickly determining its emotional importance, and contributing to the initial decision to approach or withdraw from a person or situation (see Chapter 13). It instantly assesses danger or threat, and it plays an important role in mediating anxiety and depression; PET scans find that depressed and anxious patients show increased neural activity in this structure (Davidson et al., 1999; Drevets, 2000). In addition, the amygdala is involved in forming and retrieving emotional memories (see Chapter 8).

The Hippocampus

Another important area traditionally classified as limbic is the **hippocampus**, whose shape must have reminded someone of a sea horse, for in Latin, that is what its name means. This structure compares sensory information with what the brain has learned to expect about the world. When expectations are met, it tells the reticular activating system to cool it. There's no need for neural alarm bells to go off every time a car goes by, a bird chirps, or you feel your saliva trickling down the back of your throat!

The hippocampus has also been called the "gateway to memory." It enables us to form spatial memories so that we can accurately navigate through our environment. And, along with adjacent brain areas, it enables us to form new memories about facts and events—the kind of information you need to identify a flower, tell a story, or recall a vacation trip. The information is then stored in the cerebral cortex, which we will be discussing shortly. When you recall meeting someone yesterday,

pituitary gland A small endocrine gland at the base of the brain that releases many hormones and regulates other endocrine glands.

limbic system A group of brain areas involved in emotional reactions and motivated behavior.

amygdala [uh-MIG-dul-uh] A brain structure involved in the arousal and regulation of emotion and the initial emotional response to sensory information.

hippocampus A brain structure involved in the storage of new information in memory.

cerebrum [suh-REE-brum] The largest brain structure, consisting of the upper part of the brain; divided into two hemispheres, it is in charge of most sensory, motor, and cognitive processes. From the Latin for "brain."

various aspects of the memory—information about the person's greeting, tone of voice, appearance, and location—are probably stored in different locations in the cortex. But without the hippocampus, the information would never get to these destinations. As we discuss in Chapter 8, this structure is also involved in the retrieval of information during recall.

The Cerebrum

At this point in our tour, the largest part of the brain still looms above us. It is the cauliflower-like **cerebrum**, where the higher forms of thinking take place. The complexity of the human brain's circuitry far exceeds that of any computer in existence, and much of its most complicated wiring is packed into this structure. Compared to many other creatures, we humans may be ungainly, feeble, and thin-skinned, but our well-developed cerebrum enables us to overcome these limitations and creatively control our environment (and, some would say, to mess it up).

The cerebrum is divided into two separate halves, or **cerebral hemispheres**, connected by a large band of fibers called the **corpus callosum**. In general, the right hemisphere is in charge of the left side of the body and the left hemisphere is in charge of the right side of the body. The two hemispheres also have somewhat different tasks and talents, a phenomenon known as **lateralization**.

The Cerebral Cortex

Working our way right up through the top of the brain, we find that the cerebrum is covered by several thin layers of densely packed cells known collectively as the **cerebral cortex**. Cell bodies in the cortex, as in many other parts of the brain, produce a grayish tissue, hence the term *gray matter*. In other parts of the brain (and in the rest of the nervous system), long, myelin-covered axons prevail, providing the brain's *white matter*. Although the cortex is only about 3 millimeters (1/8 inch) thick, it contains almost three-fourths of all the cells in the human brain. The cortex has many deep crevasses and wrinkles, which enable it to contain its billions of neurons without requiring us to have the heads of giants—heads that would be too big to permit us to be born. In other mammals, which have fewer neurons, the cortex is less crumpled; in rats, it is quite smooth.

Lobes of the Cortex

In each cerebral hemisphere, deep fissures divide the cortex into four distinct regions, or lobes (see Figure 4.11):

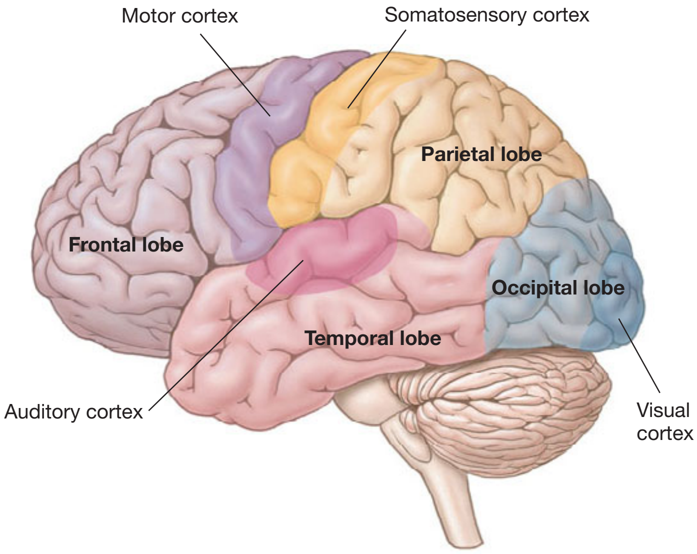


FIGURE 4.11

Lobes of the Cerebrum

Deep fissures divide the cortex of each cerebral hemisphere into four regions.

- The **occipital lobes** (from the Latin for "in back of the head") are at the lower back part of the brain. Among other things, they contain the *visual cortex*, where visual signals are processed. Damage to the visual cortex can cause impaired visual recognition or blindness.
- The **parietal lobes** (from the Latin for "pertaining to walls") are at the top of the brain. They contain the *somatosensory cortex*, which receives information about pressure, pain, touch, and temperature from all over the body. The areas of the somatosensory cortex that receive signals from the hands and the face are disproportionately large because these body parts are particularly sensitive.
- The **temporal lobes** (from the Latin for "pertaining to the temples") are at the sides of the brain, just above the ears and behind the temples. They are involved in memory, perception, and emotion, and they contain the *auditory cortex*, which processes sounds. An area of the left temporal lobe known as *Wernicke's area* is involved in language comprehension.
- The **frontal lobes**, as their name indicates, are located toward the front of the brain, just under the skull in the area of the forehead. They contain the *motor cortex*, which issues orders to the 600 muscles of the body that produce voluntary movement. In the left frontal lobe, a region known as *Broca's area* handles speech production. During short-term memory tasks, areas in the frontal

cerebral hemispheres The two halves of the cerebrum.

corpus callosum [CORE-puhs cah-LOW-suhm] The bundle of nerve fibers connecting the two cerebral hemispheres.

lateralization Specialization of the two cerebral hemispheres for particular operations.

cerebral cortex A collection of several thin layers of cells covering the cerebrum; it is largely responsible for higher mental functions. *Cortex* is Latin for "bark" or "rind."

occipital [ahk-SIP-uh-tuhl] lobes Lobes at the lower back part of the brain's cerebral cortex; they contain areas that receive visual information.

parietal [puh-RYE-uh-tuhl] lobes Lobes at the top of the brain's cerebral cortex; they contain areas that receive information on pressure, pain, touch, and temperature.

temporal lobes Lobes at the sides of the brain's cerebral cortex; they contain areas involved in hearing, memory, perception, emotion, and (in the left lobe, typically) language comprehension.

frontal lobes Lobes at the front of the brain's cerebral cortex; they contain areas involved in short-term memory, higher-order thinking, initiative, social judgment, and (in the left lobe, typically) speech production.

lobes are especially active. The frontal lobes are also involved in emotion and in the ability to make plans, think creatively, and take initiative.

Because of their different functions, the lobes of the cerebral cortex tend to respond differently when stimulated. If a surgeon applied electrical current to your somatosensory cortex in the parietal lobes, you might feel a tingling in the skin or a sense of being gently touched. If your visual cortex in the occipital lobes were electrically stimulated, you might report a flash of light or swirls of color. And, eerily, many areas of your cortex, when stimulated, would produce no obvious response or sensation. These "silent" areas are sometimes called the *association cortex* because they are involved in higher mental processes.

The Prefrontal Cortex Psychologists are especially interested in the most forward part of the frontal lobes, the *prefrontal cortex*. This area barely exists in mice and rats and takes up only 3.5 percent of the cerebral cortex in cats and about 7 percent in dogs, but it accounts for approximately one-third of the entire cortex in human beings. It is the most recently evolved part of our brains, and is associated with such complex abilities as reasoning, decision making, and planning.

Scientists have long known that the frontal lobes, and the prefrontal cortex in particular, must also have something to do with personality. The first clue appeared in 1848, when a bizarre accident drove an inch-thick, 3½-foot-long iron rod clear through the head of a young railroad worker named Phineas Gage. As you can see in the photo, the rod (which is still on display at Harvard University, along with Gage's skull) entered beneath the left eye and exited through the top of the head, destroying much of the prefrontal cortex (H. Damasio et al., 1994). Miraculously, Gage survived this trauma and, by most accounts, he retained the ability to speak, think, and remember. But his friends complained that he was "no longer Gage." In a sort of Jekyll-and-Hyde transformation, he had changed from a mild-mannered, friendly, efficient worker into a foul-mouthed, ill-tempered, undependable lout who could not hold a steady job or stick to a plan. His employers had to let him go, and he was reduced to exhibiting himself as a circus attraction.

There is some controversy about the details of this sad incident, but many other cases of brain injury, whether from stroke or trauma, support the conclusion that most scientists draw from the Gage case: Parts of the frontal lobes are involved in social judgment, rational decision making, and the ability to set goals and to make and carry

On the left is the only known photo of Phineas Gage, taken after his recovery from an accident in which an iron rod penetrated his skull, altering his behavior and personality dramatically. The exact location of the brain damage remained controversial for almost a century and a half, until Hanna and Antonio Damasio and their colleagues (1994) used measurements of Gage's skull and MRIs of normal brains to plot possible trajectories of the rod. The reconstruction on the right shows that the damage occurred in an area of the prefrontal cortex associated with emotional processing and rational decision making.

through plans. Like Gage, people with damage in these areas sometimes mismanage their finances, lose their jobs, and abandon their friends. Interestingly, the mental deficits that characterize damage to these areas are accompanied by a flattening out of emotion and feeling, which suggests that normal emotions are necessary for everyday reasoning and the ability to learn from mistakes (Damasio, 1994, 2003; Levenson & Miller, 2007).

The frontal lobes also govern the ability to do a series of tasks in the proper sequence and to stop doing them at the proper time. The pioneering Soviet psychologist Alexander Luria (1980) studied many cases in which damage to the frontal lobes disrupted these abilities. One man Luria observed kept trying to light a match after it was already lit. Another planed a piece of wood in the hospital carpentry shop until it was gone and then went on to plane the workbench!

Quick Quiz

Pause to see how your own brain is working by taking this quiz.

Match each description on the left with a term on the right.

1. Filters out irrelevant information
2. Known as the "gateway to memory"
3. Controls the autonomic nervous system; involved in drives associated with survival
4. Consists of two hemispheres
5. Wrinkled outer covering of the brain
6. Site of the motor cortex; associated with planning and taking initiative

a. reticular activating system
b. cerebrum
c. hippocampus
d. cerebral cortex
e. frontal lobes
f. hypothalamus

Answers:

1. a **2.** c **3.** f **4.** b **5.** d **6.** e

✓ **Study** and **Review** on **mypsychlab.com**

YOU are about to learn...

- what would happen if the two cerebral hemispheres could not communicate with each other.
- why researchers often refer to the left hemisphere as "dominant."
- why "left-brainedness" and "right-brainedness" are exaggerations.

The Two Hemispheres of the Brain

We have seen that the cerebrum is divided into two hemispheres that control opposite sides of the body. Although similar in structure, these hemispheres have somewhat separate talents, or areas of specialization.

Split Brains: A House Divided

In a normal brain, the two hemispheres communicate with one another across the corpus callosum, the bundle of fibers that connects them. Whatever happens in one side of the brain is instantly flashed to the other side. What would happen, though, if the two sides were cut off from one another?

In 1953, Ronald E. Myers and Roger W. Sperry took the first step toward answering this question by severing the corpus callosum in cats. They also cut parts of the nerves leading from the eyes to the brain. Normally, each eye transmits messages to both sides of the brain. (See Figure 4.12 on the next page.) After this procedure, a cat's left eye sent information only to the left hemisphere and its right eye sent information only to the right hemisphere.

At first, the cats did not seem to be affected much by this drastic operation. But Myers and Sperry showed that something profound had happened. They trained the cats to perform tasks with one eye blindfolded; a cat might have to push a panel with a square on it to get food but ignore a panel with a circle. Then the researchers switched the blindfold to the cat's other eye and tested the animal again. Now the cats behaved as if they had never learned the trick. Apparently, one side of the

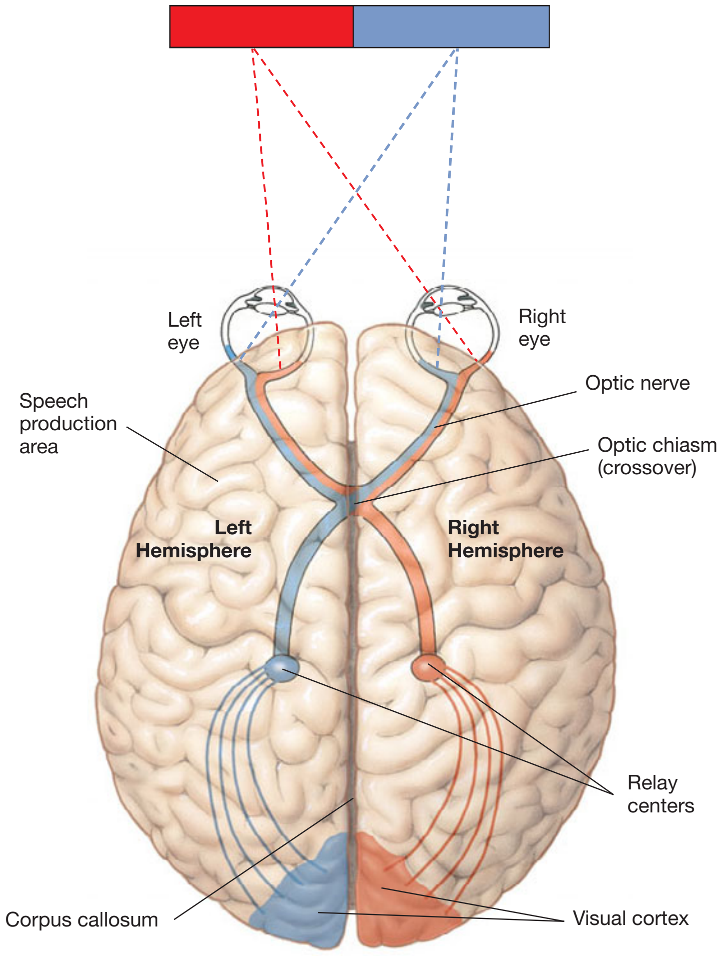


FIGURE 4.12

Visual Pathways

Each cerebral hemisphere receives information from the eyes about the opposite side of the visual field. Thus, if you stare directly at the corner of a room, everything to the left of the juncture is represented in your right hemisphere and vice versa. This is so because half the axons in each optic nerve cross over (at the optic chiasm) to the opposite side of the brain. Normally, each hemisphere immediately shares its information with the other one, but in split-brain patients, severing the corpus callosum prevents such communication.

brain did not know what the other side was doing; it was as if the animals had two minds in one body. Later studies confirmed this result with other species, including monkeys (Sperry, 1964).

In all of the animal studies, ordinary behavior, such as eating and walking, remained normal. In the early 1960s, a team of surgeons decided to try cutting the corpus callosum in patients with debilitating, uncontrollable epilepsy. In severe forms of this disease, disorganized electrical activity spreads from an injured area to other parts of the brain. The surgeons reasoned that cutting the connection between the two halves of the brain might stop the spread of electrical activity from one side to the other. The surgery was done, of course, for the sake of the patients, who were desperate. But there was a bonus for scientists, who would be able to find out what each cerebral hemisphere can do when it is quite literally cut off from the other.

The results of this *split-brain surgery* generally proved successful. Seizures were reduced and sometimes disappeared completely. In their daily lives, split-brain patients did not seem much affected by the fact that the two hemispheres were incommunicado. Their personalities and intelligence remained intact; they could walk, talk, and lead normal lives. Apparently, connections in the undivided deeper parts of the brain kept body movements and other functions normal. But in a series of ingenious studies, Sperry and his colleagues (and later, other researchers) showed that perception and memory had been affected, just as they had been in the earlier animal research. Sperry won a Nobel Prize for his work.

It was already known that the two hemispheres are not mirror images of each other. In most people, language is largely handled by the left hemisphere; thus, a person who suffers brain damage because of a stroke—a blockage in or rupture of a blood vessel in the brain—is much more likely to have language problems if the damage is in the left side than if it is in the right. Sperry and his colleagues wanted to know how splitting the brain would affect language and other abilities.

To understand this research, you must know how nerves connect the eyes to the brain. (The human patients, unlike Myers and Sperry's cats, did not have these nerves cut.) If you look straight ahead at the *visual field* in front of you, everything in the left side of the scene goes to the right half of your brain, and everything in the right side of the scene goes to the left half of your brain. This is true for both eyes. (Refer again to Figure 4.12.)

The procedure was to present information only to one or the other side of the patients' brains. In one early study, the researchers took photographs of different faces, cut them in two, and pasted different halves together (Levy, Trevarthen, & Sperry, 1972). The reconstructed photographs were then presented on slides (see Figure 4.13). The patients were told to stare at a dot in the middle of the screen, so that half of the image fell to the left of this point and half to the right. Each image was flashed so quickly that they had no time to move their eyes. When the patients were asked to

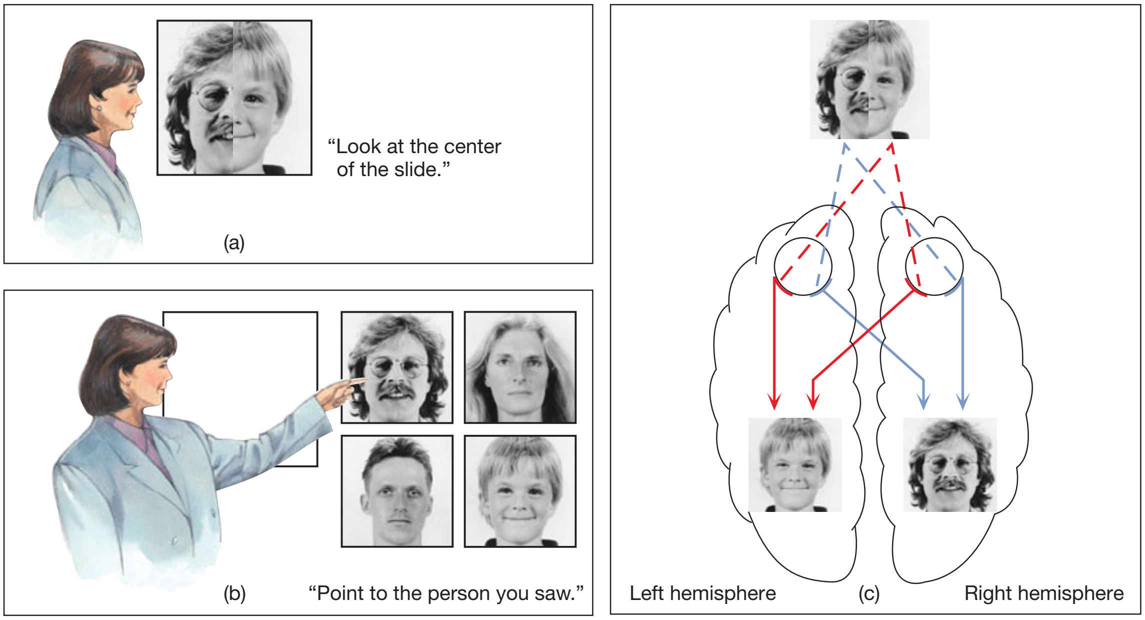


FIGURE 4.13
Divided View
Split-brain patients were shown composite photographs (a) and were then asked to pick out the face they had seen from a series of intact photographs (b). They said they had seen the face on the right side of the composite, yet they pointed with their left hands to the face that had been on the left. Because the two cerebral hemispheres could not communicate, the verbal left hemisphere was aware of only the right half of the picture, and the relatively mute right hemisphere was aware of only the left half (c).

say what they had seen, they named the person in the right part of the image (which would be the little boy in Figure 4.13). But when they were asked to point with their left hands to the face they had seen, they chose the person in the left side of the image (the mustached man in the figure). Further, they claimed they had noticed nothing unusual about the original photographs! Each side of the brain saw a different half-image and automatically filled in the missing part. Neither side knew what the other side had seen.

Why did the patients name one side of the picture but point to the other? Speech centers are usually in the left hemisphere. When patients responded with speech, it was the left side of the brain doing the talking. When patients pointed with the left hand, which is controlled by the right side of the brain, the right hemisphere was giving its version of what they had seen.

In another study, the researchers presented slides of ordinary objects and then suddenly flashed a slide of a nude woman. Both sides of the brain were amused, but because only the left side has speech, the two sides responded differently. When the picture was flashed to one woman's left hemisphere, she laughed and identified it as a nude. When it was flashed to her right hemisphere, she said nothing but began to chuckle. Asked what she was laughing at, she said, "I don't know … nothing … oh—that funny machine." The right hemisphere could not describe what it had seen, but it reacted emotionally just the same (Gazzaniga, 1967).

The Two Hemispheres: Allies or Opposites?

The split-brain operation is still being performed, and split-brain patients continue to be studied, but research on left–right differences has also been done with people whose brains are intact (Springer & Deutsch, 1998). Electrodes and brain scans have been used to measure activity in the left and right hemispheres while people perform different tasks. The results confirm that nearly all right-handed people and a majority of left-handers process language mainly in the left hemisphere. The left side is also more active during some logical, symbolic, and sequential tasks, such as solving math problems and understanding technical material. **Simulate**

Simulate **Split-Brain Experiments** on **mypsychlab.com**

Because of its cognitive talents, many researchers refer to left-hemisphere *dominance*. They believe that the left hemisphere usually exerts control over the right hemisphere. Split-brain researcher Michael Gazzaniga (1983) once argued that without help from the left side, the right side's mental skills would probably be "vastly inferior to the cognitive skills of a chimpanzee." He and others also believe that a part of the left hemisphere is constantly trying to explain actions and emotions generated by brain parts whose workings are nonverbal and outside of awareness. As one neuropsychologist put it, the left hemisphere is the brain's spin doctor (Broks, 2004).

Other researchers, including Sperry (1982), have rushed to the right hemisphere's defense. The

Get Involved! TAP, TAP, TAP

Have a right-handed friend tap on a paper with a pencil held in the right hand for one minute. Then have the person do the same with the left hand, using a fresh sheet of paper. Finally, repeat the procedure, having the person talk at the same time as tapping. For most people, talking will decrease the rate of tapping—but more for the right hand than for the left, probably because both activities involve the same hemisphere (the left one), and there is competition between them. Left-handed people vary more in terms of which hemisphere is dominant for language, so the results for them will be more varied.

Harley Schwadron/CartoonStock Ltd. CSL

right side, they point out, is no dummy. It is superior in problems requiring spatial–visual ability, the ability you use to read a map or follow a dress pattern, and it excels in facial recognition and the ability to read facial expressions. It is active during the creation and appreciation of art and music. It recognizes nonverbal sounds, such as a dog's barking. The right brain also has some language ability. Typically, it can read a word briefly flashed to it and can understand an experimenter's instructions. In a few split-brain patients, right-brain language ability has been well developed, showing that individual variation exists in brain lateralization.

Some researchers have also credited the right hemisphere with having a cognitive style that is intuitive and holistic, in contrast to the left hemisphere's more rational and analytic mode. This idea has been oversold by books and programs that promise to make people more creative by making them more "right-brained." But the right hemisphere is not always a hero: It contains frontal lobe regions that process fear and sadness, emotions that often cause us to withdraw from others. Further, the differences between the two hemispheres are relative, not absolute—a matter of degree. In most activities, the two sides cooperate naturally, with each making a valuable contribution. Be cautious, then, about thinking of the two sides as two "minds." As Sperry (1982) himself noted long ago, "The left–right dichotomy . . . is an idea with which it is very easy to run wild."

Thinking Critically about Right Brain/Left Brain Theories

Study and **Review** on **mypsychlab.com**

Quick Quiz

Use as many parts of your brain as necessary to answer these questions.

1. Bearing in mind that both sides of the brain are involved in most activities, identify which of the following is (are) more closely associated with the left hemisphere: (a) enjoying a musical recording, (b) wiggling the left big toe, (c) giving a speech in class, (d) balancing a checkbook, (e) recognizing a long-lost friend.
2. Thousands of people have taken courses and bought tapes that promise to develop the creativity and intuition of their right hemispheres. What characteristics of human thought might explain the eagerness of some people to glorify "right-brainedness" and disparage "left-brainedness" (or vice versa)?

Answers:

1. c, d **2.** One possible answer: Human beings like to make sense of the world, and one easy way to do that is to divide humanity into opposing categories. This kind of either–or thinking can lead to the conclusion that fixing up one brain hemisphere (e.g., making "left-brained" types more "right-brained") will make individuals happier and the world a better place. If only it were that simple!

YOU are about to learn...

- **why some brain researchers think a unified "self" is only an illusion.**
- **findings and fallacies about sex differences in the brain.**

Two Stubborn Issues in Brain Research

If you have mastered the definitions and descriptions in this chapter, you are prepared to follow news of advances in neuropsychology. Yet many questions remain about how the brain works, and we will end this chapter with two of them.

"THEN IT'S AGREED—YOU CAN'T HAVE A MIND WITHOUT A BRAIN, BUT YOU CAN HAVE A BRAIN WITHOUT A MIND."

Where Is the Self?

Thinking Critically about the Brain and the Self

When you say, "I am feeling unhappy," your amygdala, your serotonin receptors, your endorphins, and all sorts of other brain parts and processes are active, but who, exactly, is the "I" doing the feeling? When you say, "My mind is playing tricks on me," who is the "me" watching your mind play those tricks, and who is it that's being tricked? Isn't the self observing itself a little like a finger pointing at its own tip? Because the brain is the site of self-awareness, people even disagree about what language to use when referring to it. If we say that your brain stores events or registers emotions, we imply a separate "you" that is "using" that brain. But if we leave "you" out of the picture and just say the brain does these things, we risk ignoring the motives, personality traits, and social conditions that powerfully affect what people do—what *you* do.

Most religions resolve the problem by teaching that an immortal self or soul exists entirely apart from the mortal brain, a doctrine known as *dualism*. But modern brain scientists usually consider mind to be a matter of matter. They may have religious convictions about a soul or a spiritual response to the awesome complexity and interconnectedness of nature, but most assume that what we call "mind," "consciousness," "self-awareness," or "subjective experience" can be explained in physical terms as a product of the cerebral cortex.

Our conscious sense of a unified self may even be an illusion. Neurologist Richard Restak (1994) notes that many of our actions and choices occur without any direction by a central, conscious self. Cognitive scientist Daniel Dennett (1991) suggests that the brain or mind consists of independent brain parts that deal with different aspects of thought and perception, constantly conferring with each other and revising their versions of reality. And Michael Gazzaniga proposes that the brain is organized as a loose confederation of independent modules, or mental systems, all working in parallel, with most of these modules operating outside of conscious awareness. One verbal module, an "interpreter" (usually in the left hemisphere), is constantly explaining the actions, moods, and thoughts produced by the other modules (Gazzaniga, 1998; Roser & Gazzaniga, 2004). The result is the sense of a unified self.

The idea that the self is an illusion echoes the teachings of many Eastern spiritual traditions, such as Buddhism. Buddhism teaches that the self is not a unified, tangible thing but rather a collection of thoughts, perceptions, concepts, and feelings that shift and change from moment to moment. To Buddhists, the unity and the permanence of the self are a mirage. Such notions are contrary, of course, to what most people in the West, including psychologists, have always believed about their "selves."

Whether or not the self is an illusion, we all have a sense of self; otherwise, there would be no need for the words *I* and *me*. Yet even in these days of modern technology, and despite much debate among scientists and philosophers, the neural circuits responsible for our sense of self remain hazy. How is the inner life of the mind, our sense of subjective experience, linked to the physical processes of the brain? Some neuroscientists argue that specific groups of neurons form unique neuronal coalitions for seeing red, seeing our grandmother, or feeling joy (Koch, 2004). Others emphasize the transient synchronization of millions of neurons across wide areas of the brain, synchronization that changes from moment to moment (Greenfield & Collins, 2005). But in either case, how does that brain activity *cause* a person's joy on seeing her adored grandmother in a new red hat? We don't know. Nor do we understand why some patients with severe degeneration of the frontal lobes have unimpaired memories and language yet undergo a change in self comparable to Phineas Gage's transformation (Levenson & Miller, 2007). These patients can walk, talk, and function, and yet their families and friends don't know them; they are no longer "themselves."

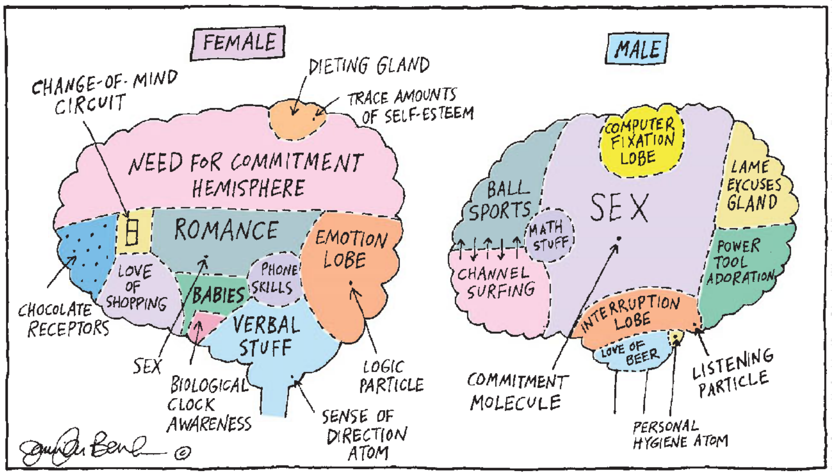
Psychologists, neuroscientists, cognitive scientists, and philosophers all hope to learn more about how our brains and nervous systems give rise to the self. In the meantime, what do you think about the existence and location of your own "self" . . . and who, by the way, is doing the thinking?

Are There "His" and "Hers" Brains?

A second stubborn issue for brain scientists concerns sex differences in the brain. On this issue, either–or thinking is a great temptation. Because of the centuries of prejudice against women and a legacy of biased research on gender differences, some scientists and laypeople do not even want to consider the possibility that the brains of women and men might differ, on average, in some ways. Others go overboard in the opposite direction, convinced that most, if not all, differences between the sexes are in fact "all in the brain." Every year, more books arrive claiming that the "female brain" and the "male brain" are as unlike as tomatoes and artichokes. To evaluate this issue intelligently, we need to ask two separate questions: *Do* the brains of males and females differ? And if so, what, if anything, do the differences have to do with men's and women's behavior, abilities, or ways of solving problems?

Let's consider the first question. Many anatomical and biochemical sex differences have been found in animal brains, and advances in technology have revealed some intriguing differences in human brains as well. In a study of nine autopsied brains, researchers found that the women's brains had an average of 11 percent more cells in areas of the cortex associated with the processing of auditory information; in fact, all of the women had more of these cells than did any of the men (Witelson, Glazer, & Kigar, 1994). Brain scans show that parts of the frontal lobes and the limbic system are larger in women, relative to the overall size of their brains, whereas parts of the parietal cortex and the amygdala are larger in men (Goldstein et al., 2001; Gur et al., 2002). Women also have more cortical folds in the frontal and parietal lobes (Luders et al., 2004).

Researchers are also using brain scans to search for average sex differences in brain activity when people work on particular tasks. In one study, 19 men and 19 women were asked to say whether pairs of nonsense words rhymed, a task that required them to process and compare sounds. MRI scans showed that in both sexes an area at the front of the left hemisphere was activated. But in 11 of the women and none of the men, the corresponding area in the right hemisphere was also active (Shaywitz et al., 1995). In another MRI study, 10 men and 10 women listened to a John Grisham thriller being read aloud. Men and women alike showed activity in the left temporal lobe, but women also showed some activity in the right temporal lobe, as you can see in Figure 4.14 (Phillips et al., 2001). These findings, along with many others, provide evidence for a sex difference in lateralization: For some types of tasks, especially those involving language, men seem to rely more heavily on one side of the brain whereas women tend to use both sides.



Cartoons like this one make most people laugh because men and women do differ, on average, in things like "love of shopping" and "power-tool adoration." But what does the research show about sex differences in the brain? And what do they mean for how people behave in real life?

Thus, the answer to our first question is that yes, average sex differences in the brain do exist. But we are still left with our second question: *What do the differences mean for the behavior or personality traits of men and women in ordinary life?* Some writers have been quick to assume that brain differences explain, among other things, women's allegedly superior intuition, women's love of talking about feelings and men's love of talking about sports, women's greater verbal ability, men's edge in math ability, why women can't read maps, and why men won't ask for directions when they're lost. There are at least three problems with such conclusions:

Thinking Critically about Sex Differences in the Brain

1. **Many supposed gender differences (in intuition, abilities, and so forth) are stereotypes, which are misleading because the overlap between the sexes is usually greater than the difference between them.** As we saw in Chapter 1, even when gender differences are statistically significant, they are often quite small in practical terms. Some supposed differences, on closer inspection, even disappear. For instance, are women more talkative than men, as many pop-psych books about the sexes assert? To test this assumption, psychologists wired up a sample of men and women with voice recorders that tracked their conversations while they went about their daily lives. There was no significant gender difference in the number of words spoken: Both sexes used about 16,000 words per day on average, with large individual differences among the participants (Mehl et al., 2007). Likewise, the difference between boys and girls in math scores is shrinking and in some studies is approaching zero (Else-Quest, Hyde, & Linn, 2010).

2. **A brain difference does not necessarily produce a difference in behavior or performance.** In many studies, males and females have shown different patterns of brain activity while they are doing something or while an ability is being tested, but they have not differed in the behavior or ability in question—which, after all, is presumably the thing to be explained. In the rhyme-judgment task, both sexes did equally well, despite the differences in their MRIs. Another research team used MRI scans to examine the brains of men and women who had equivalent IQ scores. Women's brains had more white-matter areas related to intelligence, whereas men's brains had more gray-matter areas related to intelligence; there were some other differences as well (Haier et al., 2005). The researchers concluded that brains may be organized differently yet produce the same intellectual abilities.

3. **Sex differences in the brain could be the result rather than the cause of behavioral differences.** Culture and experience are constantly sculpting the circuitry of the brain, affecting the way brains are organized and how they function. Women and men, of course, often have different experiences in childhood and throughout their lives. Thus, in commenting on the study that had people listen to a John Grisham novel, one of the researchers noted: "We don't know if the [sex difference we found] is because of the way we're raised, or if it's hard-wired in the brain" (quoted in Hotz, 2000).

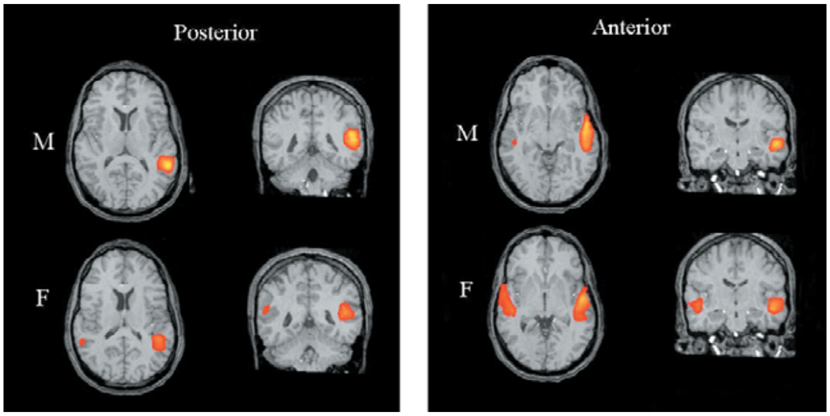


FIGURE 4.14
Gender and the Brain
When women and men listened to a John Grisham thriller read aloud, they showed activity in the left temporal lobe, but women also showed some activity in the right temporal lobe (Phillips et al., 2001). (Because of the orientation of these MRI images, the left hemisphere is seen on the right and vice versa.) Along with other evidence, these results suggest a sex difference in lateralization on tasks involving language.

In sum, the answer to our second question, whether anatomical differences are linked to behavior and abilities, is: It's uncertain. Animal studies have provided tantalizing clues, suggesting that sex differences in the brain influence reactions to acute or chronic stress, the likelihood of suffering depression and attention deficit/hyperactivity disorder, memory for emotional events, strategies for navigating around the environment, and other aspects of behavior (Cahill, 2005; Becker et al., 2008). But we simply do not yet know which of these findings are important for how human males and females manage their everyday lives—their work, their relationships, their families. It is good to keep an open mind about new findings on sex differences in the brain, but because the practical significance of these findings (if any) is not yet clear, it is also important not to oversimplify, as one popular book after another keeps doing. The topic of sex differences in the brain is a sexy one, and research in this area can easily be exaggerated and misused. **Simulate**

Simulate **Physiological Bases of Behavioral Problems** on **mypsychlab.com**

Study and **Review** on **mypsychlab.com**

Quick Quiz

Men and women alike have brains that can answer these questions.

1. Many brain researchers and cognitive scientists believe that the self is not a unified “thing” but a collection of ____________.
2. A new study reports that in a sample of 11 brains, 4 of the 6 women’s brains but only 2 of the 5 men’s brains had multiple chocolate receptors. (*Note:* We made this up; there’s no such thing as a chocolate receptor!) The researchers conclude that their findings explain why so many women are addicted to chocolate. What concerns should a critical thinker have about this study?

Answers:

1. independent modules or mental systems **2.** The sample size was very small; have the results been replicated? Were the sex differences more impressive than the similarities? Might eating chocolate affect chocolate receptors rather than the other way around? Most important, was the number of receptors actually related to the amount of chocolate eaten by the brains’ owners in real life?

Psychology in the News REVISITED

Now that you know more about the workings of the brain, let’s return to the opening story of the patients who were in vegetative or minimally conscious states but who appeared to have some brain function. Political and religious debates continue over the rights of incapacitated people, the meaning of “death by natural causes,” and when life should end if a person has left no written instructions. We cannot resolve these debates here, but the information in this chapter, and an increased understanding of the brain, can help us to separate what we might wish to be true about a patient’s mental abilities from what really is true.

Consider the tragic case of Terri Schiavo, whose parents and husband fought over the decision to terminate her life. She had been in a persistent vegetative state for 15 years, after a heart attack cut off oxygen to her brain. A few years before her death, a scan of Schiavo’s brain showed widespread destruction of brain cells in the cerebral cortex and their replacement by fluid. Yet her parents were convinced that she could recognize them and respond to questions. To a loving and desperately hopeful family, these intermittent, rare reactions seemed like signs of recognition and mental functioning. What they failed to accept is that activity in the brain stem can produce *reflexive* responses such as facial expressions and eye movements, without any awareness or thought on the patient’s part and without any connection to events in the environment.


Psychology in the News

Traces of Consciousness Found in Some Patients Diagnosed as “Vegetative”

LIEGE, BELGIUM, February 4, 2010. A 29-year-old man thought to have been in a persistent vegetative state for five years following a car accident has shown signs of brain activity in response to questions from doctors. Most patients who are in a vegetative state can open and move their eyes and may make sounds and facial expressions, but they have no conscious awareness of themselves or their environment and cannot think or reason.

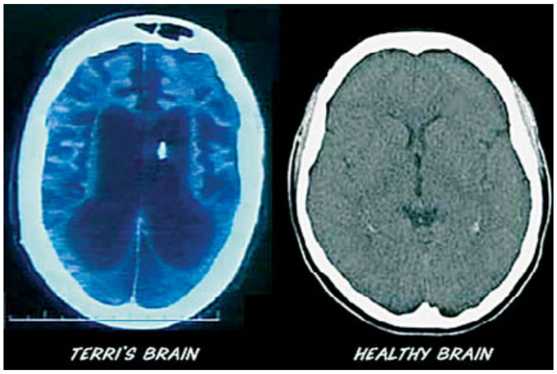
The man is one of 54 patients with severe brain damage, resulting in their being either in a vegetative or minimally conscious state, who are being studied by an international team of scientists in England and Belgium. Researchers prompted them to imagine themselves playing tennis or walking through the house they grew up in, as their brains were being scanned by functional magnetic resonance imaging (MRI). Five of the 54 were able to intentionally modulate their brain activity in response to these prompts, just as healthy people in a control group could. The researchers then instructed these five patients to respond to yes–no questions by using one type of mental imagery (either playing tennis or walking through the house) for “yes” and the other for “no.” Only the man who had been injured in the car accident was able to do this successfully. He responded accurately to simple questions, such as whether his father’s name was Paul (yes) or Alexander (no), and whether he had ever been to the United States. Yet, at a bedside evaluation by a skilled clinical team, he showed no consciousness or ability to communicate.

Experts continue to debate just what these findings mean for a patient’s state of cognition and consciousness. In 2009, Rom Houben, another victim of a car crash who apparently was unconscious for 23 years, made headlines when neurological tests indicated that he too had some possible awareness, and a brain scan revealed nearly normal activity in his brain. Therapists provided Houben with a computer touch screen that seemed to allow him to communicate by spelling out words. But skeptics pointed out that all of Houben’s messages were typed with the help of an aide who supported and guided his hand. Scientific research has discredited such “facilitated communication” and has found that the typed messages come from the facilitator, not the patient. After watching a video of Houben supposedly communicating as a facilitator guided his hand, bioethics expert Arthur Caplan commented, “That is Ouija board stuff.”

Nonetheless, these studies suggest that, in rare cases, patients with brain injury may have a greater degree of consciousness than previously believed possible. “With further development,” the researchers conclude, “this technique could be used by some patients to express their thoughts, control their environment, and increase their quality of life.”

Eventually, a judge gave Terri’s husband permission to have her feeding tube removed, and she died peacefully soon thereafter.

What, then, about the man who responded to yes–no questions by imagining scenarios that produced



The scan on the left, which was made three years before Terri Schiavo’s death, shows severe atrophy in her brain. The dark areas are massively enlarged ventricles filled with cerebral spinal fluid, which had by then replaced much of her cerebral cortex. On the right is a normal brain, showing typical small ventricles.

different patterns of activity in his brain? His brain responses suggest that he does have some awareness. His case holds out the tantalizing possibility that fMRI technology will eventually help doctors distinguish with greater certainty among conscious, minimally conscious, and persistent vegetative states (Monti et al., 2010).

Yet many challenges remain, and at present we must tolerate uncertainty about the implications of this research. Consciousness comes in many forms, including intense alertness, as when you are faced with danger or an exam; a loss of self-awareness, as when you are immersed in a good book or movie; and the floating state between sleep and wakefulness. Brain scans alone cannot necessarily reveal what form of consciousness, if any, someone with brain damage due to accident or disease is experiencing. Evidence of cortical activity is not evidence of an internal stream of conscious thought (Ropper, 2010). As we saw in this chapter, neural correlates of consciousness remain murky and, besides, a brain scan does not tell us exactly what a person is thinking or understands. As we also saw, the brain needs stimulation to survive. We do not yet know how years of what amounts to solitary confinement may affect a patient's brain.

The study of our most miraculous organ, the brain, can help us to better understand the effects of brain damage, and it inspires us to hope for the benefits that future discoveries will bring. But it also teaches us to be cautious and skeptical about the medical and ethical implications of dramatic findings that make the news. Heart-warming reports that Rom Houben, also described in our opening story, had communicated with his mother and his neurologist through "facilitated communication" flashed around the world before independent scientists demonstrated unmistakably that Houben's communications were coming from the facilitators, not Houben. When the researchers shielded the facilitator's eyes from the keyboard, for example, Houben began typing gibberish (Boudry, Termote, & Betz, 2010).

The study of the brain provides valuable insights into the abilities those of us with healthy brains take for granted every day. However, keep in mind that analyzing a human being in terms of physiology alone is like analyzing the Taj Mahal solely in terms of the materials that were used to build it. Even if we could monitor every cell and circuit of the brain, we would still need to understand the circumstances, thoughts, and cultural rules that affect whether we are gripped by hatred, consumed by grief, lifted by love, or transported by joy.

Taking Psychology with You

Cosmetic Neurology: Tinkering with the Brain

Should healthy people be permitted, even encouraged, to take "brain boosters" or "neuroenhancers"—drugs that will sharpen concentration and memory? What about a pill that could erase a traumatic memory? If having cosmetic surgery can change parts of your body that you don't like, what's wrong with allowing cosmetic neurology to tinker with parts of your brain that you don't like?

For centuries, people have been seeking ways to stimulate their brains to work more efficiently, with caffeine being an especially popular drug of choice. No one objects to research showing that diet and exercise can improve learning and memory. No one has a problem with the finding that omega-3s, found in some kinds of fish, may help protect against age-related mental decline (Beydoun et al., 2007; van Gelder et al., 2007). But when it comes to medications that increase alertness or appear to enhance memory and other cognitive functions, it's another kettle of fish oil, so to speak.

What questions should critical thinkers ask, and what kind of evidence would be needed, to make wise decisions about using such medications? A new interdisciplinary specialty, *neuroethics,* has been formed to address the many legal, ethical, and scientific questions raised by brain research, including those raised by the development of neuroenhancing drugs (Gazzaniga, 2005).

Much of the buzz has focused on Provigil (modafinil), a drug approved for treating narcolepsy and other sleep disorders, and Ritalin and Adderall, approved for attention deficit disorders. Many students, pilots, business people, and jet-lagged travelers are taking one or another of these drugs, either obtaining them illegally from friends or the Internet or getting their own prescriptions. Naturally, most of these users claim the drugs help them, and one review of the literature concluded that Provigil does improve memory and may have other cognitive benefits (Minzenberg & Carter, 2008).

Yet, as is unfortunately true of just about all medications, there is a down side that rarely makes news, especially with new drugs that promise easy fixes to old human problems and have not yet been tested over many years. Adderall, like all amphetamines, can cause nervousness, headaches, sleeplessness, allergic rashes, and loss of appetite, and, as the label says, it has "a high potential for abuse." Provigil, too, is habit-forming. Another memory-enhancing drug being studied targets a type of glutamate receptor in the brain. The drug apparently improves short-term memory nicely—at the price of detracting from long-term memories (Talbot, 2009).

Even when a drug is benign for most of its users, it may have some surprising and unexpected consequences. For example, cognitive psychologists have found that the better able people are to focus and concentrate on a task—the reason for taking stimulants in the first place—the less *creative* they often are. Creativity, after all, comes from being able to let our minds roam freely, at leisure. One neurologist therefore worries that the routine use of mind-enhancing drugs among students could create "a generation of very focussed accountants" (quoted in Talbot, 2009).

Some bioethicists and neuroscientists feel that cognitive enhancement is perfectly fine, because it is human nature for people to try to improve themselves and society will benefit when people learn faster and remember more. After all, we use eyeglasses to improve vision and hearing aids to improve hearing; why not use pills to improve our memories and other mental skills? One team of scientists has argued that improving brain function with pills is no more objectionable than eating right or getting a good night's sleep. They wrote, "In a world in which human workspans and life spans are increasing, cognitive enhancement tools . . . will be increasingly useful for improved quality of life and extended work productivity, as well as to stave off normal and pathological age-related cognitive declines" (Greely et al., 2008).

Other scientists and social critics, however, consider cosmetic neurology to be a form of cheating that will give those who can afford the drugs an unfair advantage and increase socioeconomic inequalities. They think the issue is no different from the (prohibited) use of performance-enhancing steroids in athletics. Yes, people wear glasses and hearing aids, but glasses and hearing aids do not have side effects or interact negatively with other treatments. Many neuroethicists also worry that ambitious parents will start giving these medications to their children to try to boost the child's academic performance, despite possible hazards for the child's developing brain. One reporter covering the pros and cons of neuroenhancers concluded, "All this may be leading to the kind of society I'm not sure I want to live in: a society where we're even more overworked and driven by technology than we already are, and where we have to take drugs to keep up" (Talbot, 2009).

How about using drugs not to enhance memory but to erase it, especially memories of sorrowful and traumatic events? By altering the biochemistry of the brain in mice or rats, or using a toxin to kill targeted cells, researchers have been able to wipe out the animals' memories of a learned shock, their ability to recall a learned fear, or their memory of an object previously seen, while leaving other memories intact (Cao et al., 2008; Han et al., 2009; Serrano et al., 2008). If these results eventually apply to human beings, what, again, are the implications?

Some victims of sexual or physical abuse, wartime atrocities, or a sudden horrifying disaster might welcome the chance to be rid of their disturbing memories. But could a "delete" button for the brain be used too often, changing the storehouse of memories that make us who we are? Could memory erasure be misused by unscrupulous governments to eliminate dissent, as George Orwell famously predicted it would in his great novel *1984*? Should we wish to erase memories that evoke embarrassment or guilt, emotions that are unpleasant yet enable us to develop and retain a sense of morality and learn from our mistakes? And would we come to regret the obliteration of a part of our lives that contributed to creating the person we are now? Such concerns may be the reason that most people, when asked if they would take a pill to eradicate a painful memory, respond loudly and clearly: No, thanks (Berkowitz et al., 2008).

In contrast, many people might say "Yes, please" to brain-enhancing drugs. But before they do, they will need to think critically—by separating anecdotes from data, real dangers from false alarms, and immediate benefits from long-term risks. What is to be gained from neuroenhancers, and what might be lost?

Summary

Listen to an **audio file** of your chapter on **mypsychlab.com**

- Neuropsychologists and other scientists study the brain because it is the bedrock of consciousness, perception, memory, and emotion.

The Nervous System: A Basic Blueprint

- The function of the nervous system is to gather and process information, produce responses to stimuli, and coordinate the workings of different cells. Scientists divide it into the *central nervous system* (CNS) and the *peripheral nervous system* (PNS). The CNS, which includes the brain and *spinal cord*, receives, processes, interprets, and stores information and sends out messages destined for muscles, glands, and organs. The PNS transmits information to and from the CNS by way of *sensory* and *motor nerves*.
- The peripheral nervous system consists of the *somatic nervous system*, which permits sensation and voluntary actions, and the *autonomic nervous system*, which regulates blood vessels, glands, and internal (visceral) organs. The autonomic system usually functions without conscious control. The autonomic nervous system is further divided into the *sympathetic nervous system*, which mobilizes the body for action, and the *parasympathetic nervous system*, which conserves energy.

Communication in the Nervous System

- Neurons are the basic units of the nervous system. They are held in place by *glial cells*, which nourish, insulate, and protect them, and enable them to function properly. Each neuron consists of *dendrites*, a *cell body*, and an *axon*. In the peripheral nervous system, axons (and sometimes dendrites) are collected together in bundles called *nerves*. Many axons are insulated by a *myelin sheath* that speeds up the conduction of neural impulses and prevents signals in adjacent cells from interfering with one another.

- Research has disproven two old assumptions: that neurons in the human central nervous system cannot be induced to regenerate and that no new neurons form after early infancy. In the laboratory, neurons have been induced to regenerate. And scientists have learned that *stem cells* in brain areas associated with learning and memory continue to divide and mature throughout adulthood, giving rise to new neurons. A stimulating environment seems to enhance this process of *neurogenesis*.

- Communication between two neurons occurs at the *synapse*. Many synapses have not yet formed at birth. During development, axons and dendrites continue to grow as a result of both physical maturation and experience with the world, and throughout life, new learning results in new synaptic connections in the brain. Thus, the brain's circuits are not fixed and immutable but are continually changing in response to information, challenges, and changes in the environment, a phenomenon known as *plasticity*. In some people who have been blind from an early age, brain regions usually devoted to vision are activated by sound, a dramatic example of plasticity.

- When a wave of electrical voltage *(action potential)* reaches the end of a transmitting axon, *neurotransmitter* molecules are released into the *synaptic cleft*. When these molecules bind to *receptor sites* on the receiving neuron, that neuron becomes either more likely to fire or less so. The message that reaches a final destination depends on how frequently particular neurons are firing, how many are firing, what types are firing, their degree of synchrony, and where they are located.

- Neurotransmitters play a critical role in mood, memory, and psychological well-being. Abnormal levels of neurotransmitters have been implicated in various emotional and physical disorders, such as Alzheimer's disease and Parkinson's disease.

- *Endorphins*, which act primarily by modifying the action of neurotransmitters, reduce pain and promote pleasure. Endorphin levels seem to shoot up when an animal or person is afraid or is under stress. Endorphins have also been linked to the pleasures of social contact.

- *Hormones*, produced mainly by the *endocrine glands*, affect and are affected by the nervous system. Psychologists are especially interested in *melatonin*, which promotes sleep and helps regulate bodily rhythms; *oxytocin* and *vasopressin*, which play a role in attachment and trust; *adrenal hormones* such as *epinephrine* and *norepinephrine*, which are involved in emotions and stress; and the *sex hormones*, which are involved in the physical changes of puberty, the menstrual cycle (*estrogens* and *progesterone*), sexual arousal (*testosterone*), and some nonreproductive functions—including, some researchers believe, mental functioning.

Mapping the Brain

- Researchers study the brain by observing patients with brain damage; by using the *lesion method* with animals; and by using such techniques as *electroencephalograms* (EEGs), *transcranial magnetic stimulation* (TMS), *positron emission tomography* (PET scans), *magnetic resonance imaging* (MRI), and *functional MRI* (fMRI).

- Brain scans reveal which parts of the brain are active during different tasks but do not tell us precisely what is happening, either physically or mentally, during the task. They do not reveal discrete "centers" for a particular function, and they must be interpreted cautiously.

A Tour through the Brain

- All modern brain theories assume *localization of function*, although a particular area may have several functions and many areas are likely to be involved in any particular activity.

- In the lower part of the brain, in the *brain stem*, the *medulla* controls automatic functions such as heartbeat and breathing, and the *pons* is involved in sleeping, waking, and dreaming. The *reticular activating system* (RAS) screens incoming information and is responsible for alertness. The *cerebellum* contributes to balance and muscle coordination, and may also play a role in some higher mental operations.

- The *thalamus* directs sensory messages to appropriate higher centers. The *hypothalamus* is involved in emotion and in drives associated with survival. It also controls the operations of the autonomic nervous system, and sends out chemicals that tell the *pituitary gland* when to "talk" to other endocrine glands. Along with other structures, the hypothalamus has traditionally been considered part of the *limbic system*, which is involved in emotions that we share with other animals. However, the usefulness of speaking of the limbic system as an integrated set of structures is now in dispute.

- The *amygdala* is responsible for evaluating sensory information and quickly determining its emotional importance, and for the initial decision to approach or withdraw from a person or situation. It is also involved in forming and retrieving emotional memories. The *hippocampus* has been called the "gateway to memory" because it plays a critical role in the formation of long-term memories for facts and events. It is also involved in other aspects of memory. Like the hypothalamus, these two structures have traditionally been classified as "limbic."

- Much of the brain's circuitry is packed into the *cerebrum*, which is divided into two *hemispheres* and is covered by thin layers of cells known collectively as the *cerebral cortex*. The *occipital, parietal, temporal*, and *frontal lobes* of the cortex have specialized (but partially overlapping) functions. The *association cortex* appears to be responsible for higher mental processes. The *frontal lobes*, particularly areas in the *prefrontal cortex*, are involved in social judgment, the making and carrying out of plans, and decision making.

The Two Hemispheres of the Brain

- Studies of *split-brain* patients, who have had the *corpus callosum* cut, show that the two cerebral hemispheres have somewhat different talents. In most people, language is processed mainly in the left hemisphere, which generally is specialized for logical, symbolic, and sequential tasks. The right hemisphere is associated with spatial–visual tasks, facial recognition, and the creation and appreciation of art and music. In most mental activities, however, the two hemispheres cooperate as partners, with each making a valuable contribution.

Two Stubborn Issues in Brain Research

- One of the oldest questions in the study of the brain is where the "self" resides. Many brain researchers and cognitive scientists believe that a unified self may be something of an illusion. Some argue that the brain operates as a collection of independent modules or mental systems, perhaps with one of them functioning as an "interpreter." But much remains to be learned about the relationship between the brain and the mind.

- Brain scans and other techniques have revealed some differences in the brains of males and females and in lateralization during tasks involving language (with females more likely to use both hemispheres). Controversy exists, however, about what such differences mean in real life. Speculation has often focused on behavioral or cognitive differences that are small and insignificant. Biological differences do not necessarily explain behavioral ones, and sex differences in experience could affect brain organization rather than the other way around.

Psychology in the News, Revisited

- Knowledge about the brain can help physicians assess the consequences of severe brain damage and improve their methods of diagnosing patients who are in persistent vegetative states, minimally conscious, or conscious. Consciousness itself comes in many different forms, and brain scans to date do not tell us exactly what a person is thinking or understands. The study of the brain can help us to better understand the effects of brain damage, and it also teaches us to be hopeful but cautious about the medical and ethical implications of dramatic findings that make the news.

Taking Psychology with You

- Scholars in the new field of *neuroethics* are addressing the implications of "cosmetic neurology," especially questions raised by the development of drugs that are "neuroenhancers."

Key Terms

central nervous system	**114**
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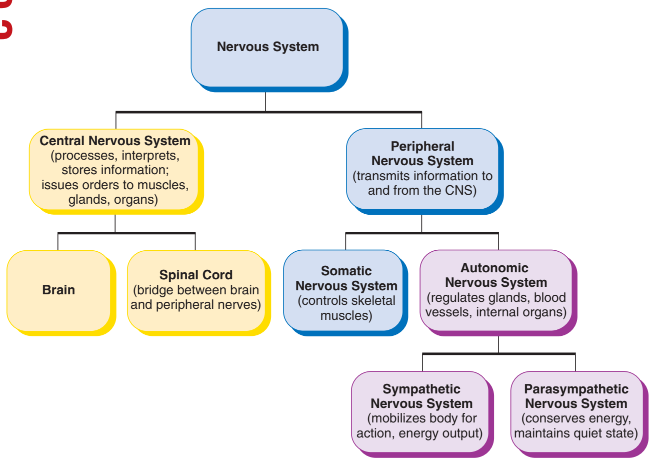
Neuropsychologists study the brain and the rest of the nervous system to gain a better understanding of consciousness, perception, memory, emotion, stress, mental disorders, and self-identity.

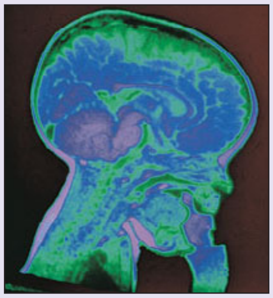
The Nervous System: A Basic Blueprint



Mapping the Brain

Methods for studying the brain:

- Observing patients with brain damage; *lesion method*
- **Electroencephalogram (EEG)**: brain-wave recording
- **Transcranial magnetic stimulation (TMS)**: used as a "virtual" lesion method
- **Positron-emission tomography (PET scan)**: method for analyzing biochemical activity in the brain
- **Magnetic resonance imaging (MRI)**: method for studying body and brain tissue, using magnetic fields and special radio receivers



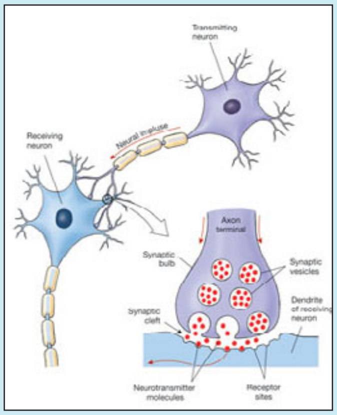
Communication in the Nervous System

- **Neurons:** basic units of the nervous system, composed of **dendrites**, a **cell body**, and an **axon**
- **Glial cells:** hold neurons in place as well as nourish, insulate, and protect them
- **Nerves:** bundles of axons and some dendrites in the peripheral nervous system
- **Myelin sheath:** speeds up the conduction of neural impulses and prevents adjacent cells from interfering with one another
- **Stem cells:** seem to give rise to new neurons throughout adulthood (**neurogenesis**)

How Neurons Communicate

Communication between neurons occurs at **synapses**, most of which develop after birth:

1. **Action potential** (changes in electrical voltage) produces a neutral impulse.
2. **Neurotransmitter** molecules are released into the synaptic cleft and bind to receptor sites on the receiving neuron.
3. Receiving neuron becomes more likely to fire or less likely to fire.



Chemical Messengers in the Nervous System

Neurotransmitters such as serotonin, dopamine, and acetylcholine play a critical role in mood, memory, and psychological well-being.

1. **Endorphins** modify the action of neurotransmitters to reduce pain and promote pleasure.
2. **Hormones,** chemical substances produced primarily by the **endocrine glands,** are released into the bloodstream and affect many organs and cells.
    - **Melatonin** promotes sleep.
    - **Oxytocin** plays a role in attachment and trust.
    - **Adrenal hormones,** such as *epinephrine* and *norepinephrine*, are involved in emotions, memory, and stress.
    - **Sex hormones** are involved in the physical changes of puberty; *estrogen* and *progesterone* are involved in the menstrual cycle, and *testosterone* is involved in sexual arousal.

The Plastic Brain

- Learning and stimulating environments increase the complexity of synaptic connections, whereas unused connections are pruned away.
- The flexibility of the brain to adapt is known as **plasticity**, and can account for many instances of skill recovery following brain damage.

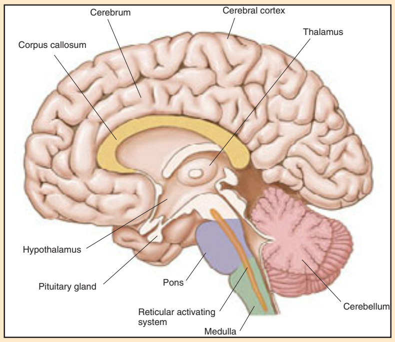
A Tour through the Brain

All modern brain theories assume **localization of function**.

The **brain stem** is in the lower brain.

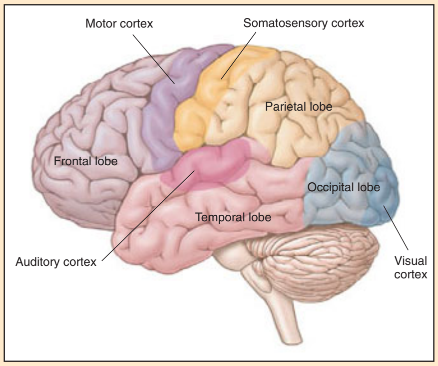
- The **medulla** controls automatic functions such as heartbeat and breathing.
- The **pons** is involved in sleeping, waking, and dreaming.
- The **reticular activating system** (**RAS**), a dense network of neurons, screens incoming information and is responsible for alertness.

- The **cerebellum** contributes to balance and muscle coordination.
- The **thalamus** directs sensory messages.
- The **hypothalamus** is involved in emotion and drives vital to survival and controls operations of the autonomic nervous system. It controls the **pituitary gland,** or master gland.
- The **limbic system** is group of brain areas involved in emotional reactions and motivated behavior.
- The **amygdala** evaluates sensory information and determines its emotional importance and helps to make the initial decision to approach or withdraw from a situation.
- The **hippocampus** plays a critical role in long-term memory for facts and events.
- The **cerebrum** contains much of the brain's circuitry; it is divided into two **cerebral hemispheres**, connected by a band of fibers called the **corpus callosum.** The cerebrum is covered by thin layers of cells called the **cerebral cortex.**



Lobes of the Cortex

- The **occipital lobes** contain the visual cortex.
- The **parietal lobes** contain the somatosensory cortex, which receives information about pressure, pain, touch, and temperature.
- The **temporal lobes** involve memory, perception, and emotion.
- The **frontal lobes** are involved in social judgment, the making and carrying out of plans, and decision making. Also contains the motor cortex, which controls voluntary movement, and Broca's area, which handles speech production.
- The *association cortex* appears to be responsible for higher mental process.



The Two Hemispheres of the Brain

Split Brains

- **Lateralization** is the specializing of each hemisphere.
- The left hemisphere is more active in processing language, logic, and symbolic–sequential tasks.
- The right hemisphere is associated with spatial-visual tasks, facial recognition, the creation and appreciation of art and music, and the processing of negative emotions.
- In most mental activities, the two sides cooperate.

Two Stubborn Issues in Brain Research

Where Is the Self?

The issue of where the "self" resides in the brain is unanswered, with some researchers viewing the brain as a collection of independent modules or mental systems, perhaps with one functioning as "interpreter." An area of the prefrontal cortex may bind together perceptions and memories that produce a sense of self.

Are There "His" and "Her" Brains?

Brain scans reveal some anatomical differences in male and female brains, and sex differences in lateralization during language tasks. However, the real-life significance of these and other findings remains unclear:

- Most supposed gender differences are stereotypes; the overlap between the sexes is greater than their differences.
- Small differences found in MRI studies are often unrelated to how men and women actually behave or score on a test.
- Brain differences could be a result of sex differences in behavior and experience, rather than a cause; experience constantly sculpts the brain.