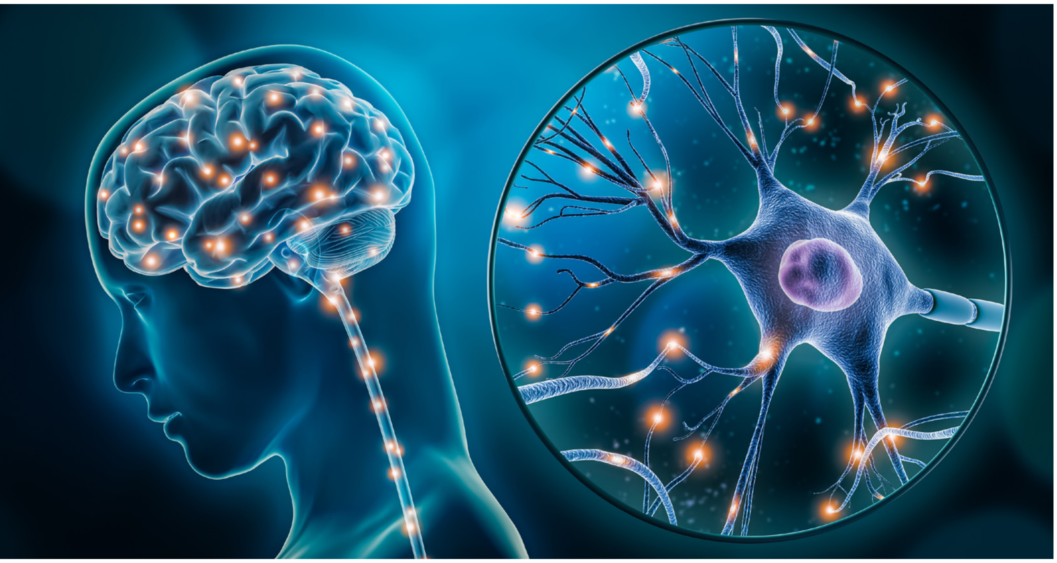
The Biological Foundations of Behavior

CHAPTER 2



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Chapter Outline

Questions You Will Be Able to Answer

After reading Chapter 2, you should be able to answer the following questions:

- What are the major parts of a neuron?
- What is myelin, and what functions does it serve?
- What is the nature of a neural impulse?
- What is the all-or-none principle, and what are neural thresholds?
- What is the synapse, and in general terms, what happens there?
- What are the major divisions of the human nervous systems, and what do they do?
- What is the function of the endocrine system in general and the pituitary gland, thyroid gland, and adrenal glands in particular?
- What are sensory neurons, motor neurons, and interneurons?
- What is the basic structure of the spinal cord, and what are its two functions?
- Where are the medulla and the pons, and what do they do?
- What is meant by cross laterality?
- What are the major functions of the cerebellum and the reticular formation?
- What are the basal ganglia, and what is their relation to Parkinson's disease?

- What are the major structures of the limbic system, and what are their functions?
- What are the functions of the thalamus, and where is it located?
- What is the location of each of the four lobes of the cerebral cortex?
- What are the functions of the sensory areas, the motor areas, and the association areas of the cortex?
- What is the split-brain procedure, and what has been learned from it?

Preview

As you first look through this chapter, it may look a lot more like biology than what you expected in a psychology text. Perhaps it does, but here is the point: All of your behaviors, from the simple blink of an eye to typing a text on your phone; every emotion you have ever experienced, from mild annoyance to extreme fear; your every thought, from the trivial to the profound—all of these can be reduced to molecules of chemicals racing in and out of the tiny cells that comprise your nervous system.

Every day, a huge array of sights, sounds, smells, tastes, and tactile (touch) stimuli bombard you. Some go unnoticed; some are ignored; some elicit a response on your part. Most of the time, we take these reactions for granted. Now, they are the focus of this chapter. The processes of getting information to and from the brain (and other parts of your body) involve a beautifully complex set of actions on a cellular level.

We will take a building-block approach to this discussion of the biological underpinnings of psychological functioning and behavior. We will begin by considering the structures and functions of the individual nerve cell. As remarkable as these microscopically tiny cells are, they would have little impact without their ability to pass information from one part of the body to another in nerve fibers. We will see that nerve cells communicate with one another through a remarkable set of chemical actions. Before we go on, we will survey how scientists organize their discussion of nervous systems, and we will briefly examine a system of glands and hormones that can significantly affect psychological functioning—the endocrine system.

Then, we can put together what we have been discussing into the truly complex structures of the central nervous system, or the CNS. The CNS is composed of the spinal cord and the brain. In our discussion of the spinal cord, we see the first indication of how stimuli from the environment produce behaviors—simple reflexive reactions.

Then, there is the brain. No more complex structure exists in nature than the human brain. It is in the brain that conscious, voluntary actions begin, emotions are experienced, and cognitions are formed, manipulated, and stored. Because of the brain's complexity, it is necessary to study its structures and their functions one at a time. Although we will examine the parts of the brain one at a time, we must keep in mind that all of these structures are part of an integrated, unified system in which all the parts work together and influence one another in complex ways.

Neurons—The Building Blocks of the Nervous System

Neuron—a microscopically small cell that transmits information—in the form of neural impulses—from one part of the body to another.

Our exploration of the nervous system begins with the nerve cell, or neuron. A **neuron** is a microscopically small cell that transmits information—in the form of neural impulses—from one part of the body to another. Neurons were not recognized as separate structures until around the end of the 19th century. To underscore how small neurons are, consider that there are approximately *125 million* light-sensitive neurons that line the back of each of your eyes, an estimated *1 billion* neurons in your spinal cord, and about *100 billion* neurons in your brain (Zillmer & Spiers, 2001). Add to these staggering numbers that a single neuron may, on average, establish 10,000 connections with other neurons (Beatty, 1995).

Even though, much like snowflakes, no two neurons are exactly alike, there are some commonalities among neurons. **Figure 2.1** illustrates these shared features.

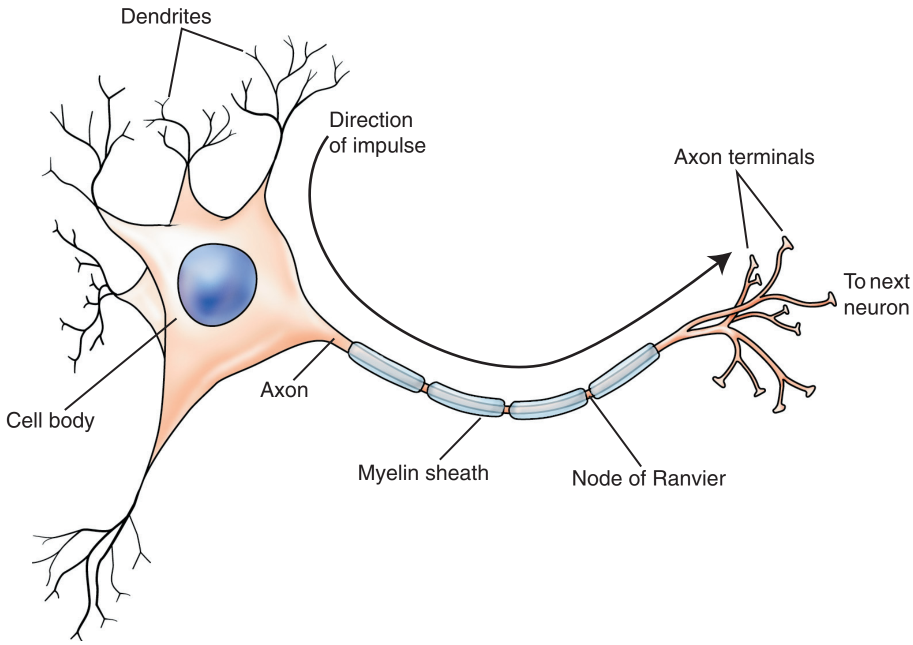


FIGURE 2.1
The Neuron

The main structures of the neuron are the dendrites, the cell body, and the axon. The dendrites receive neural impulses from other neurons; the soma regulates neuronal cell body (or *soma*) functions; and the axon conveys signals to other neurons, skeletal muscles, or internal organs. When a neuron receives sufficient stimulation from other neurons, it transmits an electrical-chemical neural impulse along its entire axon.

All neurons have a **cell body**, the largest concentration of mass in the neuron, containing the nucleus of the cell and other structures necessary for the neuron's life. Protruding from a neuron's cell body are several tentacle-like structures, called dendrites, and one particularly long structure called the axon. Typically, a **dendrite** is the part of a neuron reaching out to receive messages, or neural impulses, from nearby neurons. Also extending from the cell body is an **axon**, the part of a neuron that sends messages along its length to other neurons, muscles, or glands. Some axons are quite long—as long as two to three feet in the spinal cord, whereas others are microscopic (such as those in your brain). Within a neuron, impulses go *from dendrite to cell body to axon*, and most of the distance traveled is along the axon.

Cell body—the largest concentration of mass in the neuron, containing the nucleus of the cell and other structures necessary for the neuron's life.

Dendrite—the part of a neuron reaching out to receive messages, or neural impulses, from nearby neurons.

Axon—the part of a neuron that sends messages along its length to other neurons, muscles, or glands.

The neuron in Figure 2.1 has a feature not found on all neurons. This axon has a cover, or sheath, made of myelin. **Myelin** is a white substance composed of fat and protein, and is found on about half of the axons in an adult's nervous system. Myelin is not an outgrowth of the axon itself but is produced by other cells throughout the nervous systems. Myelin covers an axon in lumpy segments, separated by gaps (Nodes of Ranvier) rather than in one continuous coating. It is largely the presence of myelin that allows us to distinguish between the gray matter (dendrites, cell bodies, and bare, unmyelinated axons) and white matter (myelinated axons) of nervous-system tissue. We tend to find myelin on axons that carry impulses relatively long distances. For instance, most neurons that carry messages up and down the spinal cord have myelin on their axons, whereas most of those that carry impulses back and forth across the spinal cord do not.

Myelin—a white substance composed of fat and protein; found on about half of the axons in an adult's nervous system.

Myelin serves several functions. It protects the long and delicate axon. It also acts as an insulator, separating the activity of one neuron from those nearby. Myelin speeds impulses along the length of the axon. Myelinated neurons carry impulses nearly ten times faster than unmyelinated ones—up to 150 yards per second, or well over 300 miles an hour!

Whether covered with myelin or not, axons end in a branching series of bare end points called **axon terminals**. So to review: Within a neuron, impulses travel from the dendrites to the cell body, to the axon (which may be myelinated), and then to axon terminals.

Axon terminals—a branching series of bare end points of an axon.

Have you noticed that discussing the structure of the neuron is nearly impossible without referring to its function: the transmission of neural impulses? We have seen that neural impulses are typically received by dendrites, passed on to cell bodies, then to axons, and ultimately to axon terminals. We know that myelin insulates some axons and speeds neural impulses along, but what exactly is a neural impulse? We will explore the neural impulse next.

The function of a neuron is to transmit neural impulses from one place in the nervous system to another. A **neural impulse** is a rapid, reversible change in the electrical charges within and outside a neuron. When a neuron transmits an impulse (when a neuron "fires"), this change in electrical charge travels from the dendrites to the cell body, to the axon, to the axon terminal. Even as you sit quietly reading your textbook, millions of neurons are transmitting impulses to and from various parts of your body. Some are moving (incredibly fast) from your eyes to your brain, which is trying to make sense of these invisible processes. Some are racing from your brain to your arms and hands, directing you to go to the next page or shift your weight in your chair.

Neural impulse—a rapid, reversible change in the electrical charges within and outside a neuron.

Neurons don't fire every time they are stimulated. That is to say, they don't always transmit a neural impulse when they are stimulated. The **all-or-none principle** states that a neuron either fires or it doesn't. There is no such thing as a weak or strong neural impulse; the impulse is there or it isn't. This raises an interesting psychological question: How does the nervous system react to differences in stimulus intensity? How do neurons react to the difference between a bright light and a dim one, a soft sound and a loud one, or a tap on the shoulder and a slap on the back? Remember, neurons do not fire partially, so we cannot say that a neuron fires partially for a dim light and fires to a greater extent for the brighter light. Part of the answer involves neural thresholds.

All-or-none principle—a principle stating that a neuron either fires or it doesn't.

Indeed, neurons do not generate impulses every time they are stimulated. In fact, each neuron has a level of stimulation that must be reached to produce an impulse. The minimum level of stimulation required to fire a neuron is the **neural threshold**. This concept, coupled with the all-or-none principle, is the key to understanding how we process stimuli of varying intensities. High-intensity stimuli (bright lights, loud sounds, etc.) do not cause neurons to fire more vigorously; they stimulate *more* neurons to fire. And, as it happens, those neurons will fire more frequently as well. High-intensity stimuli are above the neural threshold of a greater number of neurons than are low-intensity stimuli. The difference in our experience of a flash going off near our faces and how we see a candle at a distance reflects the number of neurons involved and the rate at which they fire, not the degree or extent to which they fire.

Neural threshold—the minimum level of stimulation required to fire a neuron.

Now that we have examined the individual nerve cell in detail, we are ready to learn how neurons communicate with each other—how impulses are transmitted from one cell to another. How impulses travel between neurons is as remarkable, but quite different from how impulses travel within neurons.

The location at which a neural impulse is relayed from one neuron to another is called the **synapse**. At these synapses (see **Figure 2.2**), neurons do not touch each other. Instead, there is a microscopic gap (the *synaptic cleft*) between the axon terminal of one neuron and the dendrites (or cell body) of another neuron. At the end of an axon, there are many branches that themselves end at axon terminals. Concentrated at the axon terminal are **vesicles**, incredibly small containers that hold complex chemicals called neurotransmitters. **Neurotransmitters** are chemicals released into the synapse that act to excite or inhibit the transmission of a neural impulse in the next neuron. Notice that across the synaptic cleft, there are *receptor sites* that receive the neurotransmitter molecules. Receptor sites are specialized areas that accept molecules of particular neurotransmitters. Think about neurotransmitters as being tiny keys that fit into tiny locks at the receptor sites.

Synapse—the location at which a neural impulse is relayed from one neuron to another.

Vesicles—incredibly small containers that are concentrated at axon terminals and hold neurotransmitters.

Neurotransmitters—chemicals released into the synapse that act to excite or inhibit the transmission of a neural impulse in the next neuron.

When an impulse reaches the axon terminal, the vesicles burst open and release the neurotransmitters they have been holding. Then what happens? Actually, any number of things can happen. Let's look at two. The most logical scenario is that the neurotransmitters float across the gap between neurons, enter into receptor sites in the next neuron in a chain of nerve cells, and excite that neuron to fire a new impulse down to its axon terminals. Some neurotransmitters are excitatory in nature. An **excitatory neurotransmitter** stimulates the next neuron in a sequence to fire.

Excitatory neurotransmitter—a neurotransmitter that stimulates the next neuron in a sequence to fire.

As it happens, there are many places throughout our nervous systems where the opposite effect occurs. An **inhibitory neurotransmitter** prevents (inhibits) the next neuron from firing. One final note: Impulse transmission also occurs at the synapse of neurons and other kinds of cells. For instance, when a neuron forms a synapse with a muscle

Inhibitory neurotransmitter—a neurotransmitter that prevents the next neuron from firing.

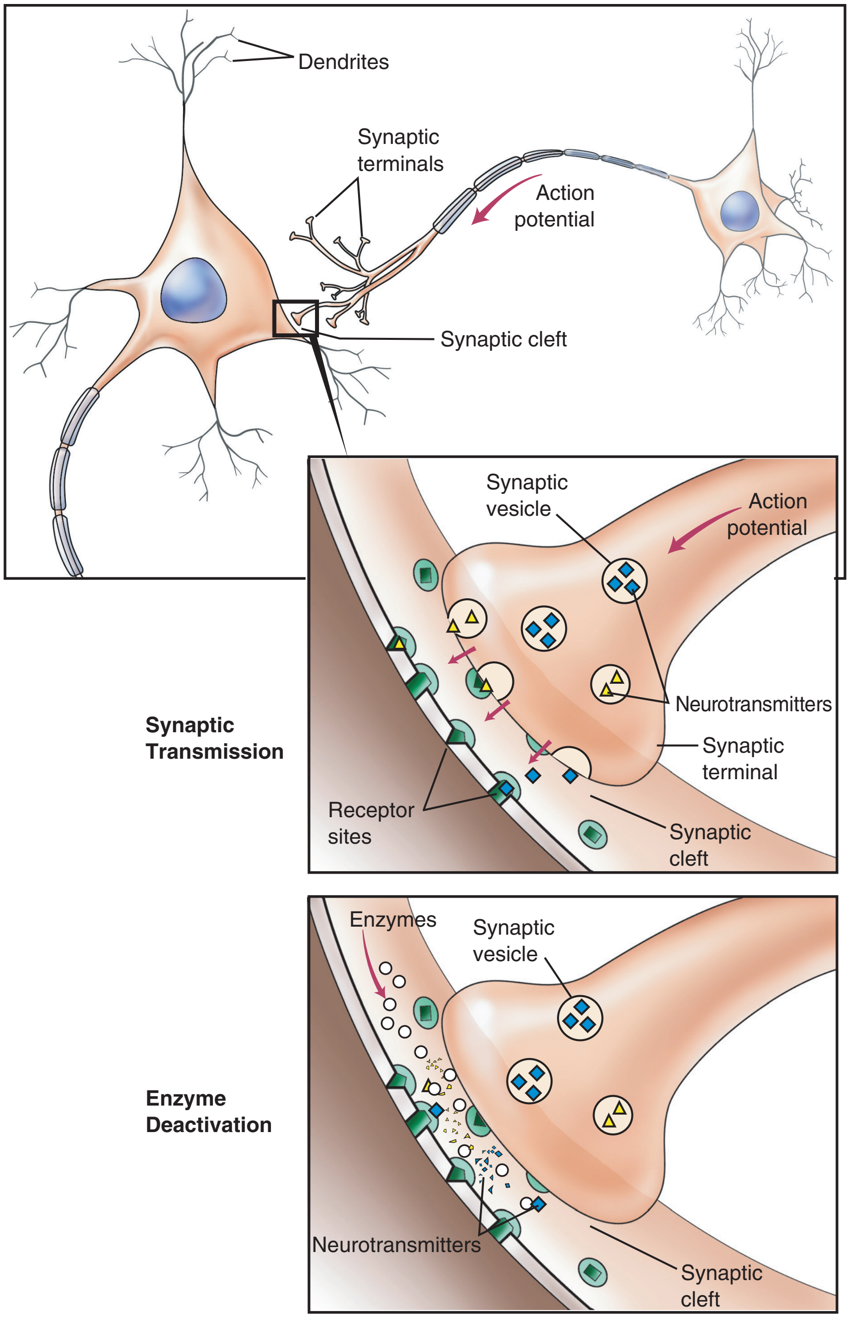


FIGURE 2.2
Mechanisms of Synaptic Transmission
When a neural impulse reaches the end of an axon, it stimulates synaptic vesicles to release neurotransmitter molecules into the synaptic cleft. The molecules diffuse across the fluid in the synaptic cleft and interact with receptor sites on another neuron. The molecules then disengage from the receptor sites and are either broken down by enzymes or taken back into the axon in a process called reuptake.

cell, the release of a neurotransmitter from the neuron's axon terminals may excite that muscle to contract momentarily. Similarly, neurons that form synapses with the cells of a gland may cause that gland to secrete a hormone when stimulated by the appropriate neurotransmitter. After the neurotransmitter has done its job, there are mechanisms that eliminate them so they will not have a long-term effect.

STUDY CHECK

What are the major parts of a neuron?
What is myelin, and what functions does it serve?
What is the nature of a neural impulse?
What is the all-or-none principle, and what are neural thresholds?
What is the synapse, and in general terms, what happens there?

THINKING CRITICALLY

Neural impulses may begin when stimuli activate one's sense receptors. In what other ways might neural impulses begin? Once neurons begin to fire and send impulses on to other neurons, what do you suppose stops the process, i.e., when does neural transmission stop?

Human Nervous Systems: The Big Picture

Now that we know how neurons work individually and in combination, let's consider the context in which they function. Behaviors and mental activities require large numbers of integrated neurons working together in complex, organized systems. **Figure 2.3** depicts these systems.

The major division of the nervous systems is determined wholly on the basis of anatomy. The **central nervous system (CNS)** includes all neurons and supporting cells found in the spinal cord and brain. This system of nerves is the most complex and most intimately involved in the control of behavior and mental processes. The **peripheral nervous system (PNS)** consists of all neurons in the body not in the CNS—the nerve fibers in the arms, face, fingers, intestines, and so on. Neurons in the peripheral nervous system carry impulses from the central nervous system to the muscles and glands or to the CNS from receptor cells.

The peripheral nervous system is divided into two parts, based largely on the part of the body being served. The **somatic nervous system** includes those neurons that are outside the CNS and serve the skeletal muscles and pick up impulses from our sense receptors, such as the eyes and ears. The other part of the PNS is the autonomic nervous system (ANS). "Autonomic" essentially means "automatic." This name implies that the activity of the ANS is largely independent of central nervous system control. The nerve fibers of the **autonomic nervous system** are involved in activating the smooth muscles, such as those of the stomach and intestines, and the glands. The ANS provides feedback to the CNS about this internal activity.

The ANS also consists of two parts: the sympathetic division and the parasympathetic division. These two components commonly work in opposition to each other. The **sympathetic division** is active when we are emotionally aroused or excited, as we might be when riding up that first incline of a roller coaster. The **parasympathetic division** is active when we are relaxed and quiet, as we might be after a long day at the amusement park, half asleep in the back seat on the drive home. Both divisions of the ANS act on the same organs, but they do so in opposite ways.

There is good reason to categorize the various organizations of neurons: It makes a very complex system easier to understand, and it reminds us that not all neurons in our body are doing the same thing for the same reason at the same time. Note that the outline

Central nervous system (CNS)—a division of the nervous system that includes all neurons and supporting cells found in the spinal cord and brain.

Peripheral nervous system (PNS)—a division of the nervous system that consists of all neurons in the body not in the CNS—the nerve fibers in the arms, face, fingers, intestines, and so on.

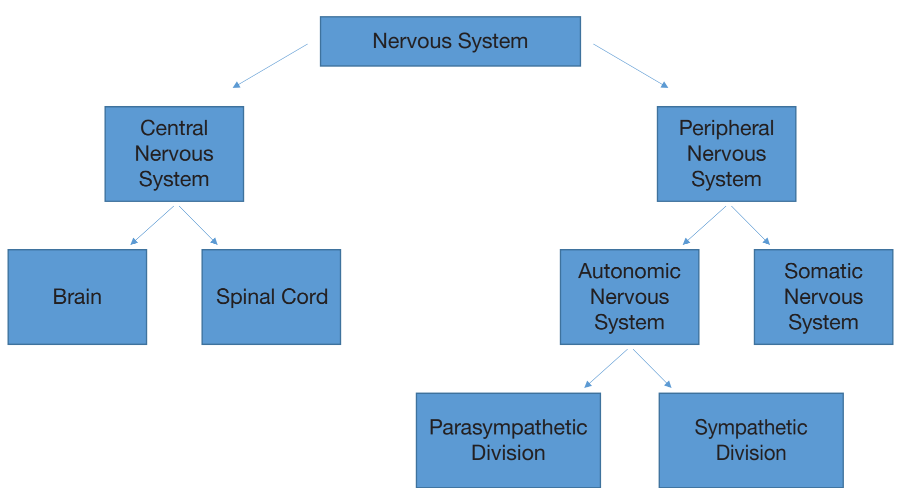
Somatic nervous system—consists of those neurons that are outside the CNS and serve the skeletal muscles and pick up impulses from our sense receptors, such as the eyes and ears.

Autonomic nervous system—consists of neurons involved in activating the smooth muscles, such as those of the stomach and intestines, and the glands.

Sympathetic division—division of the autonomic nervous system that is active when we are emotionally aroused or excited.

Parasympathetic division—division of the autonomic nervous system that is active when we are relaxed and quiet.

FIGURE 2.3
Organization of the Nervous System



of the nervous system in Figure 2.3 is very simplified to this extent: The nerve fibers in each of the systems have profound influences on one another. They are not at all as independent as our diagram might imply.

The **endocrine system** is a network of glands that affect behaviors by secreting chemicals called *hormones*. All hormones travel through the bloodstream and can affect organs far from where the hormones are produced. Many hormones produced by the glands of the endocrine system are chemically similar to neurotransmitters and have similar effects. The endocrine system's glands and hormones are controlled by parts of the brain and by the autonomic nervous system. Although not composed of neurons and synapses, the endocrine system is relevant to our discussion for two reasons. First, its function is like that of the nervous system: to transmit information from one part of the body to another. Second, hormones exert a direct influence on behavior.

Endocrine system—a network of glands that affect behaviors by secreting chemicals called hormones.

Consider the so-called sex hormones, testosterone and estrogen. These hormones are found in both males and females, but testosterone is much more common in males, whereas estrogen is more common in females. High levels of testosterone in males have long been associated with increased aggression (Booth et al., 2003; Dabbs et al., 1995), but the relationship between testosterone and aggression is quite complex and weaker in research using human participants versus animal subjects (Geniole et al., 2020). The connection between testosterone and aggression is complicated by findings that aggression (particularly the activation of aggressive behaviors) is influenced not just by the "male" testosterone, but also by the "female" estrogen. Other research indicates that what seems to matter most is the relative levels or balance of the two hormones.

Let us consider three endocrine glands—the pituitary, the thyroid, and the adrenal glands. Perhaps the most important endocrine gland is the pituitary gland. The **pituitary gland** is often referred to as the master gland, reflecting its direct control over the activity of many other glands in the system. The pituitary is nestled under the brain and secretes many different hormones. One hormone released by the pituitary is *growth hormone*, which regulates the growth of the body during its fastest physical development. Extremes of overproduction or underproduction cause the development of giants or dwarfs. The so-called "growth spurt" associated with early adolescence is due to the activity of the pituitary gland. It is the pituitary gland that stimulates the release of hormones that regulate the amount of water held within the body. It is the pituitary that directs the mammary glands in the breasts to release milk after childbirth. In its role as master over other glands, the pituitary regulates the output of the thyroid and the adrenal glands, as well as the sex glands.

Pituitary gland—a gland often referred to as the master gland, reflecting its direct control over the activity of many other glands in the endocrine system.

The **thyroid gland** is located in the neck and produces a hormone called *thyroxin*. Thyroxin regulates the pace of the body's functioning—the rate at which oxygen is used and the rate of body function and growth. When a person is easily excited, edgy, having trouble sleeping, and has lost weight, a person may have too much thyroxin in his or her system, a condition called *hyperthyroidism*. Too little thyroxin leads to a lack of energy, fatigue, and an inability to do much, a condition called *hypothyroidism*.

Thyroid gland—a gland located in the neck that produces a hormone called thyroxin. Thyroxin regulates the pace of the body's functioning.

The **adrenal glands**, located on the kidneys, secrete a variety of hormones into the bloodstream. The hormone *adrenaline* (more often referred to as epinephrine) is very useful in times of stress, danger, or threat. Adrenaline quickens breathing, causes the heart to beat faster, directs the flow of blood away from the stomach and intestines to the limbs, dilates the pupils of the eyes, and increases perspiration. When our adrenal glands flood epinephrine into our system during a perceived emergency, we usually feel the resulting reactions; but, typical of endocrine-system activity, these reactions may be delayed.

Adrenal glands—glands located on the kidneys that secrete a variety of hormones into the bloodstream.

For example, as you drive down a busy street, you see a child dart out from behind a parked car and race to the other side of the street. You slam on the brakes, twist the steering wheel, and swerve to avoid the child. As the child scampers away, oblivious to the danger, you proceed down the street. Then, about a block later, your body reacts to the near miss: your heart pounds, a lump forms in your throat, your mouth dries, and your palms sweat. Why does your reaction come when the incident is over and you are out of danger? The delay in your body's reaction is because your reaction is largely hormonal. Your body's adrenal glands secrete epinephrine, and it takes time for this substance to travel through the bloodstream to the heart, pupils of the eyes, and the brainstem. You begin to feel effects once the epinephrine reaches these places.

STUDY CHECK

What are the major divisions of the human nervous systems, and what do they do?
What is the function of the endocrine system in general and the pituitary gland, thyroid gland, and adrenal glands in particular?

THINKING CRITICALLY

Imagine you are walking barefoot in the dark and step on a tack. Which of your various nervous systems might be involved, and how?

The Spinal Cord

The central nervous system consists of the brain and the spinal cord. In this section, we consider the structure and function of the spinal cord, reserving our discussion of the brain for the next section.

The spinal cord is a mass of interconnected neurons within the spinal column that looks rather like a section of rope or thick twine. It is surrounded and protected by the hard bone and cartilage of the vertebrae. A cross-sectional view of the spinal column and the spinal cord is illustrated in **Figure 2.4**. A few structural details need to be mentioned. Note that the spinal cord is located in the middle of the spinal column, which extends from the lower back to high in the neck just below the brain. Note also that nerve fibers enter and leave the spinal cord from the side. In fact, there are three types of neurons in the spinal cord. **Sensory neurons** or nerve fibers carry impulses toward the brain or spinal cord. **Motor neurons** or nerve fibers carry impulses away from the spinal cord and brain to the muscles and glands. **Interneurons** are neurons within the spinal cord and central nervous system that transmit information between neurons.

Sensory neurons—nerve fibers that carry impulses toward the brain or spinal cord.

Motor neurons—nerve fibers that carry impulses away from the spinal cord and brain to the muscles and glands.

Interneurons—neurons within the spinal cord and central nervous system that transmit information between neurons.

Notice also that the center area of the spinal cord consists of gray matter, while the outside area is light white matter. This color difference means that the center portion is filled with cell bodies, dendrites, and unmyelinated axons, while the outer section is filled with myelinated axons. These observations about the structure of the spinal cord are the key to understanding its functions.

The spinal cord has two major functions. One involves transmitting impulses rapidly to and from the brain. When sensory impulses originate in sense receptors below the neck and make their way to the brain, they do so through the spinal cord. When the brain

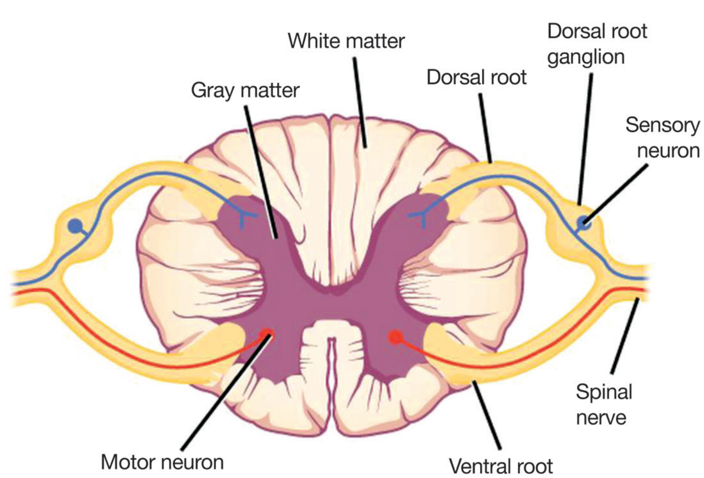


FIGURE 2.4 Cross-Sectional Diagram of the Spinal Column and Spinal Cord

transmits motor impulses to move or activate parts of the body below the neck, those impulses first travel down the spinal cord. For example, if you stub your toe, pain messages travel up the spinal cord and register in the brain. When you decide to reach for that cup of coffee and bring it toward your mouth, impulses originating in your brain move to the muscles in your back, arm, and hand by traveling first down the spinal cord.

Impulses to and from various parts of the body leave and enter the spinal cord at different points. Impulses to and from the legs, for example, enter and leave at the very base of the spinal cord. If the spinal cord is damaged, communication may be disrupted. The consequences of such an injury are disastrous, resulting in a loss of feeling and a loss of voluntary movement (that is, paralysis) of the muscles in those parts of the body served by the spinal cord below the injury. The higher in the spinal cord that damage takes place, the greater is the resulting loss.

Source: Suriyawut Suriya/Shutterstock.

A spinal reflex: Stimulation of receptor cells in the skin stimulates sensory neurons, interneurons, and motor neurons without the conscious voluntary action of the brain. You don't have to think about moving your hand after hitting your thumb with a hammer!

The second major function of the spinal cord involves spinal reflexes. **Spinal reflexes** are simple, automatic behaviors that occur without conscious, voluntary action of the brain. To understand how these reflexes work, see **Figure 2.5**. In this drawing of the spinal cord, you can see that impulses are sent from the finger to the spinal column via sensory neurons. Interneurons then connect the sensory neurons to motor neurons. Finally, motor neurons carry impulses back to the hand to withdraw the finger.

Spinal reflexes—simple, automatic behaviors that occur without conscious, voluntary action of the brain.

Let's trace your reaction to holding the tip of your finger over a burning candle. Receptor cells in your fingertip respond to the heat of the flame, sending neural impulses racing along sensory neurons, up your arm and shoulder, and into the spinal cord. Then two things happen at almost the same time. Impulses rush up the ascending pathways of the spinal cord's white matter to your brain (very quickly you learn how silly putting a finger near a flame was). Impulses also travel on interneurons and leave the spinal cord on motor neurons to your arm and hand, where muscles are stimulated to contract, and your hand jerks back.

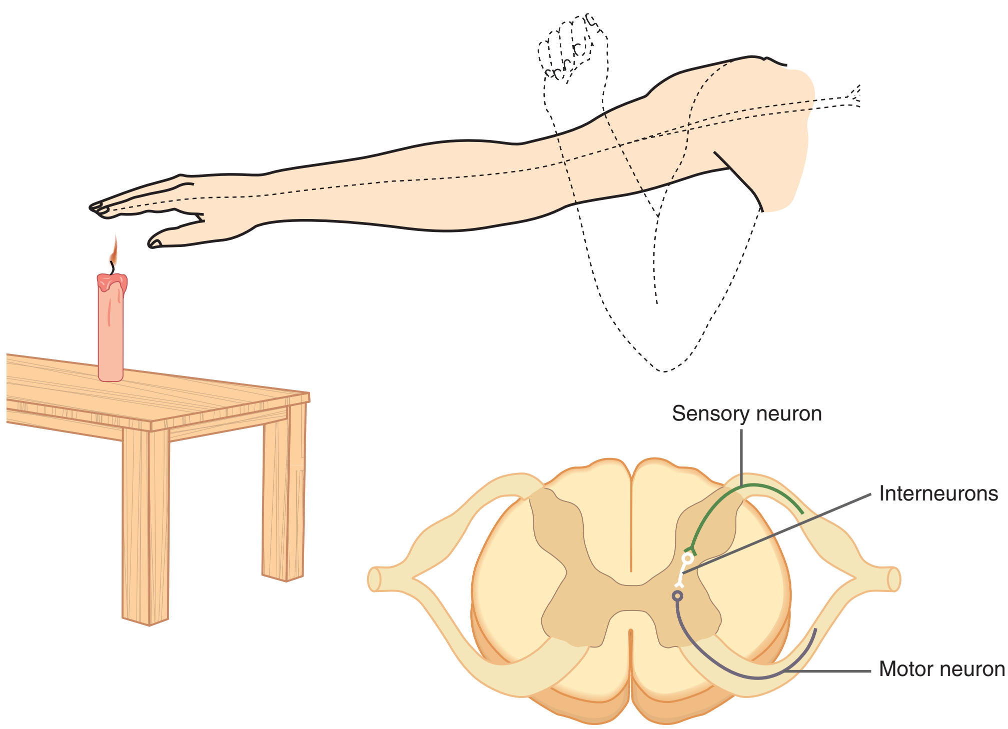


FIGURE 2.5 Spinal Reflex Example

Example of a spinal reflex involving only sensory and motor neurons. **Top:** Sensory neurons detect the heat of the flame, and motor neurons signal the arm to withdraw. **Bottom:** Impulses travel along sensory neurons to the spinal cord and then out via motor neurons to activate muscles to withdraw the hand.

PSYCHOLOGY IN ACTION

The Neuropsychology of Addiction

If you have been following the news, you probably know that the United States is in the midst of a serious problem: addiction to opioids. Opioids belong to a class of drugs called opiates that includes heroin, cocaine, codeine, and an array of prescription pain-reducing drugs (e.g., *OxyContin*). Another opioid is fentanyl, which is a synthetic opioid that is 100 times more potent than morphine and 50 times more potent than heroin (Drug Enforcement Agency, 2022). Fentanyl is manufactured both legally as a prescription pain medication and illegally. Fentanyl, especially in its illegal form, is especially dangerous because it is often mixed in with other drugs and disguised as a legitimate prescription drug (e.g., Xanax). Individuals may believe that they are taking a safe pill when they are actually taking an often-lethal dose of fentanyl. Fentanyl was responsible for 73,654 deaths in 2022, more than double the number in 2019 (USA Facts, 2023). A principal effect of taking an opiate is an intense feeling of euphoria and well-being, which causes many people to use these drugs. Unfortunately, these drugs are highly addictive. Many people who are addicted to illegal drugs like heroin and cocaine started on the path of addiction by taking legally prescribed pain medications for medical conditions. This has led in recent years to an explosion in the number of people who become addicted to and may even die as a result of abusing opiate drugs.

The statistics on opioid addiction are grim. According to the Substance Abuse and Mental Health Administration (2023), in 2019, 10.2 million people misused prescription opioids, and 1.8 million did so for the first time. The reasons for this abuse are many and include relieving pain, helping one to sleep, relieving tension, seeing what doing the drug feels like, and getting high (Lipari et al., 2017). Alarmingly, 62,486 Americans died from opioid-related causes in 2020. Approximately 75% of all drug overdose deaths in 2020 involved the use of opioids (U.S. Department of Health and Human Services, n.d.). So, becoming addicted to prescription drugs and, later, illegal drugs is a major problem. Two interesting questions are: What do these drugs do in the brain, and how does that relate to addiction?

As you just learned, communication between neurons in the brain involves impulses being transmitted between nerve cells via the synapse. When a neural impulse gets to the end of a neuron, a chemical is secreted (neurotransmitter) that affects receptor sites on the next neuron. The key to understanding how opioids work in the brain centers on the neurotransmitter dopamine and its receptor sites. Opioids operate on these receptor sites in many parts of the brain, spinal cord, and bodily organs. These receptor sites are intimately involved in pleasure and pain. The opioids act to block pain signals, and with higher doses, they arouse feelings of euphoria and pleasure (National Institute on Drug Abuse, n.d.). Opioids affect the brain on all levels, including brain cells, the circuits in the brain, and the general system (Evans & Cahill, 2016). Essentially, according to Evans and Cahill, the drug creates a "new normal" in the user's brain. In short, what happens is that when the opioid is present in an addicted person's brain, the brain operates "normally" for that person. When the drug is not there, the brain does not operate in this new normal manner (Kosten & George, 2002). Addiction appears to involve a change to the reward circuitry in the brain leading to a strong desire for the opioid. According to one theory, changes in the reward circuity relate to positive reinforcement from drug use and loss of inhibitory controls (Evans & Cahill, 2016). The reward circuitry in the brain includes an *endogenous opioid system* (EOS), which is distributed throughout the central nervous system and body tissues. This system controls a number of physiological responses, including memory, learning, emotions, and regulation of the reward circuits (Trigo et al., 2019). According to Trigo et al., repeated use of opioids results in changes to the EOS, giving rise to drug tolerance and dependence.

Withdrawal from an opioid addiction involves physical symptoms that are unpleasant. Treatment can be effective, but relapse can occur.

A big problem with opioid use is that as a person uses them more and more, the brain needs higher doses to produce the same effects. This is referred to as *tolerance*. Tolerance develops because the receptors involved become less responsive to the drug over the period of drug use, requiring higher and higher doses to obtain the same effect (Kosten & George, 2002). Once tolerance occurs, a person becomes drug *dependent*, which means that he or she will be susceptible to negative withdrawal symptoms when the opioid is not taken. As drug dependence becomes stronger, the addicted person keeps taking the drug to avoid the negative consequences of not taking the drug (withdrawal) (Kosten & George, 2002).

As you might expect, breaking an opioid addiction is extremely difficult. When the person stops taking the drug, it triggers *withdrawal*. Withdrawal typically involves some physical symptoms (e.g., sweating, tremors, and diarrhea) that go away relatively quickly and others (e.g., dysphoria, anxiety, and insomnia) that can last for months (Evans & Cahill, 2016). Treatment typically involves some form of drug therapy. Drugs such as Methadone and LAAM (a long-acting Methadone derivative) are used to treat the short-term symptoms of addiction. These drugs act on the same receptors as the opioid, but in a different way (Kosten & George, 2002). Another drug, Naltrexone, is used in the longer term to help

PSYCHOLOGY IN ACTION

The Neuropsychology of Addiction *(continued)*

avoid relapse. These drugs may be combined with other forms of psychological therapies (e.g., cognitive-behavioral therapy or contingency management [see Chapter 13]) to help break addiction. Physical exercise can also be beneficial when treating drug addiction (Lu et al., 2021). In their study, Lu et al. randomly assigned individuals addicted to methamphetamine to one of three conditions: aerobic exercise (e.g., cycling), anaerobic exercise (e.g., weight lifting), or a no-exercise control group. After a 12-week period, participants were assessed on a number of measures relating to drug addiction. Overall, Lu et al. found that aerobic and anaerobic exercise had positive effects on measures of addiction compared to the control group. They suggest that either type of exercise can be beneficial as part of an addiction treatment program. Although treatment can be effective, many people relapse and start using drugs again. It is widely known that individuals addicted to opioids are susceptible to stress. When stress is encountered, it triggers a desire to return to drug use (Kosten & George, 2002).

This is a simple spinal reflex. Impulses travel *in* on sensory neurons, *within* on interneurons, and *out* on motor neurons. Here we have an environmental stimulus (a flame), activity in the central nervous system (neurons in the spinal cord), and an observable response (withdrawal of the hand). Notice that, for this sequence of events of the spinal reflex, the involvement of the brain is not at all necessary.

There are a few observations we must make about the reflex of the type shown in Figure 2.5. First, the fact that impulses enter the spinal cord and immediately race to the brain is not indicated in the drawing. In a situation such as the candle example, you may jerk your hand back “without thinking about it,” but very soon thereafter you are aware of what has happened. Awareness occurs in the brain, not in the spinal cord. It is also true that some reflexes are simpler than the one in Figure 2.5. Some reflexes involve three types of neurons—sensory, motor, and interneurons. Other spinal reflexes involve only sensory neurons and motor neurons, which directly interact within the spinal cord. The common knee-jerk reflex is an example—sensory neurons and motor neurons synapse directly with no interneurons involved.

STUDY CHECK

What are sensory neurons, motor neurons, and interneurons?
What is the basic structure of the spinal cord, and what are its two functions?

THINKING CRITICALLY

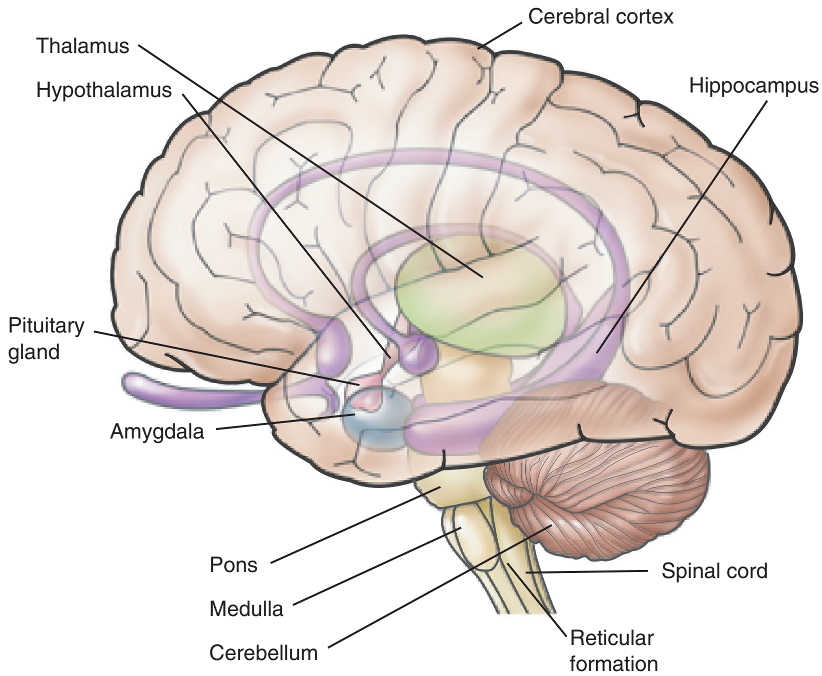
What sort of therapy or treatment might you imagine for persons who, because of spinal cord injury, lose feeling and become paralyzed?

“Lower” Brain Centers and What They Do

Perched atop your spinal cord, encased in bone, is a wonderful, mysterious organ: your brain (see **Figure 2.6**). Your brain is a mass of neurons, supporting cells, blood vessels, and ventricles (interconnected cavities containing fluid). Your brain accounts for a small fraction of your body weight, but due to its importance, it receives almost 20 percent of the blood in your body. Your brain contains a storehouse of memories and is the seat of your emotions and motivation. It regulates your breathing and the beating of your heart.

For convenience, we will divide the brain into two major categories of structures. We first discuss the role of some of the “lower” brain centers, which are involved in several important aspects of behavior. Then we will examine the role of the cerebral cortex, the outer layers or covering of the brain that controls higher mental functions.

FIGURE 2.6
The Structures of the Human Brain
The structures of the brain serve a variety of life-supporting, sensory, motor, and cognitive functions.



The "lower" centers of the brain contain vital structures involved in crucial, involuntary functions like respiration and heartbeat. Although we may call these structures "lower," they are by no means unimportant. Lower brain centers are "lower" in two ways. First, they are physically located beneath the cerebral cortex. Second, these brain structures develop first—both in an evolutionary sense and within the developing human brain. The lower brain structures are those we most clearly share with other animals and upon which our very survival depends.

If you look at the spinal cord and brain, you cannot tell where one ends and the other begins. There is no abrupt division of these two aspects of the central nervous system. Just above the spinal cord, there is a slight widening of the cord that suggests the transition to brain tissue. At this point of widening, two structures form the brainstem: the medulla and the pons.

Medulla—part of the brain that controls such functions as heart rate, respiration, blood pressure, coughing, sneezing, tongue movements, and reflexive eye movements.

The lowest structure in the brain is the medulla. In many ways, the medulla acts like the spinal cord in that its major functions involve involuntary reflexes. The **medulla** controls such functions as heart rate, respiration, blood pressure, coughing, sneezing, tongue movements, and reflexive eye movements. You do not think about blinking your eye as something rushes toward it, for example; your medulla produces that eye blink reflexively.

The medulla contains neurons that control breathing reflexes, mediate blood pressure levels, and regulate the muscles of the heart to keep it beating. We can control some of the neurons of the medulla, but only within limits. For example, the medulla controls our respiration (breathing), but we can override the medulla and hold our breath. We cannot, however, hold our breath until we die, as some children occasionally may threaten. We can hold our breath until we lose consciousness, which is to say until we give up voluntary control; then the medulla takes over and breathing resumes.

Cross laterality—arrangement of nerve fibers in the brainstem crossing from one side of the body to the opposite side of the brain.

At the level of the medulla, most nerve fibers to and from the brain cross from right to left and vice versa. That is, motor neurons from the left side of the brain cross over to control the right side of the body. Motor neurons from the right side of the brain cross to control the left side of the body. Similarly, sensory nerve fibers from each side of the body cross over to carry information to the opposite side of the brain. This crossover explains why electrically stimulating the correct area in the *left* side of the brain produces a movement in the *right* arm. It also explains why a cerebral stroke in the left side of the brain causes loss of movement in the right side of the body. The arrangement of nerve fibers in the brainstem crossing from one side of the body to the opposite side of the brain is called **cross laterality**.

Just above the medulla is a structure called the pons. (The pons is one structure; there is no such thing as a "pon.") The **pons** serves as a relay station or bridge, sorting out and relaying sensory messages from the spinal cord and the face up to higher brain centers and similarly relaying motor impulses from higher centers of the brain down to the rest of the body. The cross laterality that begins in the medulla continues in the pons. Cells in the pons are also partially responsible for the rapid eye movement that occurs when we dream. Other centers in the pons are involved in determining when we sleep and when we awaken.

Pons—a structure in the brain serving as a relay station or bridge, sorting out and relaying sensory messages from the spinal cord and the face up to higher brain centers and similarly relaying motor impulses from higher centers of the brain down to the rest of the body.

The cerebellum sits behind your pons, tucked up under the base of your skull. Your cerebellum (literally, "small brain") is about the size of your closed fist and is the second-largest part of your brain. Oddly, the cerebellum, as small as it is, contains nearly half of all the neurons in the human brain (Zillmer & Spiers, 2001). The major role of the **cerebellum** is to smooth and coordinate rapid body movements. Most intentional movements originate in higher brain centers (the motor area of the cerebral cortex) and are coordinated by the cerebellum. Because of the close relationship between body movement and vision, many eye movements originate in the cerebellum.

Cerebellum—the part of the brain that smooths and coordinates rapid body movements.

Your ability to stoop, pick a dime off the floor, and slip it into your pocket involves a complex series of movements smoothed and coordinated by your cerebellum. When athletes practice or rehearse a movement, such as a golf swing or a gymnastic routine, we may say that they are trying to "get into a groove," so that their trained movements can be made simply and smoothly. In a way, the athletes are training their cerebellums, which play such an important role in coordinating "automatic" movements. Examples would be catching a fast line drive hit right to you, playing a well-practiced piano piece, or quickly reaching out to save a priceless vase you just knocked off a table with your elbow. It appears that such movements are not reflexive, but rather the cerebellum learns to make them—a process that is the focus of research by neuroscientists interested in how one's learning experiences are represented in the brain.


Source: sirtravelalot/Shutterstock.

Catching a hard-hit baseball is an example of the cerebellum in action.

Few behaviors are as well coordinated or as well learned as the movements needed to speak. The next time you're talking to someone, focus on how quickly and effortlessly your lips, mouth, and tongue are moving, thanks to the cerebellum. Damage to the cerebellum slurs speech. In fact, damage to the cerebellum disrupts all coordinated movements. Someone with cerebellum damage may shake and stagger when he or she walks. To the casual observer, such a person may appear to be drunk. (On what region of the brain do you suppose alcohol has a direct effect? Yes, the cerebellum.)

The reticular formation is hardly a brain *structure* at all. It is a complex network of nerve fibers that begins in the brainstem and works its way up through and around other structures to the top portions of the brain. What the reticular formation does, and exactly how it does so, remains something of a mystery, but we do know that the **reticular formation** is involved in determining our level of activation or arousal. It influences whether we are awake, asleep, or somewhere in between. Electrical stimulation of the reticular formation can produce patterns of brain activity associated with alertness. Classic research has shown that lesions of the reticular formation cause a state of constant sleep in laboratory animals (Lindsley et al., 1949; Moruzzi & Magoun, 1949). In a way, the reticular formation acts like a valve that either allows sensory messages to pass from lower centers up to the cerebral cortex or shuts them off, partially or totally. We don't know what stimulates the reticular formation to produce these effects.

Reticular formation—brain structure involved in determining our level of activation or arousal.

A curious set of tissues is the basal ganglia. The basal ganglia are a collection of small, loosely connected structures deep within the center of the brain. Like the cerebellum, the basal ganglia primarily control motor responses. Unlike the cerebellum, the **basal ganglia** are involved in the planning, initiation, and coordination of large, slow

Basal ganglia—brain structures involved in the planning, initiation, and coordination of large, slow movements.

movements. Although the basal ganglia are clearly related to the movements of some of our body's larger muscles, there are no direct pathways from the ganglia down the spinal cord and to those larger muscles.

Parkinson's disease—a disorder involving the basal ganglia in which the most noticeable symptoms are impairment of movement and involuntary tremors.

Researchers have come to better understand the functions of the basal ganglia as they have come to better understand **Parkinson's disease**, a disorder involving the basal ganglia in which the most noticeable symptoms are impairment of movement and involuntary tremors. At first, patients with Parkinson's may have tightness or stiffness in the fingers or limbs. As the disease progresses, patients lose their ability to move themselves, or they are able to move but only with great effort. Walking, once begun, involves a set of stiff, shuffling movements. In advanced cases, voluntary movement of the arms is nearly impossible. Parkinson's disease is the second most common neurological disorder behind Alzheimer's disease. It was estimated that by the end of 2023, 1.2 million Americans would be diagnosed with Parkinson's (Parkinson's Foundation, n.d.). Parkinson's is more common with increasing age, afflicting approximately 1 percent of the population.

Limbic system—a collection of brain structures controlling many of the complex behavioral patterns that are often considered to be instinctive.

The limbic system is more a collection of small structures than a single unit. It is particularly important in controlling the behaviors of animals, which do not have as well-developed cerebral cortexes as humans. In humans, the **limbic system** controls many of the complex behavioral patterns that are often considered to be instinctive. The limbic system is located in the middle of the brain. Figure 2.6 shows some of the limbic system's major structures: thalamus, amygdala, hippocampus, and hypothalamus. There are other structures in the limbic system not shown in Figure 2.6 (septum, basal ganglia, and the cingulate gyrus).

Parts of the limbic system are involved in the display of emotional reactions. One structure in the limbic system, the *amygdala*, produces reactions of rage or aggression when stimulated, while another area, the *septum*, has the opposite effect, reducing the intensity of emotional responses when it is stimulated. The influence of the amygdala and the septum on emotional responding is immediate and direct in non-humans. In humans, their role is more subtle, reflecting the influence of other brain centers. The connection between the amygdala and the pons is related to depression (Wong et al., 2022). Wong et al. found that depressed individuals showed hyperactivity in the connection between the amygdala and pons compared to nondepressed individuals.

The amygdala also plays an important role in the emotion of fear (Davis et al., 2010). The authors of a case study of a woman (SM) with damage to her amygdala (Feinstein et. al., 2011) report that SM is incapable of experiencing fear to a wide range of stimuli (e.g., snakes, spiders, a haunted house, a scary film), nor does she report experiencing fear in her everyday life. SM is also not able to "read" the facial expression associated with fear in others. However, SM is fully capable of experiencing a range of other emotions including anger and happiness. So, the damage to her amygdala does not disrupt emotions generally, but rather only the emotion of fear. The amygdala is also important when deciding whether or not a stimulus is dangerous (Ekman, 1992; LeDoux, 1995), an ability that is also related to the experience of fear.

Another structure in the limbic system, called the *hippocampus*, is less directly involved in emotion and more involved with the formation of memories. (Vargha-Khadem et al., 1997). People with a damaged hippocampus are often unable to "transfer" experiences (e.g., a birthday party) into permanent memory storage (Wheeler & McMillan, 2001). They may remember events for short periods and may be able to remember events from the distant past, but only if these events occurred before the hippocampus was damaged.

The role of the hippocampus may differ according to the nature of the memory. Brian Witgen and his colleagues (2010) report that detailed memories require activity of the hippocampus, whereas less detailed memories do not. Another study demonstrated the role of the hippocampus in the formation of fear-related memories (McEwon & Treit, 2010).

The *hypothalamus* is a structure that plays a complex role in motivational and emotional reactions. Among other things, it influences many of the functions of the endocrine system, which, as we have seen, is involved in emotionality. The major responsibility of the hypothalamus is to monitor critical internal bodily functions. One subsection (nucleus), for example, mediates feeding behaviors. Destruction of this nucleus in a rat results in a condition that causes the animal to lose its ability to regulate food intake and become obese. (As you can imagine, researchers who study the various eating disorders have been very interested in the hypothalamus (e.g., Polivy & Herman, 2002)). In a similar way, another area in the hypothalamus is involved in the detection of thirst and regulation of fluid intake.

The hypothalamus also plays a role in aggression. Stimulation of the lateral nucleus in a cat produces aggression that looks much like predatory behavior. The cat is highly selective in what it attacks and stalks its prey before pouncing. Stimulation of the medial nucleus results in an anger-based aggression (Edwards & Flynn, 1972). The cat shows the characteristic signs of anger (arched back, ears flattened, hissing and spitting) and will attack anything in its way. Interestingly, the role of the hypothalamus in hunger and aggression is not as simple as it may seem. For example, if you apply mild stimulation to the lateral nucleus, a cat will show signs of hunger (but not aggression). Increase the strength of the stimulation to the same site, and a cat will display aggression. Stress early in life can lead to changes in the hypothalamus that increase aggression in adulthood (Veenema et al., 2006). For example, separating rat pups from their mothers (a highly stressful event) produced changes in the levels of a hormone and a neurotransmitter in parts of the hypothalamus. These changes led to higher levels of aggression among adult male rats.

The hypothalamus also acts something like a thermostat, triggering a number of automatic reactions should we become too warm or too cold. It does this by integrating temperature information from the environment, the central core of the body, and the peripheral regions of the body. Scientists believe that the temperature regulation function of the hypothalamus may be linked to the aging process and longevity (Tabarean et al., 2010). This structure is also involved in aggressive and sexual behaviors. It acts as a regulator for many hormones. The hypothalamus has been implicated in the development of sexual orientations, an implication we'll discuss in later chapters when we study needs, motives, and emotions.

The thalamus sits below the cerebral cortex and is intimately involved in its functioning. Like the pons, the **thalamus** is a relay station for impulses traveling to and from the cerebral cortex. Many impulses traveling from the cerebral cortex to lower brain structures, the spinal cord, and the peripheral nervous system pass through the thalamus. Overcoming the normal function of the medulla (for example, by holding your breath) involves messages that pass through the thalamus. The major role of the thalamus, however, involves the processing of information from the senses.

Thalamus—a brain structure acting as a relay station for impulses traveling to and from the cerebral cortex.

In handling incoming sensory impulses, the thalamus collects, organizes, and then directs sensory messages to the appropriate areas of the cerebral cortex. Sensory messages from the lower body, eyes, and ears, (but not the nose) pass through the thalamus. For example, at the thalamus, nerve fibers from the eyes are spread out and projected onto the back of the cerebral cortex. It is believed by many neuroscientists that the thalamus "decides" what information will be sent to the cortex and enter consciousness, but empirical data to support this hypothesis have proven difficult to obtain.

STUDY CHECK

Where are the medulla and the pons, and what do they do?
What is meant by cross laterality?
What are the major functions of the cerebellum and the reticular formation?
What are the basal ganglia, and what is their relation to Parkinson's disease?
What are the major structures of the limbic system, and what are their functions?
What are the functions of the thalamus, and where is it located?

THINKING CRITICALLY

One way to study how the various structures in the central nervous system work is to contemplate what would happen if those structures were damaged or destroyed. For example, what would be the result of an accident that damaged the medulla? What if the pons were destroyed?

The Cerebral Cortex

The human brain is a homely organ. There is nothing pretty about it. When we look at a human brain, the first thing we are likely to notice is the large, soft, lumpy, creviced outer covering of the cerebral cortex (cortex means "outer bark," or covering). The cerebral cortex of the human brain is significantly larger than any other brain structure. It is the complex and delicate **cerebral cortex** that makes us uniquely human by giving us our ability to think, reason, and use language.

Cerebral cortex—the large part of the brain that makes us uniquely human by giving us our ability to think, reason, and use language.

Lobes and Localization

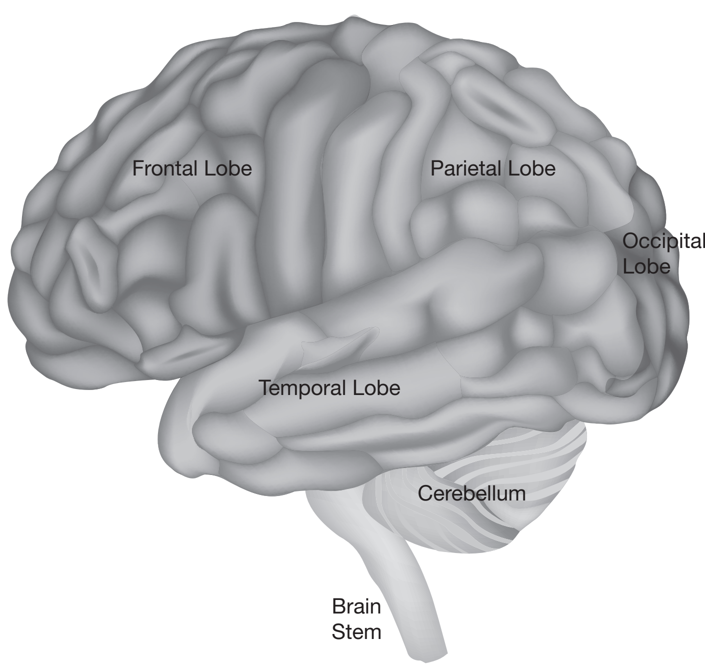
Figure 2.7 presents a lateral (side) view of the cerebral cortex. You can see that the deep folds of tissue provide us with markers for dividing the cerebrum into major areas. There is a deep crevice that runs down the middle of the cerebral cortex from front to back, dividing it into the left and right cerebral hemispheres.

Figure 2.7 allows us to see the four major divisions of each hemisphere, called "lobes." The *frontal lobes* (plural because there is one on the left and one on the right, as is the case for the other lobes) are the largest and are defined by two large crevices called the central fissure and the lateral fissure. The *temporal lobes* are located at the temples below the lateral fissure, with one on each side of the brain. The *occipital lobes*, at the back of the brain, are defined somewhat arbitrarily, with no large fissures setting them off, and the *parietal lobes* are wedged behind the frontal lobes and above the occipital and temporal lobes.

Researchers have learned much about what normally happens in the various regions of the cerebral cortex, but many of the details of cerebral function are yet to be understood. Neuroscientists have mapped three major areas of the cortex: *sensory areas*, where impulses from sense receptors are sent; *motor areas*, where most voluntary movements

FIGURE 2.7 The Lobes of the Brain

The cerebral cortex covering each cerebral hemisphere is divided into four lobes: the frontal lobe, the temporal lobe, the parietal lobe, and the occipital lobe.



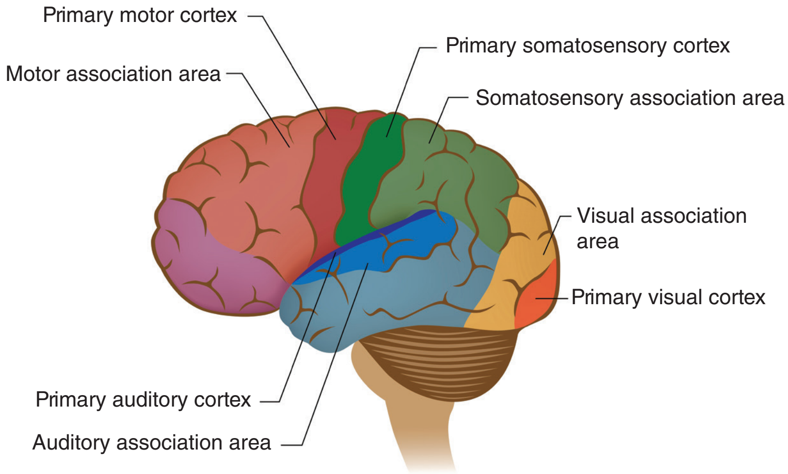


FIGURE 2.8 Various Areas of the Brain

The various areas of the brain are involved in different functions, including sensory, motor, and association.

Source: Alila Medical Media/ Shutterstock.

originate; and *association* areas, where sensory and motor functions are integrated and where higher mental processes are thought to occur. We will review each of these in turn, referring to **Figure 2.8** as we go along.

Let's review for a minute. Receptor cells (specialized neurons) in our sense organs respond to stimulus energy from the environment. These cells then pass neural impulses along sensory nerve fibers, eventually to the cerebral cortex. Senses in our body below our neck first send impulses to the spinal cord. Then it's up the spinal cord, through the brainstem, where they cross from left to right and from right to left, on up to the thalamus, and beyond to the cerebrum. After impulses from our senses leave the thalamus, they go to a **sensory area**, an area of the cerebral cortex that receives impulses from the senses. Which sensory area gets involved depends on which sense was activated.

Sensory area—the area of the cerebral cortex that receives impulses from the senses.

Large areas of the human cerebral cortex are involved with vision and hearing. Virtually the entire occipital lobe processes visual information (labeled "visual association area" in Figure 2.8). Auditory (hearing) impulses go to large centers ("auditory areas") in the temporal lobes. Bodily senses (touch, pressure, pain, etc.) send impulses to a strip at the very front of the parietal lobe (labeled "primary somatosensory cortex" in Figure 2.8). In this area of the parietal lobe, researchers have mapped out specific regions that correspond to the various parts of the body. Looking at such a "map," we find that some body parts—the face, lips, and fingertips, for example—are over-represented in the body sense area of the cerebral cortex, reflecting their high sensitivity.

Finally, let's remind ourselves of cross laterality, the crossing over of information from senses on the left side of the body to the right side of the brain, and vice versa, that occurs in the brain stem. When someone touches your right arm, that information ends up in your left parietal lobe. A tickle to your left foot is processed by the right side of your cerebral cortex.

We have seen that some of our actions, at least very simple and reflexive ones, originate below the cerebral cortex. Although lower brain centers, such as the basal ganglia, may be involved, most voluntary activity is initiated in the **motor areas** of the cerebral cortex in strips at the very back of the frontal lobes. These areas (again, there are two of them, left and right) are directly across the central fissure from the body sense areas in the parietal lobe (labeled "primary motor cortex" in Figure 2.8). We need to make the disclaimer that the actual *decision* to move probably occurs farther forward in the frontal lobes.

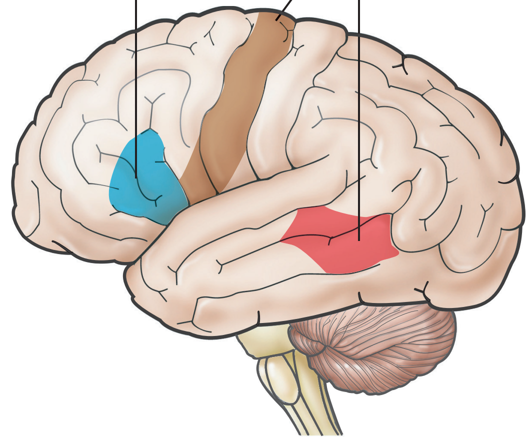
Motor area—the area of the cerebral cortex located in strips at the very back of the frontal lobes that coordinates and initiates most voluntary activity.

Electrical stimulation techniques have allowed neuroscientists to map locations in the motor areas that correspond to, or control, specific muscles or muscle groups. As is the case for sensory processing, some muscle groups (e.g., those that control movements of the hands and mouth) are represented by disproportionally larger areas of the cerebral cortex.

As you know, cross laterality is also at work with the motor area. It is your right hemisphere's motor area that controls movements of the left side of your body, and the left

FIGURE 2.9 Speech and the Brain

Wernicke's area, Broca's area, and the motor cortex interact in producing speech.



hemisphere's motor area that controls the right side. Someone who has suffered a cerebral stroke (a disruption of blood flow in the brain that results in the loss of neural tissue) in the left side of the brain will have impaired movement in the right side of his or her body.

Once we have located the areas of the cerebral cortex that process sensory information and initiate motor responses, there is a lot of cortex left over. The remaining areas of the cerebral cortex are called **association areas**, which are areas of the cerebrum where sensory input is integrated with motor responses and where cognitive functions such as problem solving, memory, and thinking occur. There is an association area in each of the two frontal, parietal, and temporal lobes. As shown in Figure 2.8, a large portion of the occipital lobe is taken up by the visual association area, which processes visual information.

Association areas—areas of the cerebral cortex where sensory input is integrated with motor responses and where cognitive functions such as problem solving, memory, and thinking occur.

There is considerable support for the idea that the "higher mental processes" occur in the association areas. Frontal association areas are involved in many such processes (Schall, 2004). Normal speech functions are controlled by this portion of the brain (located on the left side of the brain in most people), called *Broca's area* (see **Figure 2.9**). That is, it coordinates the actual functions needed to express an idea. A person with damage to Broca's area shows an interesting pattern of speech defects. If asked a question like, "Where is your car?" a person with Broca's area damage might be able to tell you, but only in broken, forced language. For example, the person might say, "Car . . . lot . . . parked by . . . supermarket." Understanding language and organizing linguistic responses are functions of *Wernicke's area* (see Figure 2.9). If you asked a person with damage to Wernicke's area where his or her car was, the person might say, "The cat is sitting on the table." Notice that this response is well formed (because Broca's area is working fine) but makes no sense with respect to the question.

Damage to the very front of the right frontal lobe or to an area where the parietal and temporal lobes come together often interrupts or destroys the ability to plan ahead, to think quickly, reason, or think things through (Greene & Haidt, 2002). Interestingly, these association areas of the brain involved in forethought and planning nearly cease to function when one is feeling particularly happy (e.g., George et al., 1995) or one consumes alcohol (Pihl et al., 2003).

We should not get too carried away with cerebral localization of function. Please do not fall into the trap of believing that separate parts of the cerebral cortex operate independently or that they have the sole responsibility for any one function. It is also true that the brain shows a remarkable degree of flexibility in both structure and function. Brain scientists refer to this as plasticity. *Plasticity* is the nervous system's "capacity to respond in a dynamic manner to the environment and experience via modification of neural circuitry" (Anderson et al., 2011, p. 2198). Tissue in the nervous system has the capacity to adapt and take on new functions because of environmental conditions. So, for example, if a part of the brain with a specific function is damaged, it is possible for other areas of the brain to take over its function.

The Two Cerebral Hemispheres: Splitting the Brain

The ancient Greeks knew that the cerebral cortex was divided into two major sections, or hemispheres. That the cerebral cortex is divided in half seems quite natural. After all, we have two eyes, arms, legs, lungs, and so forth. Why not two divisions of the brain? In the last decades, interest in this division into hemispheres has heightened as scientists have accumulated evidence that suggests that each half of the cerebral cortex may have primary responsibility for its own set of functions.

In most humans, the left hemisphere is the larger of the two halves, contains a higher proportion of gray matter, and is considered the *dominant hemisphere* (active to a greater degree in more tasks). We have already noted that the major language centers are housed in the left cerebral hemisphere. At least this is true for nearly all right-handed people. For some left-handers, language may be processed primarily by the right hemisphere. Because humans are so language-oriented, little attention was given to the right hemisphere until a remarkable surgical procedure performed in the 1960s gave us new insights about the cerebral hemispheres (Sperry, 1968, 1982; Springer & Deutsch, 1981).

Normally, the **corpus callosum**, a network of hundreds of thousands of fibers, connects the two hemispheres of the cerebral cortex (see **Figure 2.10**). Through the corpus callosum, one side of our cortex remains in constant and immediate contact with the other. Separating the functions of the two hemispheres is possible, however, through a surgical technique called a **split-brain procedure**, which is neither as complicated nor as dangerous as it sounds. The procedure was first performed on a human in 1961 by Joseph Brogan to lessen the severity of the symptoms of epilepsy. As a treatment of last resort, the split-brain procedure has been very successful. Although the procedure destroys the corpus callosum's connections between the hemispheres, it does leave intact other, smaller, connections between the two hemispheres.

Corpus callosum—a network of hundreds of thousands of fibers connecting the two hemispheres of the cerebral cortex.

Split-brain procedure—a surgical technique used to separate the functions of the two cerebral hemispheres.

Most of what we know about the activities of the cerebral hemispheres has been learned from split-brain subjects, both human and animal. One of the things that makes this procedure remarkable is that, under normal circumstances, split-brain patients behave normally. Only in the laboratory, using specially designed tasks, can we see the results of independently functioning hemispheres of the cerebral cortex (Corballis et al., 2002; Foerch, 2005; Gazzaniga et al., 2002).

Experiments with split-brain patients confirm that speech production is a left-hemisphere function in most people. Imagine you have your hands behind your back. I place a house key in your left hand and ask you to tell me what it is. Your left hand feels the key. Impulses travel up your left arm, up your spinal cord, and cross over to your right cerebral hemisphere (remember cross laterality). You tell me that the object in your left hand is a key because your brain is intact. Your right hemisphere quickly passes the

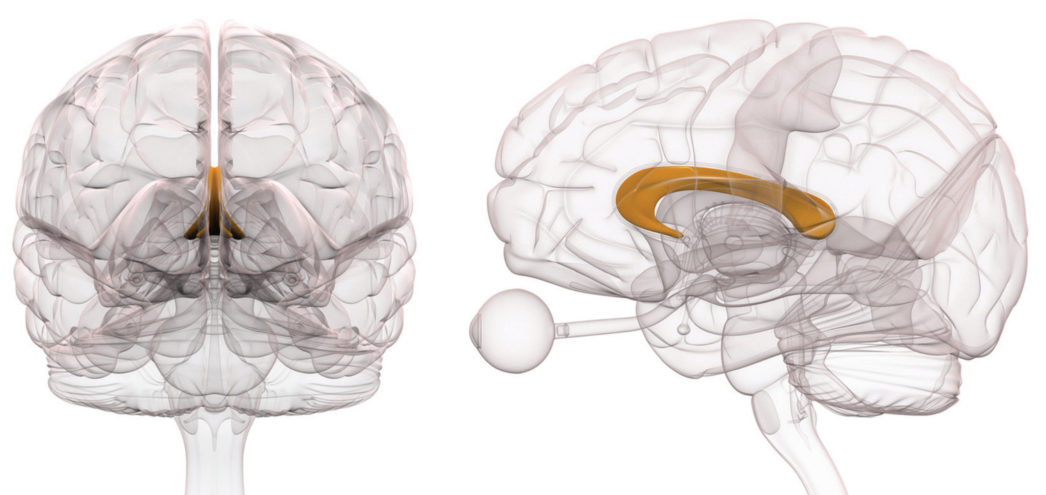


FIGURE 2.10
The Corpus Callosum

A frontal and lateral view of the brain showing the location and shape of the corpus callosum within the brain. The corpus callosum is a wide band of axons that connects the right and left hemispheres.

Source: decade3d—anatomy online/Shutterstock.

FOCUS ON DIVERSITY

Gender Differences in the Brain

There are obviously many anatomical differences between men and women. Can the same be said of the brains of men and women? As we explore the answer to this question, keep in mind that we are asking about general differences and not about the specific brains of one man and one woman. If there are differences in the anatomy of male and female brains, we then must ask if these differences are significant. Do they have a measurable impact on psychological functioning?

Research shows that there are some anatomical differences between the male and female brain. Generally, research in this area has focused on three aspects of male–female brain differences: brain development, communication among brain cells, and communication between brain hemispheres (Zelco et al., 2023). There are anatomical differences between the male and female brains. For example, the male brain is larger than the female brain (even after body size is controlled) but has a lower ratio of gray matter to white matter (Sacher et al., 2013). Additionally, females have more white matter in regions of the left hemisphere and men in the right hemisphere (Sacher et al., 2013). Other interesting anatomical gender differences are that the two hemispheres (halves) of women's brains are more highly connected, but there is more connectivity within the hemispheres in men (Ingalhalikar et al., 2013). This suggests that the two hemispheres of women's brains might work together more than the hemispheres of men's brains. There is also evidence that there are gender differences in the lateralization of the male and female brain. Research shows that the hemispheres of the cerebral cortex are more separate and distinct (more lateralized) in males than in females. This may account for the fact that women are more likely to recover from strokes than are men, perhaps because functions lost as a result of damage in one hemisphere can be taken over more easily by the other, undamaged hemisphere (McGlone, 1980). Interestingly, anatomical sex differences in the brain result in females being less vulnerable to age-related changes than males (Zelco et al., 2023).

Do the anatomical differences between male and female brains translate into any differences in function or behavior? Yes, they do—at least to some extent. Women tend to perform better than men when it comes to verbal short-term memory tasks in both brain connectivity and activity. Men, on the other hand, outperform women on visuospatial tasks (Zelco et al., 2023). Women recall or recognize emotional information better than men (Canli et al., 2002). Canli et al. found that women's recollections of emotionally stimulating photographs were 10 to 15 percent more accurate than men's recollections of similar photographs. The study also found that women's brains were more active than men's when looking at pictures of emotional stimuli. Another widely reported gender difference is that males show more interest in playing video games than females. This difference may relate to differences in brain functioning (Hoeft et al., 2008). Using functional magnetic resonance imaging, Hoeft et al. found greater activity in parts of the limbic system associated with reward and addiction in males compared with females. The authors believe this may help explain why males are more likely than females to become "hooked" on video games.

Another area where sex-related brain differences translate into behavioral differences in behavior is psychopathology (Zelco et al., 2023). In their review of the research on sex differences in the brain, Zelco et al. report several such differences. For example, women have a far higher rate of emotional disorders, such as anxiety and depression, than men. Women also have higher rates of Alzheimer's disease than men. On the other hand, males show higher rates of aggression, attention-deficit hyperactivity disorder, autism, and schizophrenia than females.

So, there is enough evidence to show that there are anatomical and functional differences between the male and female brains. However, keep in mind that the differences found are small; only about 1 percent of lateralization differences are accounted for by gender (Boles, 2005). Despite this relatively small difference, researchers believe that continued research will give us a greater understanding of brain functioning and potential treatments for brain trauma and other disorders.

information about the key to your left hemisphere, and your left hemisphere directs you to say, "It's a key."

Now suppose that you are a split-brain patient. You cannot answer my question even though you understand it perfectly. Why not? Your right brain knows that the object in your left hand is a key, but without an intact corpus callosum, it cannot inform the left hemisphere, where speech production is located. Under the direction of the right cerebral hemisphere, you would be able to point with your left hand to the key placed among other objects before you. Upon seeing your own behavior, your eyes would communicate that information to your left hemisphere.

So, a major task for the left hemisphere is the production of speech and the processing of language. But we must remain cautious about making too much of the specialization of function. When the results of the first research efforts on split-brain patients were made public, many people, less skeptical than the researchers themselves, jumped to faulty, overly simplistic conclusions. We now know that virtually no behavior or mental process is the product of one hemisphere alone. For example, Gazzaniga (1998) reports of one split-brain patient who learned to speak from the right hemisphere 13 years after surgery severed the corpus callosum.

Still, what about the right hemisphere? The clearest evidence is that the right hemisphere dominates the processing of visually presented information (Bradshaw & Nettleton, 1983; Kosslyn, 1987). Putting together a jigsaw puzzle, for instance, uses the right hemisphere more than the left. Skill in the visual arts (e.g., painting, drawing, and sculpting) is associated with the right hemisphere. It is involved in the interpretation of emotional stimuli and in the expression of emotions. While the left hemisphere is analytical and sequential, the right hemisphere is considered better able to grasp the big picture—the overall view of things—and tends to be somewhat creative.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Yes, there are exceptions, but very often artistic, visual skills are processed more in the right cerebral hemisphere than the left.

These possibilities are intriguing. While it seems that there are differences in the way the two sides of the cerebral cortex normally process information, these differences are slight, and many are controversial. In fact, the more we learn about hemispheric differences, the more we discover similarities. And let's not lose sight of the enormous ability of the human brain to repair itself. In 2003, the Associated Press published a story about Christina Santhouse, a 16-year-old high school student. When she was 9 years old, the entire right cerebral hemisphere of her brain was surgically removed. The treatment was for an advanced case of Rasmussen's encephalitis, a neurological disease that gradually eats away brain tissue. The surgery was done at Johns Hopkins Hospital, where over 100 such "hemispherectomies" have been performed. Yes, Christina suffers from side effects of the procedure (e.g., partial paralysis in her left arm and leg and the loss of peripheral vision in one eye), but in most ways, the fully functioning left hemisphere has managed to take over the functions of the missing right hemisphere. Christina, now an adult, is a speech pathologist.

STUDY CHECK

What is the location of each of the four lobes of the cerebral cortex?
What are the functions of the sensory areas, the motor areas, and the association areas of the cortex?
What is the split-brain procedure, and what has been learned from it?

THINKING CRITICALLY

Might it be possible to train or educate one hemisphere of the brain while ignoring the other? Imagine that you wanted to strengthen the abilities of your right cerebral hemisphere. How might you proceed?

Chapter Summary

What are the major parts of a neuron?

A neuron is the basic cell of the nervous system. Every neuron has three parts: the cell body, dendrites, and axon. The cell body contains the structures needed to sustain the life of the neuron. Dendrites extend from the cell body and receive messages from other neurons, while the axon extends from the cell body and carries the neural message away from the cell body. At their ends, axons branch out to form several axon terminals.

What is myelin, and what functions does it serve?

Myelin is a white fatty substance that coats the axons of some neurons of the nervous system. The myelin sheath covers the axon in segments, rather than in one continuous covering. The myelin sheath has several functions. First, it protects the delicate axon from damage. Second, it insulates the axon against signals from other neurons. Third, it speeds the rate of the neural impulse as it travels down the axon.

What is the nature of a neural impulse?

A neural impulse is the electrical signal, or activity, that travels down the axon after a neuron has been stimulated.

What is the all-or-none principle, and what are neural thresholds?

The all-or-none principle is the name for the observation that if a neuron fires, the neural impulse occurs at full force, or not at all. Thus, there is no such thing as a strong or weak neural impulse; it is either present or not. Neural thresholds describe the minimal level of stimulation necessary to get a neuron to transmit an impulse of its own. Some neurons have very low thresholds (and, thus, are very sensitive), while some have high thresholds (and require considerable stimulation before they fire).

What is the synapse, and in general terms, what happens there?

A synapse is the location where two neurons communicate with each other. The neurons do not physically touch; there is a small gap separating the axon of one neuron from the dendrite or cell body of the next. Communication between neurons across the gap between neurons is accomplished chemically. When the neural impulse reaches the axon terminal, a neurotransmitter is released into the synaptic cleft. It is through this chemical that the neural impulse is communicated across the synapse.

What are the major divisions of the human nervous systems, and what do they do?

The central nervous system (CNS) includes all of the neurons and supporting cells found in the brain and spinal cord. It is a complex system involved in the control of behavior and mental processes. The peripheral nervous system (PNS) consists of all of the neurons in our body that are not in the central nervous system. It includes the nerve fibers in our arms, face, fingers, intestines, etc. Neurons in the peripheral nervous system carry impulses either from the central nervous system to the muscles and glands or to the central nervous system from receptor cells. The somatic and autonomic nervous systems are subdivisions of the peripheral nervous system. The somatic nervous system includes the neurons that serve the skeletal muscles and pick up impulses from our sense receptors. The autonomic nervous system (ANS) is composed of the nerve fibers that activate the smooth muscles, such as those of the stomach, intestines, and glands. The autonomic nervous system has two subsystems. The sympathetic system is activated under conditions of excitement or arousal, and the parasympathetic system is activated when a person is relaxed and calm.

What is the function of the endocrine system in general and the pituitary gland, thyroid gland, and adrenal glands in particular?

The endocrine system is a network of glands that influence behaviors through the secretion of chemicals called hormones. The hormones, which circulate through the blood system, can have an effect on behavior. The pituitary gland is often called the "master gland" because it controls many other glands in the endocrine system. It is located under the brain and secretes a variety of hormones. Pituitary hormones affect growth, lactation, regulation of the amount of water held in the body, and the regulation of other glands. The thyroid gland, located in the neck, produces a hormone, thyroxin, which regulates the body's "pace" (e.g., the rate at which oxygen is used). Hyperthyroidism occurs when too much thyroxin in the blood results in excitability, edginess, insomnia, and weight loss. Too little thyroxin leads to hypothyroidism, associated with fatigue and lack of energy. The adrenal glands, located on the kidneys, secrete a variety of hormones into the blood. One such hormone, adrenaline, is released during times of danger. It increases respiration and heart and perspiration rates, directs the flow of blood away from the digestive system toward the limbs, and causes pupils to dilate.

What are sensory neurons, motor neurons, and interneurons?

Sensory neurons carry information (in the form of neural impulses) from the body to the central nervous system. Motor neurons carry information from the central nervous system to muscles and glands in the body. Interneurons are those neurons located and functioning within the central nervous system.

What is the basic structure of the spinal cord, and what are its two functions?

The spinal cord, encased in the spinal column, is a mass of interconnected neurons resembling a piece of rope that extends from the lower back to just below the brain. It has nerve fibers that carry messages to and from the brain and to and from the body. The spinal cord also is involved in reflex actions. When a receptor is stimulated (e.g., your hand touches a hot surface) sensory neurons transmit the information to the spinal cord. There, interneurons form synapses with motor neurons that then send impulses to muscles in your arm and hand to withdraw your hand. At the same time, however, information is transmitted up the spinal cord, and you consciously experience the pain. Note that some reflexes do not involve interneurons to mediate sensory experience and motor response, and instead work through direct synaptic connections between sensory and motor neurons. These synapses are located within the spinal cord.

Where are the medulla and the pons, and what do they do?

Like the spinal cord, the medulla's major functions involve involuntary reflexes. There are several small structures in the medulla that control functions such as coughing, sneezing, tongue movements, and reflexive eye movements. The medulla also sends out impulses that keep your heart beating and your respiratory system breathing. The pons serves as a relay station, sorting and relaying sensory messages from the spinal cord and the face to higher brain centers, and reversing the relay for motor impulses coming down from higher centers. The pons is also responsible, at least in part, for the sleep/waking cycle and the rapid movement of our eyes that occurs when we dream.

What is meant by cross laterality?

Cross laterality means that the right side of your brain controls the left side of your body, while the left side of your brain controls the right side of your body. In the same fashion, sensory impulses from the right side of your body cross to be received by the left side of your brain, and sensory impulses from the left side of your body are registered in the right side of your brain.

What are the major functions of the cerebellum and the reticular formation?

The cerebellum is located under the base of the skull. The major function of the cerebellum is to smooth out and coordinate rapid body movements. Most voluntary movements originate in the higher brain centers and are coordinated by the cerebellum. Damage to the cerebellum can lead to a variety of motor problems including loss of coordination, tremors, and speech problems. The reticular formation is more a network of nerve fibers than a true brain structure. Most of the functions of the reticular formation remain a mystery. However, we know it is involved in alertness and the sleep/waking cycle.

What are the basal ganglia, and what is their relation to Parkinson's disease?

The basal ganglia are a collection of small, loosely connected structures deep in the middle of the brain. The basal ganglia primarily control the initiation and the coordination of large, slow movements. In Parkinson's disease, the cells in the basal ganglia that produce the neurotransmitter dopamine die, and the levels of dopamine in the basal ganglia drop. This loss of dopamine is thought to produce the characteristic motor problems associated with the disease.

What are the major structures of the limbic system, and what are their functions?

The limbic system is a collection of structures rather than a single one. The limbic system is composed of the amygdala, hippocampus, septum, and hypothalamus. The limbic system controls many of the behaviors that we consider instinctive. When stimulated, the amygdala evokes reactions of rage or aggression. It also helps you to decide whether or not a stimulus is dangerous. The septum reduces the intensity of emotional responses when it is stimulated. The influence of the amygdala and the septum on emotional responding is immediate and direct in non-humans. In humans, it is more subtle, which reflects the influence of other brain centers.

The hippocampus is involved with forming memories. Persons with damage to the hippocampus have difficulty transferring memories from temporary memory storage to permanent storage. The hypothalamus is a part of the limbic system involved in the mediation of motivation. It is not a unitary structure, but rather a collection of smaller structures called nuclei. Each nucleus plays a different role. The major function of the hypothalamus is to monitor and control internal body functions such as hunger, thirst, and body temperature, as well as to regulate many hormones.

What are the functions of the thalamus, and where is it located?

The thalamus is a lower brain structure located just below the cerebral cortex. It relays impulses traveling to and from the cortex. The primary function of the thalamus is to relay sensory information to the cerebral cortex, and perhaps to regulate access to consciousness.

What is the location of each of the four lobes of the cerebral cortex?

The cerebral cortex, also known as the cerebrum, is associated with those higher mental processes that make us human. The lobes of the cerebral cortex are divisions of each of the two cerebral hemispheres. The frontal lobes are defined by two large crevices called the central and lateral fissures, and are located at the front of the brain. The temporal lobes are located at the temples, below the lateral fissure on each side of the brain. The occipital lobes are located at the very back of the brain, and the parietal lobes are sandwiched between the frontal, occipital, and temporal lobes.

What are the functions of the sensory areas, the motor areas, and the association areas of the cortex?

The sensory areas of the brain are portions of the brain specialized for receiving neural impulses from the senses. Nearly all of the occipital lobe is dedicated to receiving information from visual stimuli. Impulses relating to hearing are directed to the temporal lobes. Information from the body senses goes to the body sense areas located in the parietal lobe. The motor areas of the cerebral cortex initiate and control most voluntary motor movements. The motor areas of the cortex are located at the back of the frontal lobes. The association areas of the cortex are the parts of the cortex not directly involved in the mediation of sensory and motor activities. The association areas make up a large portion of the cortex and are involved in the integration of sensory input, motor responses, and higher cognitive functions (e.g., problem-solving and memory).

What is the split-brain procedure, and what has been learned from it?

The split–brain procedure is a surgical technique performed to relieve the symptoms of severe epilepsy. The procedure involves severing the corpus callosum. The result is that the two hemispheres become disconnected and can be studied independently. In most people, the left hemisphere of the cerebrum is larger and is referred to as the "dominant hemisphere" because it is active in so many tasks and because it is the seat of language in most people. The differences in function of the two hemispheres of the cortex are quite minimal, but the right hemisphere seems to be specialized for visual and spatial information. Artistic skills like painting and sculpting are also associated with the right hemisphere, as is the interpretation of emotional stimuli.

Key Terms

Neuron (p. 22)
Cell body (p. 23)
Dendrite (p. 23)
Axon (p. 23)
Myelin (p. 23)
Axon terminals (p. 23)
Neural impulse (p. 24)
All-or-none principle (p. 24)
Neural threshold (p. 24)
Synapse (p. 24)
Vesicles (p. 24)
Neurotransmitters (p. 24)
Excitatory neurotransmitter (p. 24)
Inhibitory neurotransmitter (p. 24)
Central nervous system (CNS) (p. 26)
Peripheral nervous system (PNS) (p. 26)
Somatic nervous system (p. 26)
Autonomic nervous system (p. 26)
Sympathetic division (p. 26)
Parasympathetic division (p. 26)
Endocrine system (p. 27)
Pituitary gland (p. 27)
Thyroid gland (p. 27)
Adrenal glands (p. 27)
Sensory neurons (p. 28)
Motor neurons (p. 28)
Interneurons (p. 28)
Spinal reflexes (p. 29)
Medulla (p. 32)
Cross laterality (p. 32)
Pons (p. 33)
Cerebellum (p. 33)
Reticular formation (p. 33)
Basal ganglia (p. 33)
Parkinson's disease (p. 34)
Limbic system (p. 34)
Thalamus (p. 35)
Cerebral cortex (p. 36)
Sensory area (p. 37)
Motor area (p. 37)
Association areas (p. 38)
Corpus callosum (p. 39)
Split-brain procedure (p. 39)

Practice Quiz

1. A microscopically small cell that transmits information from one part of the body to another is a(n)
   a. axon.
   b. neuron.
   c. nerve fiber.
   d. dendrite.
2. A(n) __________is a rapid, reversible change in the electrical charges within and outside a neuron.
   a. neural impulse
   b. axonal impulse
   c. neurotransmission
   d. dendritic stimulus
3. The sympathetic and parasympathetic divisions are parts of the ___________ nervous system.
   a. central
   b. somatic
   c. automatic
   d. autonomic
4. According to your text, the two major functions of the spinal cord are
   a. transmitting and controlling spinal reflexes.
   b. regulating the endocrine system and controlling spinal reflexes.
   c. regulating the endocrine system and transmission.
   d. none of the above.
5. The major role of the cerebellum is in
   a. controlling basic survival functions, such as respiration.
   b. timing cycles of alertness and the sleep–wake cycle.
   c. smoothing and coordinating fine muscle movements.
   d. offsetting the power of instinctive and reflexive actions.
6. The small structure near the limbic system in the center of the brain, associated with feeding, temperature regulation, and aggression, is the
   a. thalamus.
   b. corpus callosum.
   c. hypothalamus.
   d. hippocampus.
7. Hearing is to the ___________ lobe as vision is to the ___________ lobe.
   a. temporal; occipital
   b. parietal; temporal
   c. frontal; occipital
   d. occipital; parietal
8. The "___________" areas of the cortex are where sensory input is integrated with motor responses and where cognitive functions such as problem solving, memory, and thinking occur.
   a. integrative
   b. association
   c. organizational
   d. relationship
9. The large, lumpy, creviced outer covering of the human brain is known as the
   a. cerebral cortex.
   b. adrenal cortex.
   c. organ of Corti.
   d. cerebellum.
10. Which is most likely to be a function of your left cerebral hemisphere?
    a. Answering questions such as this one
    b. Drawing pictures from memory
    c. Working on a jigsaw puzzle
    d. Experiencing vivid, colorful dreams

Answers can be found in the end-of-book Answers section.