CHAPTER 3: THE BIOLOGY OF BEHAVIOR

This sample chapter includes Touring the Nervous System and the Brain, a set of instructional transparencies for your students.

For a simulation of how transparencies can help challenge your students, visit www.mhhe.com/hssl/feist/story and click on TRANSPARENCY SIMULATION.
The Biology of Behavior
Chapter Outline

Genes and Behavior
The Nervous System
The Brain
Psychology in the Real World: Brain–Computer and Brain–Machine Interfaces
Breaking New Ground: Neurogenesis in the Adult Brain
Measuring the Brain
The Endocrine System
Bringing It All Together: Making Connections in the Biology of Behavior
Chapter Review

Challenge Your Assumptions

TRUE OR FALSE?

- Learning can change the size of your brain.
- Traits that are genetically influenced are set and unchanging after conception.
- In people who are blind, vision areas of the brain do not function.
- You can’t easily learn a new language as an adult.

Answers can be found at the end of the chapter.
Take a look at the painting in Figure 3.1. It is pleasing, colorful, and nicely done. It features realistic color, perspective, and shadowing. It seems, perhaps, not extraordinary—except by virtue of its maker. He cannot see at all.

Born blind to an impoverished family in Turkey, Esref Armagan started drawing at a young age; later he began painting with oils and acrylics. Armagan has been actively painting for over 30 years. His work strikes us not only for its beauty but also for how it depicts objects in a way that a sighted person would see them. How can someone who has never seen anything in his life create beautiful paintings that depict realistic images? It seems as if his brain is doing something that his eyes cannot.

You can find a hint of how this is possible at the Tactile Dome, part of the Exploratorium in San Francisco. Once there, you enter a room full of common, recognizable objects such as a cheese grater, an egg carton, and a sieve. You look at them and feel them.

Then you proceed through a pitch-black tunnel. As you find your way through it by touch, you feel the common objects that you saw earlier. When you reach the end, you are prompted to think back and remember your way through the tunnel. Surprisingly, the memory of what you encountered along the path in the dark with your hands is visual! Your brain has taken a tactile experience and unwittingly converted it into a visual memory. How?

The Tactile Dome and the skills of Esref Armagan both suggest that our experience of the world is not a direct representation of what is out there. The brain can change our experiences—give us visual memories for tactile experiences. The brain is both fixed and flexible in how it acts. While most of us use the rear portion of our brains to process visual information, Esref Armagan uses that area when he paints by the feel of his hands.

In this chapter and the one that follows, we will explore what is known about how the brain works, how it supports behavior, and how it is transformed by experience. Our main task in this chapter is to introduce the biological systems that are most relevant to a basic understanding of psychology. In so doing, we will look at the role of heredity and evolution in shaping the brain and behavior, explore the workings of the nervous system, and learn of the relationship between chemicals called hormones and behavior. Given how much biological and environmental forces interact and influence each other, we use the term softwire to reflect this new way of thinking about nature and nurture. As mentioned in Chapter 1, softwiring, in contrast to hardwiring, means that biological systems involved in thought and behavior—genes, brain structures, brain cells, etc.—are inherited but open to modification from the environment (Herbert & Rich, 1999; Ottersen, 2010). Much of who we are is more softwired than hardwired.
**GENES AND BEHAVIOR**

We seldom have trouble accepting the idea that heredity is responsible for outward family resemblances, such as the shape of the nose and face, height, and the color of hair and skin. But when it comes to behavior, many of us are uncomfortable with the idea that heredity might determine what we think and do. Yet heredity very much affects behavior and experience, although it does not operate on thought and behavior in a simple, deterministic way.

Before we can explore how heredity and behavior interact, we must know something about the structures and mechanisms involved in heredity. A chromosome is a cellular structure that holds our genetic information in threadlike strands of DNA. Humans have 23 pairs of chromosomes in the nucleus of each cell of the body, except red blood cells, which do not have nuclei. DNA (deoxyribonucleic acid), the genetic material that makes up chromosomes, is a large coiled molecule that contains genes. Genes are small segments of DNA that contain information for producing proteins. These proteins in turn make up most chemicals and structures in the body (see Figure 3.2). Genes influence specific characteristics, such as height or hair color, by directing the synthesis of proteins. All of the genetic information contained in our DNA makes up our genome.

The fact that the individuals in a population are different from one another on a given trait—such as eye color, height, or personality—is a result of genetic variation. Each chromosome contains numerous genes, segments of DNA that contain instructions to make proteins—the building blocks of life.
differences. More specifically, genes within a population, or entire species, often take different forms. These different forms are known as alleles (W. R. Clark & Grunstein, 2000; Starr & Taggart, 2004). Individuals inherit one allele from each parent. Sometimes both alleles have the same form, but not always. Each gene in an allele pair can produce different characteristics. Take eye color, for example. The allele inherited from one parent may produce brown eyes, but the allele inherited from the other parent may produce blue eyes. Brown eyes result from a dominant gene. Dominant genes show their effect even if there is only one copy of that gene in the pair. So if you have one brown eye allele and one blue eye allele, chances are you will have brown eyes.

A recessive gene shows its effects only when both alleles are the same. Consequently, a person will have blue eyes only if he or she inherits an allele for blue eyes from each parent.

To understand how heredity affects behavior, psychologists turn to the science of behavioral genetics (J. L. Fuller & Thompson, 1960). Four principles of behavioral genetics are especially relevant in psychology:

1. The relationship between specific genes and behavior is complex.
2. Most specific behaviors derive from dozens or hundreds of genes—not one or two.
3. By studying twins and adoptees, behavioral geneticists may disentangle the contributions of heredity and environment to behavior.
4. The environment influences how and when genes affect behavior.

Let’s consider each of these principles in turn.

The Complex Connection Between Genes and Behavior

The connection between genes and behavior is complex. To understand how genes influence behavior, we must abandon the notion of simple causation (Rutter, 2006). Genes seldom make behaviors a certainty. For example, no single gene causes anxiety. Both genetic and environmental factors make anxiety more likely to trouble some people than others.

In a few cases, having a specific gene guarantees an outcome—such as the incurable neuromuscular disease called Huntington’s disease—but these outcomes are primarily physical, not behavioral. Typically, a specific gene plays only a small part in creating a given behavior, and genetic influence itself is only part of the story. Environmental events such as smoking during pregnancy, early childhood experiences, stress or trauma, and enriched environments all interact with genes to make specific behaviors more or less likely.

Polygenic Influence on Behavior

The second principle of behavioral genetics states that traits tend to be influenced by many genes (W. R. Clark & Grunstein, 2000; Hamer & Copeland, 1998). Relatively few human traits result from single genes. And, as stated above, they tend to be physical rather than behavioral characteristics. The hereditary passing on of traits determined by a single gene is known as monogenic transmission. Huntington’s disease is an example of monogenic transmission.
Genes and the Environment

A third principle of behavioral genetics is that teasing apart and identifying genetic and environmental influences on behavior requires special techniques. The extent to which a characteristic is influenced by genetics is known as heritability. Researchers use twin-adoption studies and gene-by-environment studies to study heritability.

In order to tease apart the role of genes and environment on behavior experimentally, researchers would have to hold one of these factors constant while varying the other one. That is hard to do because, for obvious ethical reasons, researchers cannot assign people to grow up in the same or different environments. Nor can researchers assign people to be either genetically alike or different. Fortunately, nature does both of these things for us. Researchers take advantage of genetically similar and different people by studying twins, siblings, and unrelated individuals reared together or apart.

**Twin-Adoption Studies** Fraternal twins develop from two different eggs fertilized by two different sperm, as are any two siblings born at separate times. Thus, genetically speaking, fraternal twins are no more alike or different than are nontwin brothers and sisters. Identical twins develop from a single fertilized egg that splits into two independent cells. As a result, identical twins develop from two embryos with identical genetic information. Fraternal and identical twins provide a natural population for research to determine how much of a trait is due to genetics and how much is due to environment.

The best way to untangle the effects of genetics and environment is to study twins who are adopted, which is what twin-adoption studies do. The logic of the twin-adoption approach is simple yet powerful. Identical twins are 100% alike genetically, whereas fraternal twins, like all siblings, share only 50% of their genes.

Adopted children and their adoptive parents must both have either one or two alleles for blue eyes. However, the number of potential outcomes for most traits and behaviors is not small. There is wide variation in intelligence, for example. Numerous genes contribute to intelligence. When many genes interact to create a single characteristic, the process is known as polygenic transmission. Other examples of polygenic traits include skin color, mental disorders, personality traits (such as whether a person is likely to be adventurous), height, and weight (W. R. Clark & Grunstein, 2000; Ebstein, 2006; Evans et al., 2007).
parents and siblings share no genes. If genes play a strong role in a trait, then the
greater the genetic similarity, the greater the similarity on the trait should be.
That is, similarity should be strongest in identical twins reared together and next
in identical twins reared apart. It should be modest in siblings reared together
and biological parent–offspring. Similarity should be weakest in adopted sib-
lings and adoptive parent–offspring. As we will see in later chapters, this pattern
holds for intelligence, mental disorders, and even personality, suggesting a mod-
erately strong genetic component to these outcomes.

**Gene-by-Environment Studies**  A second technique in the study of
heritability, gene-by-environment interaction research, allows research-
ers to assess how genetic differences interact with environment to produce cer-
tain behavior in some people but not in others (Moffitt, Caspi, & Rutter,
2005; Thaparet et al., 2007). Instead of using twins, family members,
and adoptees to vary genetic similarity, gene-by-environment stud-
ies directly measure genetic variation in parts of the genome itself
and examine how such variation interacts with different kinds
of environments to produce different behaviors. Individuals do
not differ in whether or not they have a gene, but rather in the
form that gene takes. For example, the same gene in different peo-
ple might vary in the number of particular DNA sequences it has.
Some DNA sequences are long in some people and short in others.
Differences in the length of DNA sequences represent a genetic
marker. Through gene-by-environment studies, researchers have
learned that genetic markers interact with a stressful environment to
make depression more likely in some people (short DNA sequence) than in oth-
ers (long DNA sequence) (Caspi, Sugden, et al., 2003; Kendler et al., 2005).

**Epigenetics: How the Environment Changes**

**Gene Expression**

A fourth—and, in many ways, the most important—principle of behavioral genetics is a relatively new one: The unique and incomparable genotype, or genetic makeup, that each of us is born with is not the end point but the starting point of gene expression. Genes can be switched off by many different things, and our experiences and environmental exposure, starting in the womb, are among the off switches. This principle is seen most clearly in epigenetics (Meaney, 2010; Rutter, 2006). Epigenetics is the study of changes in the way genes are expressed—that is, are activated or deactivated—without changing the sequence of DNA. This means that experience (nurture) shapes our nature. More specifically, chemical tags attach to the double-helix structure of DNA and different patterns of tags turn off a gene or leave it on (see Figure 3.3). The incredible fact is that whether these tags get activated or “turned on” is determined by environmental events such as diet, drinking, and even exercise (Watters, 2006; I. C. G. Weaver et al., 2004).

The food we eat, the drugs we take, and our exposure to certain chemicals in the environment, among other things, can have epigenetic consequences. Contrary to what many people think, genes are not destiny. They are simply the starting point for biological structures. Many things—including experience—can turn genes on or off. Epigenetic effects have been demonstrated in a host of psychological traits from attention deficit hyperactivity disorder (ADHD) and aggression to dementia, obesity, and anxiety—just to name a few (Curley et al., 2010;
What is even more amazing is that these environmentally produced tags can be inherited—passed on from parent to offspring. In other words, genetics is not the only way inheritance works. It also works via epigenetics (Meaney, 2010; Zimmer, 2008). For example, a gene that is “on” in your grandparent but gets turned off environmentally in one of your parents can be inherited by you as turned off. This secondary form of inheritance via epigenetics is sometimes referred to as soft inheritance to contrast it with traditional genetically based inheritance (Graff & Mansury, 2008). The term soft inheritance is similar and related to softwiring—both express the fact that nature and nurture work side-by-side.

Epigenetics offers one explanation for why identical twins—whose genome is 100% alike—end up being not completely identical on numerous traits. Indeed, they do not have identical fingerprints. Recent longitudinal research shows that differences in epigenetic tags in identical twins already exist in early to middle childhood and that these differences can be related to personality differences in twins (Kaminsky et al., 2008; Wong et al., 2010). In short, although identical twins share 100% of their genotype, their phenotype—or their observed characteristics—may be subtly different because different epigenetic tags are turning different genes on or off.

Quick Quiz 3.1: Genes and Behavior

1. Genes occur in pairs, or alternate forms of each other, called
   a. chromosomes
   b. alleles
   c. base-pairs
   d. ribosomes

2. Why are twin-adoption studies powerful ways to untangle the effects of genes and environment on thought and behavior?
   a. because they allow both genetic and environmental similarity to be compared and contrasted
   b. because twins share genes

3. Nurturing behavior in rats can produce calmer, less-stressed offspring because genes that are involved in stress reactions are turned off. This is an example of
   a. epigenetics
   b. genetic engineering
   c. recessive genes
   d. dominant genes

Answers can be found at the end of the chapter.
THE NERVOUS SYSTEM

The human genome contains an estimated 20,000–25,000 genes (National Human Genome Research Institute, 2010). At least half of these genes code for proteins in the brain, where they play a central role in seeing, hearing, thinking, memory, learning, movement, and all other behavior. The brain mediates all of our experiences and orchestrates our responses to those experiences.

The nervous system controls all the actions and automatic processes of the body. Ultimately, everything we experience and do results from the activity of nerve cells, which are organized in a net of circuits far more complex than any electrical system you could imagine. Let’s look at the organization and basic elements of the nervous system and at how the nervous system transmits information.

Organization of the Nervous System

The human nervous system has two main parts and several components, as depicted in Figure 3.4. It is divided into the central nervous system (CNS), which includes the brain and spinal cord, and the peripheral nervous system, which consists of all the other nerve cells in the body. The peripheral nervous system includes the somatic nervous system and the autonomic nervous system. The somatic nervous system transmits sensory information to the brain and spinal cord and from the brain and spinal cord to the skeletal muscles. The autonomic nervous system (ANS) serves the involuntary systems of the body, such as the internal organs and glands.

Autonomic means “self-governing,” and to a large extent the structures served by the autonomic nervous system control bodily processes over which we have little control.

FIGURE 3.4
THE NERVOUS SYSTEM. The central nervous system processes incoming information and crafts a response if one is needed. The peripheral nervous system transmits information between the external environment and internal systems of the body and the central nervous system.
have little conscious control, such as changes in heart rate and blood pressure. The ANS has two main branches: the **sympathetic nervous system** and the **parasympathetic nervous system**. The nerves of these systems control muscles in organs such as the stomach, small intestine, and bladder and in glands such as the sweat glands. The sympathetic branch of the ANS is responsible for what the physiologist Walter Cannon (1939) labeled the *fight-or-flight response*; that is, it activates bodily systems in times of emergency. The main function of the sympathetic nervous system is activating the body, for example, by increasing the heart rate, dilating the pupils of the eyes, or inhibiting digestion. The function of the parasympathetic branch of the ANS is largely one of relaxation, or returning the body to a less active, restful state. All of the systems that are aroused by the sympathetic nervous system are relaxed by the parasympathetic nervous system (see Figure 3.5). Because of its effects on these various bodily

**FIGURE 3.5**
The sympathetic and parasympathetic nervous systems. The sympathetic nervous system prepares the body for action, while the parasympathetic nervous system returns it to a relaxed and resting state.
systems, the ANS produces many of the physical sensations we experience during emotional arousal, such as a racing heart or sweaty palms.

The Cells of the Nervous System: Glial Cells and Neurons

Without a nervous system, we would have no sensory experiences—no seeing, hearing, touching, tasting, smelling, or feeling. We would also have no thoughts, memories, or emotions. Everything we sense or do is accomplished by means of nerve cells.

The central nervous system is made up of two types of cells: glial cells and neurons. *Glia* is the Greek word for glue. Indeed, **glial cells** serve the primary function of holding the CNS together. Specifically, they provide structural support, promote efficient communication between neurons, and remove cellular debris (Kandel, 2000b). We now know that they also play an important role in communication between neurons, produce the material that insulates neurons (myelin), aid cell metabolism, help form the blood-brain barrier, and play a key role in the control of breathing (Ballanyi, Panaitescu, & Ruangkittisakul, 2010; Eroglu & Barres, 2010; Pfrieger, 2002).

**Neurons** are the cells that process and transmit information throughout the nervous system. Within the brain, neurons receive, integrate, and generate messages. By most estimates, there are more than 10 billion neurons in the human brain. Each neuron has approximately 10,000 connections to other neurons, making for literally trillions and trillions of neural connections in the human brain (Hyman, 2005; Nauta & Feirtag, 1979). Thus, it is understandable that some scientists consider the human brain to be one of the most complex structures in the known universe. Over the last 125 years, three major principles of neuroscience have emerged concerning the neuron and how it communicates with other neurons (Kandel, 2006):

1. Neurons are the building blocks of the nervous system. All the major structures of the brain are composed of neurons.
2. Information travels within a neuron in the form of an electrical signal by action potentials.
3. Information is transmitted between neurons by means of chemicals called **neurotransmitters**.

Let’s explore each of these principles to better understand the mechanisms of brain function and behavior.

**The Structure and Types of Neurons** Whereas most cells in the body have a round shape, neurons are spidery, with long branches and projections. Neurons are so small they cannot be seen with the naked eye, and only a strong microscope can magnify them enough to be viewed and described. In the late 1800s, the Spanish anatomist Santiago Ramón y Cajal deciphered the precise nature and structure of nerve cells, which he named neurons. It was Ramón y Cajal who identified the three major parts of the neuron: cell body, dendrites, and axon.

As in other cells, the cell body, or **soma**, of the neuron contains a **nucleus** and other components needed for cell maintenance and function (see Figure 3.6). The genes that direct neural change and growth lie within the nucleus itself. Extending from the soma is a long projection called the **axon**, which transmits electrical impulses toward the adjacent neuron and stimulates the release of neurotransmitters.
impulses toward the adjacent neuron. On the other side of the soma are the **dendrites**, fingerlike projections that receive incoming messages from other neurons.

The axons of some neurons are wrapped in a fatty **myelin sheath**. Just like rubber around an electrical wire, the myelin sheath insulates the axon so that the impulse travels more efficiently and strengthens the connection to adjacent neurons. The process of **myelination** is a gradual one that starts before birth and continues into early adulthood (R. D. Fields, 2008). The glial cells myelinate axons throughout the nervous system (Nave, 2010). The junction between the axon and the adjacent neuron is known as the **synapse**. At the end of the axon, at each synapse, is a **terminal button** containing tiny sacs of neurotransmitters. When an electrical impulse reaches the terminal button, it triggers the release of neurotransmitter molecules into the gap between neurons, known as the **synaptic cleft**. The neurotransmitter carries the signal across the synaptic cleft to the next neuron.

There are three kinds of neurons: sensory neurons, motor neurons, and interneurons. **Sensory neurons** receive incoming sensory information from the sense organs (eyes, ears, skin, tongue, and nose). Any sensation you receive—anything you see, hear, touch, taste, or smell—activates sensory neurons, which take the message to the brain for processing. **Motor neurons** take commands from the brain and carry them to the muscles of the body. Each time you move any muscle in your body, intentionally or not, motor neurons are at work. Recently, researchers have identified motor neurons that are active when monkeys observe others performing an action as well as when the monkey itself undertakes the same action (Rizzolatti et al., 1996). Neurons that behave this way are called **mirror neurons**, and they appear to play an important role in learning (Rizzolatti & Craighero, 2004). The most connection **Mirror neurons support learning by imitation as well as empathy.**

definitive work on mirror neurons has been conducted on monkeys—because it has been possible to record directly from single neurons deep in their brains. So far this has not been done with humans, but there is indirect evidence of groups of neurons acting as mirrors in humans (Debes, 2010). The discovery of mirror neurons has changed the way we understand a wide range of human experience, including how we feel empathy toward others.

**Interneurons** communicate only with other neurons. Most interneurons connect neurons in one part of the brain with neurons in another part. Others receive information from sensory neurons and transmit it to motor neurons for action. So if you touched a sharp object, interneurons in the spinal cord would receive pain information from sensory neurons in your fingers and communicate it to motor neurons in the muscles of your arm so that you could pull your hand away. Interneurons are the most common kind of neuron in the brain, outnumbering sensory and motor neurons by at least 10 to 1 (Nauta & Feirtag, 1979).

**Neural Communication: The Action Potential**  
Neural communication is a two-step process. First, an impulse travels one way from the dendrites along the axon and away from the soma, a process that is both electrical and chemical. Second, the impulse releases chemicals at the ends of the neurons, which are released into the synaptic cleft to transmit the message to another neuron. The first process is known as an action potential, and the second is neurotransmission, which we discuss in the next section.

The **action potential** is the positively charged impulse that moves down an axon. This happens by virtue of changes in the neuron itself. The neuron, like all cells in the body, is surrounded by a membrane. This membrane is somewhat permeable, which means that it lets only certain particles move through it. The fluid inside and outside the cell contains electrically charged particles called **ions**. Positively charged sodium and potassium ions and negatively charged ions dominate in bodily fluids; found both inside and outside cells.
chloride ions are the most common. Channels in the membrane of the neuron allow ions to flow between the inside and outside of the cell. Some of these channels are always open. Others, called voltage-dependent channels, open only when certain electrical conditions are met, as we will discuss shortly.

Due to the flow of ions into and out of the neuron, there is a difference in charge inside the cell compared to outside the cell at all times. In the resting state, there is an excess of negatively charged particles inside the axon. The fluid outside the axon has a positive charge. This charge difference between the inside and outside of the neuron is known as a potential. When a neuron is at rest, the charge difference between the inside and the outside of the axon is –70 millivolts (mV). This value is the resting potential of the neuronal membrane (see Figure 3.7a).

Neurons do not stay at rest, however. An incoming impulse—which may have been stimulated by events as different as pressure to the skin and the thought of a loved one—can temporarily change the potential. How does this happen? A message received from sense receptors in the skin or from other neurons changes the axonal membrane’s permeability, especially to positively charged sodium ions. If an incoming impulse increases the positive charge inside the neuron to a certain threshold, the neuron becomes depolarized and fires an action potential. The sodium channels at the top of the axon fly open and positively charged sodium ions pour into the cell. The influx of sodium leads to a brief spike in positive charge, raising the membrane potential from –70 mV to +40 mV. This surge in positive charge is the action potential (see Figure 3.7b).

Once initiated, the action potential causes sodium channels to close and potassium voltage-dependent channels to open (see Figure 3.7c). As positively charged potassium ions flow out of the cell, the membrane potential returns to its resting state of –70 mV. While the neuron is returning to its resting state, it temporarily becomes super negatively charged. During this brief period, known as the refractory period, the neuron cannot generate another action potential.

We can summarize the electrical changes in the neuron from resting to action potential to refractory period and back to the resting state as follows (see also Figure 3.7d):

1. Resting potential is –70mV.
2. If an incoming impulse causes sufficient depolarization, voltage-dependent sodium channels open and sodium ions flood into the neuron.
3. The influx of positively charged sodium ions quickly raises the membrane potential to +40 mV. This surge in positive charge inside the cell is the action potential.
4. When the membrane potential reaches +40 mV, the sodium channels close and potassium channels open. The outward flow of positively charged potassium ions restores the negative charge inside the cell.

This process repeats all along the axon, as the impulse moves toward the synapse. As the action potential subsides in one area, it immediately depolarizes the next portion of membrane, causing sodium channels to open there, continuing or propagating the action potential. Like a wave, the action potential travels along the axon, until it reaches the terminal buttons. In myelinated neurons, the action potential travels faster still, as depolarization occurs only at gaps in the myelin sheath and the action potential jumps from gap to gap (see Figure 3.6).
CHAPTER 3  The Biology of Behavior

(a) Resting potential: Time 1.
In the resting neuron, the fluid outside the axon contains a higher concentration of positive ions than the inside of the axon, which contains many negatively charged anions (A–).

(b) Action potential: Time 2.
An action potential occurs in response to stimulation of the neuron. Sodium channels in the axonal membrane open, and positively charged sodium ions (Na+) pour into the axon, temporarily raising the charge inside the axon up to +40 mV.

(c) Resting potential restored: Time 3.
As the impulse moves on down the axon, potassium (K+) channels open, allowing more K+ to flood out of the cell, restoring the negative resting potential (~70mV).

(d) This graph depicts the electrical changes that occur during each stage of an action potential (resting, depolarization, repolarization, refractory period). The top portion shows changes in voltage over time as measured by direct recording from single neurons in animal research. The lower four pictures show the membrane changes that correspond to each stage. The electrical changes of an action potential occur in a few thousandths of a second. During the refractory period, no new action potential can be generated.

FIGURE 3.7 MEMBRANES AND VOLTAGE CHANGES IN ACTION POTENTIALS.
Each change in membrane potential corresponds to specific changes in the axonal membrane.

A touch or squeeze from a friend will generate an action potential.
How fast are action potentials anyway? In the 1920s, Edgar Douglas Adrian recorded individual action potentials of sensory neurons and confirmed a speed of about 100 feet per second (Kandel, 2006). Adrian’s work also confirmed the existence of thresholds—a point of no return. Once the charge inside the neuron exceeds threshold (and only if it exceeds threshold), the action potential fires. This is known as the all-or-none principle; that is, either an action potential fires or it does not.

Communication Between Neurons: Neurotransmission The arrival of an action potential at the terminal buttons of a neuron triggers the second phase in neural transmission—the release of neurotransmitters into the synaptic cleft to pass on the impulse to other neurons. Neurotransmitters are packaged in sacs called synaptic vesicles in the terminal button. When an action potential reaches the terminal button, the vesicles fuse with the cell membrane of the terminal and release neurotransmitter molecules into the synaptic cleft, where they may be taken up by receptors in the dendrites of adjacent neurons (J. H. Schwartz, 2000).

Neurotransmitters bind with receptors in the receiving, or postsynaptic, neuron in a lock-and-key type of arrangement (see Figure 3.8). There are different types of neurotransmitters, each of which binds only with a specific receptor. For example, some receptors bind only with the neurotransmitter acetylcholine. If other neurotransmitters come in contact with acetylcholine receptors, they will not bind to them and no signal will be transmitted. Not all of the neurotransmitter molecules that are released into the synaptic cleft bind with receptors. Usually, excess neurotransmitter remains in the synaptic cleft and needs to be removed. There are two ways to remove excess neurotransmitter from the synaptic cleft. One involves destruction by enzymes. In this process of enzymatic degradation, enzymes specific to that neurotransmitter bind with the neurotransmitter and destroy it. The second method, called reuptake, returns excess neurotransmitter to the sending, or presynaptic, neuron for storage in vesicles and future use. Even the neurotransmitter that binds to the dendrites of the postsynaptic neuron does not stay there. Eventually it disengages from the receptor and floats away. This excess neurotransmitter must be removed as well. After a neurotransmitter binds to a receptor on the postsynaptic neuron, a series of changes occurs in that neuron’s cell membrane. These small changes in membrane potential are called graded potentials. Unlike action potentials, these are not “all-or-none.” Rather, they affect the likelihood that an action potential will occur in the receiving neuron. Some neurotransmitters, called inhibitory neurotransmitters, create graded potentials that decrease the likelihood of a neuron firing. One such neurotransmitter is GABA (gamma-aminobutyric acid). In contrast, excitatory neurotransmitters create graded potentials that increase the likelihood of an action potential. Glutamate is the most common excitatory neurotransmitter in the brain.

The excitatory potentials bring the neuron closer to threshold, while the inhibitory potentials bring it further away from threshold. The soma in the postsynaptic neuron integrates the various graded potentials in the postsynaptic neuron. If the integrated message from these graded potentials depolarizes the axon enough to cross the threshold, then an action potential will occur.
CHAPTER 3  The Biology of Behavior

FIGURE 3.8 HOW SYNAPSES AND NEUROTRANSMITTERS WORK. In (a) two neurons connect, a presynaptic neuron and a postsynaptic neuron. They do not touch, but terminal buttons in the presynaptic neuron form a synaptic cleft with the postsynaptic neuron. In (b) the synaptic cleft has been enlarged to show the synaptic vesicles that carry neurotransmitters. They release neurotransmitters into the cleft where they bind to receptor sites on the postsynaptic neuron. In (c) we see a further enlargement of the neurotransmitters being released into the synaptic cleft and binding to receptor sites in the postsynaptic neuron. To the left is a three-dimensional artistic interpretation of neurons in the brain. In (d) we see how each receptor site binds to only one specific kind of neurotransmitter.
The Nervous System

Common Neurotransmitters

Within the past century, researchers have discovered at least 60 distinct neurotransmitters and learned what most of them do. Of the known neurotransmitters, the ones that have the most relevance for the study of human thought and behavior are acetylcholine, epinephrine, norepinephrine, dopamine, serotonin, GABA, and glutamate (see Figure 3.9). Neurotransmitters are found only in the brain. They are synthesized inside the neuron for the purpose of neurotransmission.

The neurotransmitter **acetylcholine (ACh)** controls muscle movement and plays a role in mental processes such as learning, memory, attention, sleeping, and dreaming. Whether ACh excites muscles or slows them down depends on what kind of receptor receives it. Furthermore, researchers have discovered that the degenerative memory disorder called Alzheimer’s disease results at least partly from a decrease in ACh activity and that drugs that enhance ACh aid memory. ACh enhancers are now used to treat memory disorders such as Alzheimer’s disease, and they seem to slow the progression of memory loss (Czech & Adessi, 2004; Selkoe, 2002).

**Dopamine** is involved in voluntarily controlling your muscles and is released during feelings of pleasure or reward. Eating a good meal, doing well on an exam, having an orgasm, or drinking a glass of water when really thirsty—each of these behaviors stimulates dopamine activity in the brain (Hamer & Copeland, 1998). Because dopamine activity makes us feel good, many drug addictions involve increased dopamine activity. For instance, cocaine blocks the reuptake of dopamine into the presynaptic neuron, leaving it in the synaptic cleft for a longer period of time before it binds to receptors in the postsynaptic neuron (Bradberry, 2007). The result is a feeling of euphoria and pleasure.

![FIGURE 3.9 NEUROTRANSMITTERS AND THEIR FUNCTIONS. Neurotransmitters can be excitatory, increasing the likelihood of an action potential, or inhibitory, decreasing the likelihood of an action potential.](image-url)
**CHAPTER 3 The Biology of Behavior**

**Epinephrine** and **norepinephrine** primarily have energizing and arousing properties. (Epinephrine was formerly called “adrenaline,” a term that is still widely used in everyday speech—“Wow! What an adrenaline rush!”) Both epinephrine and norepinephrine are produced in the brain and by the adrenal glands that rest atop the kidneys. Epinephrine tends not to affect mental states, whereas norepinephrine increases mental arousal and alertness. Norepinephrine activity also leads to physical arousal—increased heart rate and blood pressure. People who suffer from ADHD have unusually low norepinephrine levels, and treatment sometimes includes drugs to increase norepinephrine levels (Barr et al., 2002).

**Serotonin** plays a role in a wide range of behaviors, including dreaming and controlling emotional states such as anger, anxiety, and depression. People who are generally anxious and/or depressed often have low levels of serotonin (Caspĩ, Sugden, et al., 2003; Frokjaer et al., 2009; Kendler et al., 2005). Drugs that block the reuptake of serotonin in the synapse are used to treat anxiety and depression.

People who are consistently angry and/or aggressive (especially males) often have abnormally low levels of serotonin as well. The administration of serotonin reduces aggressive behavior in monkeys (Suomi, 2005). The street drug ecstasy (MDMA), which makes people feel social, affectionate, and euphoric, stimulates extremely high levels of serotonin. Ironically, however, ecstasy ultimately interferes with the brain’s ability to produce serotonin, and so depression can be an unpleasant side effect of the drug (de Win et al., 2004).

**GABA (gamma-aminobutyric acid)** is a major inhibitory neurotransmitter in the brain. Remember that inhibitory neurotransmitters tell the postsynaptic neurons **not** to fire. GABA slows CNS activity and is necessary for the regulation and control of neural activity. Without it, the central nervous system would have no “brakes” and could run out of control. In fact, one theory about epilepsy is that GABA does not function properly in people who suffer from the disorder (Laschet et al., 2007). Many drugs classified as depressants, such as alcohol, increase GABA activity in the brain and lead to relaxing yet ultimately uncoordinated states. Because GABA inhibits much of the CNS activity that keeps us conscious, alert, and able to form memories, large amounts of alcohol consumption can lead to memory lapses, blackouts, loss of consciousness, and even death (A. M. White, 2003).

---

**Research to Real Life**

Recently both of your authors went to their own family reunions. What struck us was seeing relatives we hadn’t seen in years and seeing how cousins, aunts, and uncles remind us of ourselves, our siblings, and our parents. The shape and color of their eyes, their voice, their laugh—we could see right away a common lineage. But there were differences too. Some from the same family were thin, some were not; some siblings looked like one parent, while other siblings looked like the other parent.

**Connecting Psychology to Your Life:** Think about your own extended family and the physical traits they share in common and on which they differ. Start with those most genetically related, your parents and your siblings. Then move to grandparents, uncles, aunts, and cousins. What traits do you share and on what traits do you differ? Can you see how genes and environment have shaped these traits in your family?
Glutamate, the brain’s major excitatory neurotransmitter, is important in learning, memory, neural processing, and brain development. More specifically, glutamate facilitates growth and change in neurons and the migration of neurons to different sites in the brain, all of which are basic processes of early brain development (Nadarajah & Parnavelas, 2002). It also amplifies some neural transmissions so that a person can tell the difference between important and less important information. For example, which is more important? To notice that a car is skidding out of control in front of you or that your shoes are still the same color they were when you put them on this morning? Glutamate boosts the signals about the car.

The physiologically stimulating effects of nicotine in tobacco stem from glutamate synapses (Guillem & Peoples, 2010).

Connection


Summary of the Steps in Neural Transmission

We have considered the complex phenomena of action potentials and neurotransmission and described the neurotransmitters involved in human thought and behavior. Before we discuss the major structures of the brain, let’s take time to summarize the process of neural communication.

- The information in neural transmission always travels in one direction in the neuron—from the dendrites to the soma to the axon to the synapses. This process begins with information received from the sense organs or other neurons, which generate a nerve impulse.
- The dendrites receive a message from other neurons. That message, in the form of an electrical and chemical impulse, is then integrated in the soma.
• If the excitatory messages pass the threshold intensity, an action potential will occur, sending the nerve impulse down the axon. If the inhibitory messages win out, the likelihood that the postsynaptic neuron will fire goes down.

• The nerve impulse, known as the action potential, travels down the axon, jumping from one space in the axon’s myelin sheath to the next, because channels are opening and closing in the axon’s membrane. Ions pass in and out of the membrane—mostly sodium and potassium.

• This impulse of opening and closing channels travels like a wave down the length of the axon, where the electrical charge stimulates the release of neurotransmitter molecules in the cell’s synapses and terminal buttons.

• The neurotransmitters are released into the space between neurons known as the synaptic cleft. Neurotransmitters released by the presynaptic neuron then bind with receptors in the membrane of the postsynaptic neuron.

• This binding of neurotransmitter to receptor creates electrical changes in the postsynaptic neuron’s cell membrane, at its dendrites. Some neurotransmitters tend to be excitatory and increase the likelihood of an action potential. Others tend to be inhibitory and decrease the likelihood of an action potential.

• The transmission process is repeated in postsynaptic neurons, which now become presynaptic neurons.

Quick Quiz 3.2: The Nervous System

1. Which branch of the nervous system is responsible for the fight-or-flight response?
   a. the parasympathetic nervous system
   b. the somatic nervous system
   c. the sympathetic nervous system
   d. the central nervous system

2. The fingerlike projections on neurons that receive input from other neurons are called
   a. dendrites
   b. nuclei
   c. axons
   d. terminal buttons

3. What property of the neuron is most directly responsible for the changes that lead up to an action potential?
   a. sodium ions outside the cell
   b. its permeable membrane
   c. chloride ions inside the cell
   d. the flux of potassium ions

4. What is the most common excitatory neurotransmitter in the brain?
   a. GABA
   b. serotonin
   c. glutamate
   d. acetylcholine

Answers can be found at the end of the chapter.

THE BRAIN

The brain is a collection of neurons and glial cells that controls all the major functions of the body; produces thoughts, emotions, and behavior; and makes us human. This jellylike mass at the top of the spine has been mapped and described in astonishing detail. Here we consider the evolution of the brain, look at key brain regions, and explore what is currently known about their specialized functions. At this point, the picture is still far from complete, and neuroscientists continue to piece it together.
Evolution of the Human Brain

Evolution provides a fundamental example of how biology and environment interact. As we discussed in Chapter 1, over long periods of time, nature selects traits and behaviors that work well in a given environment. Recall the example of the beetle population becoming more brown than green as brown beetles blended into their surroundings better and were more likely to survive and reproduce. This natural selection process gradually leads to big changes in living forms and structures—from cells to muscles to brains to new species.

The human brain has been shaped, via natural selection, by the world in which humans have lived. It is worth noting here that brains do not fossilize to allow a present-day analysis, but the skulls that hold them do. By looking at the size and shape of skulls from all animals and over very long time periods, scientists can glean something about how and when human brains evolved. The evolution of the human brain is a fascinating story. Although the details lie well beyond the scope of this book, we can consider a general outline of brain evolution (Dunbar, 2001; Jerison, 2000; Klein, 1999; Striedter, 2005).

Flatworms, whose species dates back about 500 million years, were probably the first organisms with brains. Still, the flatworm brain consists of scarcely more than a bundle of nerve cells. Within a few million years, the first primitive vertebrates (animals with backbones) appeared. They were jawless fish, and they had a bigger mass of nerve cells than flatworms (Jerison, 2000). The first land animals came into existence around 450 million years ago and the first mammals around 200 million years ago. Land animals had more than a bundle of neurons above the spinal cord; they had complex brains with numerous structures.

The first primates lived around 55 million years ago—10 million years after the dinosaurs went extinct (Jerison, 2000). Compared to other mammals, birds and reptiles, and fish, primates have relatively large amounts of brain cortex, allowing more complex thinking and problem solving. The earliest ancestors of humans appeared in Africa about 6 million years ago. One of our closest evolutionary relatives, the Neanderthals (*Homo neanderthalensis*), lived from about 350,000 to 28,000 years ago, when they were replaced by our species (*Homo sapiens*). Neanderthals had brains slightly larger on average than those of modern humans (see Figure 3.10). Nevertheless, these early humans did not produce highly complex tools, may have possessed very rudimentary language, and never made symbolic pieces of art, at least none that have been found. In other words, their brains were modern in...
The brain capacity ranges from 450 to 650 cubic centimeters (cc).

Further development of skull and jaw are evident and brain capacity is 900 cc.

The human skull has now taken shape: the skull case has elongated to hold a complex brain of 1,450 cc.

The deeply convoluted brain reflects growth in areas concerned with higher mental processes (1,300 cc).

Australopithecus (4 million years ago)
Homo erectus (1.6 million to 100,000 years ago)
Neanderthal (350,000 to 28,000 years ago)
Homo sapiens (200,000 years ago to present)

FIGURE 3.10
EVOLUTION OF THE HUMAN BRAIN OVER THE LAST 4 MILLION YEARS. An early form of pre-human, Australopithecus, had a brain about one third the size of the modern human (H. sapiens) brain. In general, the overall brain size has grown over the course of 4 million years. But note that Neanderthal’s brain size was slightly larger than ours. Just as important as overall size for modern human thought and behavior is the relative enlargement of the frontal lobe area. This can be seen in the less sloped forehead of modern humans compared to their earlier ancestors.

size but not modern in function. It is possible, therefore, that the modern human brain took up to 100,000 years to become fully wired and complex, all the while staying the same overall size.

Overview of Brain Regions

In evolutionary terms, then, the human brain is the result of a few hundred million years of natural selection. The three major regions of the brain, in order from earliest to develop to newest, are the hindbrain, the midbrain, and the forebrain (see Figure 3.11). By comparing the relative size of each region in distinct kinds of animals that vary in evolutionary age (see Figure 3.12), we gain an appreciation of how these regions evolved. When we compare brains from these different groups, we see an increase in size of the forebrain in humans and other primates (Jerison, 2000).

FIGURE 3.11
THREE MAIN BRAIN STRUCTURES: HINDBRAIN, MIDBRAIN, AND FOREBRAIN. The hindbrain regulates breathing, heart rate, arousal, and other basic survival functions. The midbrain controls eye muscles, processes auditory and visual information, and initiates voluntary movement. The forebrain controls cognitive, sensory, and motor function and regulates temperature, reproductive function, eating, sleeping, and emotions.
Hindbrain The oldest brain region is the hindbrain, the region directly connected to the spinal cord. Hindbrain structures regulate breathing, heart rate, arousal, and other basic functions of survival. There are three main parts of the hindbrain: the medulla, the pons, and the cerebellum.

Extending directly from the spinal cord, the medulla regulates breathing, heart rate, and blood pressure. It also is involved in various kinds of reflexes, such as coughing, swelling, sneezing, and vomiting. Reflexes are inborn and involuntary behaviors that are elicited by very specific stimuli (Amaral, 2000). Pons means “bridge,” and the pons indeed serves as a bridge between lower brain regions and higher midbrain and forebrain activity. For instance, information about body movement and various sensations gets relayed from the cortex via the pons to the cerebellum. The cerebellum, or “little brain,” contains more neurons than any other single part of the brain. It is responsible for body movement, balance, coordination, and fine motor skills like typing and piano playing. The cerebellum is also important in cognitive activities such as learning and language (Amaral, 2000; Stroodley & Schmahmann, 2009).

Midbrain The next brain region to evolve after the hindbrain is the smallest of the three major areas, the midbrain. Different parts of the midbrain control the eye muscles, process auditory and visual information, and initiate voluntary movement of the body. People with Parkinson’s disease have problems with midbrain functioning, due to the loss of neurons that use dopamine there, and so they shake uncontrollably. The midbrain, the medulla, and the pons together are sometimes referred to as the brain stem.
A network of nerves called the **reticular formation** runs through both the hindbrain and the midbrain (*reticular* means “netlike”). The reticular formation plays a key role in wakefulness. Among the first neuroscientists to study the reticular formation were Giuseppe Moruzzi and Horace Magoun. In a classic study, Moruzzi and Magoun electrically stimulated the reticular formation of a sleeping cat, and it immediately awoke. When they lesioned, or damaged, its connection to higher brain systems, the cat went into a deep coma from which it never recovered. No kind of pinching or loud noises would arouse the cat (Moruzzi & Magoun, 1949).

**Forebrain** The last major brain region to evolve was the largest part of the human brain, the forebrain. It consists of the cerebrum and numerous other structures, including the thalamus and the limbic system. Collectively, the structures of the forebrain control cognitive, sensory, and motor function and regulate temperature, reproductive functions, eating, sleeping, and the display of emotions. Most forebrain structures are *bilateral*; that is, there are two of them, one on each side of the brain.

From the bottom up, the first forebrain structure is the **thalamus**, which receives input from the ears, eyes, skin, or taste buds and relays sensory information to the part of the cerebral cortex most responsible for processing that specific kind of sensory information. For this reason, the thalamus is often called a sensory relay station. In fact, olfaction (the sense of smell) appears to be the only sense that does not have a thalamic relay (Kay & Sherman, 2007).

**The Limbic System** In the middle of the brain directly around the thalamus lies a set of structures, traditionally referred to as the *limbic system* (see Figure 3.13). These are the hypothalamus, the hippocampus, the amygdala, and the cingulate gyrus. Together, the limbic system structures are important in emotion.

![Diagram of the brain showing the limbic system structures](image)

**FIGURE 3.13**

**THE LIMBIC SYSTEM.** The limbic system controls motivation and emotion. It includes the hypothalamus, hippocampus, amygdala, and cingulate gyrus.
The Brain

The hypothalamus

a limbic structure; the master regulator of almost all major drives and motives we have, such as hunger, thirst, temperature, and sexual behavior; also controls the pituitary gland.

and motivation. However, there is some debate as to whether these structures work together as a system, so some neuroscientists suggest the term limbic system should be abandoned altogether (LeDoux, 2003).

The structure directly below the thalamus is the hypothalamus. In fact, hypothalamic simply means “below.” The hypothalamus regulates almost all of our major drives and motives, including hunger, thirst, temperature, and sexual behavior. It also controls the pituitary gland, which is responsible for producing and controlling the hormones our body produces. Researchers in the 1940s discovered the role the hypothalamus plays in eating: lesioning one part of it produced overeating and obesity in animals, whereas lesioning another part of the hypothalamus led to undereating (Kupfermann, Kandel, & Iversen, 2000). The hypothalamus is also involved in sexual arousal (Brunetti et al., 2008; Karama et al., 2002).

Wrapped around the thalamus is the hippocampus, which plays a vital role in learning and memory. Sensory information from the sense organs goes to the hippocampus. If these events are important enough, they are processed in the hippocampus and eventually established as lasting memories.

Connection

Psychologists learned how essential the hippocampus is in memory and learning through a case study of Henry Molaison (H. M.), who had this structure surgically removed on both sides of the brain. See “Three Types of Memory,” Chapter 7, “Memory,” p. 269.

The amygdala

small, almond-shaped structure located directly in front of the hippocampus; has connections with many important brain regions and is important for processing emotional information, especially that related to fear.

As we will see throughout this book, learning and memory change the brain, another example of softwiring. The brain structure most open to such change is the hippocampus. To get a feel for the kind of research that demonstrates this capacity, let’s look at recent research conducted with taxicab drivers in London. Why study taxi drivers? Their work requires a tremendous amount of spatial and geographic knowledge, and they have to pass a difficult driving test (Maguire, Woollett, & Spiers, 2006). They must know where all the streets are relative to other streets. Neuroscientists examined images of the hippocampus and found that the hippocampi of taxi drivers was larger than that of other drivers. Moreover, the stress and frequency of driving did not account for these hippocampal size differences. Compared to bus drivers, taxi drivers had larger hippocampi (Maguire et al., 2006). Why? Bus drivers drive the same route every day, so they need to learn much less about the spatial layout of the city than taxi drivers. As this study suggests, learning changes the brain.

The amygdala

a limbic structure that wraps itself around the thalamus; plays a vital role in learning and memory.

How does this picture make you feel? The structures of the limbic system play a key part in emotion and motivation.
Studies in animals and humans show how important the amygdala is to emotions, especially fear. Electrical stimulation of the amygdala in cats makes them arch their backs in an angry-defensive manner, a response suggesting that anger and aggression involve the amygdala. Moreover, when aggressive monkeys had this region of the brain surgically lesioned, they became tame and non-aggressive. They also became fearless; for instance, rather than fleeing from snakes, they approached them (Klüver & Bucy, 1939; Meunier & Bachevalier, 2002). Similarly, in cases of disease, injury, or surgery to the human amygdala, people often lose their aggressive tendencies. They become mild-mannered, yet they also become fearless. Additionally, our ability to recognize certain emotional expressions on other people’s faces—especially fear—involves the amygdala (Adolphs, Gosselin, et al., 2005; J. S. Morris et al., 1996). Without the amygdala, we cannot learn appropriate emotional responses, especially to potentially dangerous situations. The amygdala, along with the hypothalamus and other brain structures, is also activated during sexual arousal (Fonteille & Stoleru, in press; Hamann et al., 2004; Karama et al., 2002).

The **cingulate gyrus** is a beltlike structure in the middle of the brain. Portions of the cingulate gyrus, in particular the front part, play an important role in attention and cognitive control (Botvinick, Cohen, & Carter, 2004). For instance, when people are first trying to figure out a difficult problem and preparing to solve it, parts of the cingulate gyrus are activated (Kounios et al., 2006; Qiu et al., 2010). In contrast, this area seems to malfunction in people with schizophrenia, who do have major difficulties in focusing their attention (Carter et al., 1997).

The **basal ganglia** are a collection of structures surrounding the thalamus involved in voluntary motor control. Several movement-related neurological disorders, including Parkinson’s disease and Huntington’s disease, affect the functioning of neurons in this region. Individuals who have these disorders suffer from jerky, often uncontrollable movements. Often considered part of the limbic system, the basal ganglia reside on both sides of the thalamus and above the limbic system. They connect with the cerebral cortex, thalamus, and brain stem (Kopell et al., 2006).

**The Cerebrum and Cerebral Cortex** The uppermost portion of the brain, the **cerebrum**, is folded into convolutions and divided into two large hemispheres. When most of us think about the human brain, we typically envision the outer layer, with all of its convolutions. This outer layer is called the **cerebral cortex**. The cortex is only about one tenth to one fifth of an inch thick, yet it is in this very thin layer of brain that much of human thought, planning, perception, and consciousness takes place. In short, it is the site of all brain activity that makes us most human.

Connection

The amygdala plays a significant role in emotions, especially fear.

The cerebrum is composed of four large areas called lobes, each of which carries out distinct functions. These lobes are bilateral, which means they are located on both the left and right sides of the brain. The four lobes are the frontal, temporal, parietal, and occipital (see Figure 3.14). The frontal lobes, in the front of the brain, make up one-third of the area of the cerebral cortex. One important region of the frontal lobe, descending from the top of the head toward the center of the brain, is the primary motor cortex. One of the earliest discoveries about the brain's frontal lobes involved the motor cortex. In the 1860s, the German physiologist Eduard Hitzig had noticed while caring for wounded soldiers that touching the surface of a specific side of the brain caused the soldier’s body to twitch on the opposite side. The researchers then discovered that as they moved the stimulation along this strip of cortex and stimulated one small region at a time, different parts of the soldier’s body would move. More importantly, they were the first researchers to discover and study something that few believed: Different parts of the cortex are responsible for different functions—a phenomenon known as cortical localization (Finger, 1994).

The frontal lobe carries out many important functions, including attention, holding things in mind while we solve problems, planning, abstract thinking, control of impulses, creativity, and social awareness (Miller & Cummings, 1999). The frontal lobes are more interconnected with other brain regions than any other part of the brain and therefore are able to integrate much brain activity. This integration allows for insight and creative problem solving (Furster, 1999). For example, connections between the frontal lobes and the hippocampus and temporal lobe facilitate tasks involving language and memory, respectively. More than any other part of the brain, the frontal lobes are what make humans human. They are also the “youngest” brain systems to evolve and the last to fully develop in individuals. The frontal lobes continue to develop until the early 20s. One reason why children and teenagers act more impulsively than adults is that their frontal lobes are not fully developed.

Probably the most famous story in neuroscience comes from the first case study of frontal lobe involvement in impulse control and personality (Macmillan, 2000). In September 1848, a 25-year-old railroad foreman, Phineas Gage, was laying railroad ties. While hammering a tamping iron (an iron bar), Gage accidentally ignited gun powder used to lay the track and it exploded. The iron bar shot upward, entered Gage’s left cheek, and exited through the top of his skull after passing through his frontal lobe (see Figure 3.15). The iron bar was traveling so fast that it moved cleanly through Gage’s head and landed 25 feet away. Miraculously, not only did Gage survive—he never even lost consciousness!
Although not mortally wounded, Gage suffered immediate and obvious changes to his personality. Before the accident, he had been a mild-mannered but clever businessman. After the accident he was stubborn, impulsive, and argumentative, and at times he would say offensive things. Gage’s accident was one of the first documented cases of marked personality change following an injury to the frontal lobes, suggesting that these areas play a key role in regulating social behavior.

The parietal lobes, which make up the top and rear sections of the brain, play an important role in the sensation and perception of touch. The frontmost portion of the parietal lobes is the somatosensory cortex. When different parts of the body are touched, different parts of this strip of cortex are activated. The somatosensory cortex lies directly behind the motor cortex of the frontal lobe. In fact, these two regions are “twins.” The areas of the motor and somatosensory cortices that govern specific parts of the body are parallel to and directly next to each other (see Figure 3.16). For example, the part of the motor cortex involved in moving the lips is directly opposite the region of the sensory cortex where we sense that our lips are being touched. Neural signals from the motor cortex can communicate with computers to control robotic arms or artificial limbs, as we explain in “Psychology in the Real World.”
The temporal lobes lie directly below the frontal and parietal lobes and right behind the ears. The temporal lobes have many different functions, but the main one is hearing. The temporal lobes house the auditory cortex, where sound information arrives from the thalamus for processing. Here, we “hear” our mother’s voice, a symphony, an approaching car, or any other sound. The temporal lobes also house and connect with the hippocampus and amygdala, and so are also involved in memory and emotion.

The occipital lobes occupy the rear of the brain. The optic nerve travels from the eye to the thalamus and then to the occipital lobes—specifically, to the primary visual cortex. Visual information is processed in the visual cortex; it is here where we “see” and “imagine.” Neuroscientists have discovered that different neurons in the visual cortex are activated when we see horizontal lines, diagonal lines, and vertical lines. In other words, individual neurons are specialized for the many different aspects of vision, including shape, color, shadow, light, and orientation (Wurtz & Kandel, 2000a).

The insula is a small structure that resides deep inside the cerebrum, in the area that separates the temporal lobe from the parietal lobe. The insula is active in the perception of bodily sensations, emotional states, empathy, and addictive behavior (Damasio, 2000; Naqvi et al., 2007). It communicates with structures of the limbic system and higher brain areas involved in decision making. The insula also plays a key role in our awareness of our body as our own (Tsakiris et al., 2007).

Cerebral Hemispheres The human cerebrum is divided into two equal hemispheres. Although they look similar, the hemispheres differ in shape, size, and function. In general terms, the left hemisphere processes information in a more focused and analytic manner, whereas the right hemisphere integrates information in a more holistic, or broader, manner (Beeman & Bowden, 2000; Beever & Chiarello, 2009). Insights and solutions to ideas are more likely to occur in the right hemisphere.

The hemispheres do not operate independently, however. The corpus callosum, a thick band of nerve fibers connecting the two hemispheres of the brain, provides a channel for extensive communication between hemispheres in both logical and creative tasks.

Perhaps the best-known and biggest functional difference between the cerebral hemispheres is in language. Speech and language comprehension involve two separate regions in the left hemisphere. The French physician Paul Broca is credited with being the first “neuropsychologist.” He deserves this title because his work in the early 1860s demonstrated for the first time that specific parts of the brain controlled particular behaviors (Kandel, 2006). Broca studied a man who had suffered a stroke. This man could understand language, but he could not speak in grammatical sentences. He had a type of aphasia, a deficit in the ability to speak or comprehend language. After the man died, Broca performed an autopsy and found that a cyst had damaged the man’s left hemisphere. A small region in the left frontal lobe had been damaged, and Broca inferred that this area must be responsible for a person’s ability to speak. Broca went on to discover similar damage in eight other aphasia patients (Pinker, 1994). These clinical findings have been confirmed by modern brain imaging techniques: People with aphasia often have damage or lesions in the same region of the left frontal lobe. This region is commonly referred to as Broca’s area, and this type of aphasia is known as Broca’s aphasia. Broca’s area is responsible for the ability to produce speech.
CHAPTER 3  The Biology of Behavior

Wernicke's area
an area deep in
the left temporal
lobe responsible
for the ability to
speak in meaning-
ful sentences and
to comprehend
the meaning of
speech.

Communication Between the Hemispheres  As we have seen, the two hemispheres of the brain do not operate independently. Information moves between both sides of the brain by way of the corpus callosum. All communication between one side of the brain and the other travels across the corpus callosum.
In the early 1960s a former prisoner of war from World War II developed epileptic seizures as a result of a failed parachute jump. The seizures were so severe that his doctor approached Roger Sperry, a local researcher who had begun to do research on the corpus callosum, for help (Finger, 1994).

Previous medical evidence had suggested that cutting the bundle of nerves between the two hemispheres could stop epileptic seizures. Because the war veteran’s seizures had become life threatening, he underwent the surgery under Sperry’s guidance and it was very successful. Not only did the man’s seizures stop, but there was also no noticeable change in his personality or intelligence. However, Sperry and his colleagues soon discovered a fascinating problem. The man could not name things that were presented to his left visual field, but he could do so with things presented to his right visual field. Why?

Recall that language—both speech and comprehension—resides in the left hemisphere of the human brain. In addition, information from our right visual field (the right portion of the visual scope of each eye) goes to the left occipital cortex, while information from the left visual field (the left portion of the

Forearm electrical stimulation (FES) is used to stimulate forearm muscles with fixed instructions from a computer (Peckham et al., 2001). FES can create movements in paralyzed limbs, but the actions generated are fixed and limited to only what the computer can instruct the arm to do. Ideally, one would have flexibility as with a normally functioning arm; that is, people could choose what movements to make.

Pohlmeyer and his colleagues (2009) took an important step toward creating more flexibility in moving paralyzed limbs. After putting implants deep into the brains of two monkeys to record signals from neurons in the motor cortex, they used nerve-blocking drugs to temporarily paralyze the animals’ arms. Then they wanted to see whether they could use a brain–machine interface to have these neural signals stimulate muscles in the monkeys. The monkeys—in spite of almost completely paralyzed wrists—were able to use this cortically controlled FES system to control the contraction of four forearm muscles.

More recent research employs less invasive techniques—such as brain imaging with fMRI—to control machines (Min, Marzelli, & Yoo, 2010). These new systems allow for a bidirectional line of communication between the brain and the computer. That is, feedback from a computer can be used to modulate brain activity. Such computer-to-brain interfaces might even make possible brain-to-brain interfaces in the future (Min et al., 2010).

In the early 1960s a former prisoner of war from World War II developed epileptic seizures as a result of a failed parachute jump. The seizures were so severe that his doctor approached Roger Sperry, a local researcher who had begun to do research on the corpus callosum, for help (Finger, 1994).

Previous medical evidence had suggested that cutting the bundle of nerves between the two hemispheres could stop epileptic seizures. Because the war veteran’s seizures had become life threatening, he underwent the surgery under Sperry’s guidance and it was very successful. Not only did the man’s seizures stop, but there was also no noticeable change in his personality or intelligence. However, Sperry and his colleagues soon discovered a fascinating problem. The man could not name things that were presented to his left visual field, but he could do so with things presented to his right visual field. Why?

Recall that language—both speech and comprehension—resides in the left hemisphere of the human brain. In addition, information from our right visual field (the right portion of the visual scope of each eye) goes to the left occipital cortex, while information from the left visual field (the left portion of the.
visual scope of each eye) goes to the right occipital cortex (see Figure 3.17). But, because the war veteran had had his corpus callosum cut, the information from the left visual field could not get transferred to the language centers in the left hemisphere. He could, however, consistently pick up with his left hand the image he saw! Thus, because the right hemisphere (where the image was projected) controls the left side of the body, he could move his hand to the correct object (see Figure 3.18). This split-brain research shows that we can know something even if we cannot name it (Sperry, Gazzaniga, & Bogen, 1969).

**Brain Plasticity and Neurogenesis**

When scientists began mapping the brain in the late 19th century, they did so by stimulating various brain regions in animals and observing the behavioral changes that such stimulation caused; they then diagrammed the locations of functions in the cerebral cortex (Kandel, 2006). Such mapping contributed to the notion that brain function was fixed. Certain brain regions had certain functions and that was that. But as far back as the early 20th century, researchers had stimulated different places on the motor cortex in several different monkeys and had found that maps generated from such stimulation varied from monkey to monkey. They were as individual as fingerprints.
In the early 20th century, other neuroscientists mapped the motor cortices of several monkeys many times during a 4-month period. They found that neural areas corresponding to the movement of specific fingers changed to reflect changes in the animal’s patterns of movement over that time period (Jenkins et al., 1990).

By the 1970s, there was evidence that learning occurs through synaptic change. These findings were only the tip of the iceberg. Since the 1990s, numerous principles of brain plasticity have emerged (B. D. Perry, 2002). First and most generally, neuroplasticity is the brain’s ability to adopt new functions, reorganize itself, or make new neural connections throughout life, as a function of experience. Second, almost every major structure of the neuron is capable of experience-based change. Third, not all regions of the brain are equally plastic. For example, the part of the brain most involved in learning, the hippocampus, is more plastic than just about any other part of the brain. And fourth, brain plasticity varies with age, being strongest in infancy and early childhood and gradually decreasing with age. Contrary to popular belief, at no time in our lives does the brain lose its ability to grow new neurons. Neuroplasticity occurs in all stages of life, though the different parts of the brain are not equally plastic at all times.

The four principles of brain plasticity are summarized in Figure 3.19. Experience-based change in the nervous system occurs in several ways. Most common are the formation of new neurons, the growth of dendrites

---

**FIGURE 3.18**

**PERCEPTION AND LANGUAGE IN A SPLIT-BRAIN PATIENT.** In (a) a person who has had an operation to cut the corpus callosum is shown an object (hairbrush) to her left visual field. In (b), when asked what she saw, she cannot say, because her language production center (Broca’s area) is in her left hemisphere. Because the image is shown to her left visual field, only her right visual cortex perceives it. With a split corpus callosum, there is no way for that information to cross from the right hemisphere to the left. So she is unable to say what she saw. In (c), however, she is able to pick up the object she saw with her left hand. Why her left hand? Because it is controlled by her right hemisphere, which did in fact perceive the brush.

---

**FIGURE 3.19**

**FOUR PRINCIPLES OF BRAIN PLASTICITY.**

- Neuroplasticity is the brain’s ability to adopt new functions, reorganize itself, or make new neural connections throughout life, as a function of experience.
- Almost every major structure of the neuron is capable of experience-based change, although we focus only on the three major ones: the neuron itself, dendrites, and synapses.
- Although the brain is plastic, not all regions are equally plastic.
- Brain plasticity varies with age, being strongest in infancy and early childhood and gradually decreasing with age.

---

**Connection**

If a person is not exposed to language much before mid-to late childhood, the ability to speak is limited because the brain loses some of its plasticity as we age. See “Language Development in Individuals,” Chapter 9, “Language and Thought,” p. 350.
The process of developing new neurons is known as **neurogenesis**. The growth and formation of new dendrites is called **arborization** (from the Latin *arbor*, or “tree”), because dendrites are like branches on a tree. Probably the best-known example of neuroplasticity, however, is the process known as **synaptogenesis**, the formation of entirely new synapses or connections with other neurons that is the basis of learning. All of these neuroplasticity examples are forms of softwiring—biological systems being modified by input from the environment.

Although these principles of neuroplasticity are universal—that is, apply to everyone—some of the strongest evidence for them comes out of research on people with different kinds of sensory deficits, such as blindness or deafness. It is in deafness and blindness that we see most clearly how flexible the brain really is. Brain function and localization vary considerably on the basis of the experience of the individual brain.

In most hearing people, the area that is called the **auditory cortex** processes sound. Although it is labeled by its function, anatomically the auditory cortex is actually a section of the temporal lobe. It is called the auditory cortex because the sensory neurons from the inner ear come here.

But if those neurons don’t pick up any sounds, what does this area of the brain do? Nothing? What a waste of brain tissue that would be. For centuries scientists and ordinary people have observed that deaf people see better than hearing people and that blind people hear better than sighted people. The neuroscientist Helen Neville always thought there must be truth to these observations. In the process of testing these assumptions, she discovered that—overall—blind people are not better at hearing. They are not more sensitive to softer sounds than sighted people. Similarly, deaf people do not excel at all kinds of vision, nor are they able to see fainter images than do hearing people.

What Neville found, however, was that deaf and blind people are more expert in peripheral sensory experiences. That is, deaf people have better *peripheral* vision than sighted people—they are better at seeing things “out of the corner of their eyes” (Bavelier et al., 2000). They have better motion detection as well, and this also seems to be processed by the auditory cortex. Just as deaf people see better at the periphery, those who are blind don’t hear better overall, but their *peripheral* hearing—hearing for things around the edges of a sound field (rather than the center)—is better than that of sighted people. And these peripheral sounds are processed by the visual cortex (Bavelier et al., 2000). According to Neville, “This was some of the first evidence that brain specializations such as auditory cortex are

**nature & nurture**

In blind people, the brain compensates for deficits in vision by reorganizing and rewiring the visual cortex to process sound. The brain shapes behavior, and behavior shapes the brain.

To compensate for deafness or blindness, the brain reorganizes and rewires the part normally dedicated to hearing or vision for other uses. Marlee Matlin, shown here with her dance partner from *Dancing With the Stars*, is an Oscar-winning actress with limited hearing.
not anatomically determined” (Neville, as quoted in Begley, 2007, p. 84). In short, by virtue of its natural plasticity and softwiring, the brain compensates for deficits in one sensory modality by reorganizing and rewiring unused regions to take on new functions. Once again, we see how psychological research leads to startling changes in our assumptions.

Quick Quiz 3.3: The Brain

1. This region of the brain was the last to evolve. It is also the biggest part of the brain.
   a. cerebellum
   b. forebrain
   c. hindbrain
   d. pons

2. Which limbic structure plays a crucial role in fear?
   a. hypothalamus
   b. basal ganglia

3. Where is the somatosensory cortex?
   a. in the occipital lobes
   b. in the frontal lobes
   c. in the temporal lobes
   d. in the parietal lobes

Answers can be found at the end of the chapter.

Breaking New Ground

Neurogenesis in the Adult Brain

Neurons are unique cells in the body. Unlike many other cells, including hair, blood, or skin cells, nerve cells do not grow and die on an hourly basis. Nor do they divide. Because of these two facts, discovered by the Spanish physician and Nobel Prize winner Santiago Ramón y Cajal more than 100 years ago, the prevailing wisdom was that neurons are incapable of growth, at least after early childhood.

These observations led Ramón y Cajal to put forth the neuron doctrine, which declared that neurons do not regenerate. Until the 1990s, researchers and physicians alike accepted the idea that once a region of the brain was damaged, its function was lost forever. All neural growth and change were understood to be limited to fetal and childhood development, and the adult brain did not change.

Early Evidence of Neurogenesis in Adults

By the early 1960s, however, an accumulation of evidence began to suggest that adult brains do change. Perhaps the first empirical demonstration of neurogenesis occurred when neuroscientists detected evidence of cell division (evidence of growth) in the brains of adult rats (Bryans, 1959).

In the early 1960s, Joseph Altman published a series of groundbreaking studies with adult rats and cats. Armed with a new cell-labeling technique, Altman found evidence of the growth of new neurons—neurogenesis—in several brain areas that are crucial for learning and memory (Altman & Das, 1966; C. G. Gross, 2000). Even though his reports appeared in prestigious journals, however, Altman’s findings were almost completely ignored or discounted. Why? He was working alone, and he was a little-known researcher who violated the dogma, or strongly accepted view.
As often happens with ideas that radically challenge basic assumptions and long-held beliefs, neuroscientists and others either trivialized or ignored Altman’s findings of adult neurogenesis. What does it take for a movement to change a well-entrenched, century-old idea? In this case, three scientific events took place during the 1980s and 1990s that finally turned the tide of belief.

First, a series of studies on birds showed exceptional neural growth in many areas of the adult avian brain, including the hippocampus (Nottebohm, 1985). Second, there was increasing evidence for the formation of new synaptic connections in the brains of rats when they were raised in enriched environments, more so than normally occurs with development (Comery et al., 1996). For example, rats that lived in cages with playmates and wheels to run on and toys showed more dendritic growth than those who lived alone in sparse cages (Rosenzweig & Bennett, 1969). Third, in the 1990s, researchers began to find solid evidence for neurogenesis in one particular region of the hippocampus in adult rats, monkeys, and humans. Neurogenesis was no longer something seen only in birds and rats. There was no more denying that neural growth occurs in humans.

Key Figures in the Discovery of Neural Growth in Adults

The person most responsible for demonstrating neurogenesis in humans is Fred “Rusty” Gage (ironically, a cousin of the famous Phineas Gage who had the iron rod blast through his skull) (Gage, 2002; Gage, Kemperman, & Song, 2008). But how is this research done in humans, since researchers cannot train humans and then slice open their brains to see if neural growth occurred? Indeed, the brain imaging techniques that we currently use cannot detect the growth of new cells. Gage got together with his researchers, some of whom did medical research, and they hit up on the solution that allowed them to detect new neural growth in humans. It involves injecting people with a substance called BrdU, which is incorporated into dividing cells so that they can be identified.

But there is a problem with BrdU: You can’t simply inject humans with it because it is radioactive. But—and here was the big breakthrough—some people have to have it injected for medical reasons. Gage and his colleague Peter Eriksson knew that some cancer patients receive this injection as part of their therapy. Because it identifies new cells, it is used to track how aggressively cancerous tumors are growing. After some patients

Animals reared in naturalistic settings have higher rates of neurogenesis than those reared in cages.
who had been injected with BrdU died, Gage and Eriksson examined their hippocampus tissue. Based on the presence of BrdU, they found new cells in the adult human hippocampus (Begley, 2007; Eriksson et al., 1998). In fact, it was the same part of the hippocampus that earlier had shown the greatest neuronal growth in rats and monkeys.

Another of the key figures in demonstrating new neural growth in adult primates has been Elizabeth Gould (Glasper, Leuner, & Gould, 2008). She and her colleagues have compared rates of neurogenesis and synaptic growth in the brains of primates living in naturalistic settings with those living in lab cages. The naturalistic settings simulated a wild environment, with natural vegetation where the animals could search for food, among other activities. The brains of the animals that lived in these environmentally complex settings showed brain growth in areas important for thinking and feeling. They also had higher rates of neurogenesis and more connections between neurons than the animals reared in cages. In other studies, Gould and her colleagues found that stress and impoverished environments resulted in less neurogenesis in mammals (Mirescu & Gould, 2006; Mirescu et al., 2006).

Because of the onslaught of findings demonstrating neurogenesis in adult animals during the 1990s, the dogma of no new neural growth finally died. Now we know that neurons and their dendrites and synapses change, grow, and die in both young and old animals—including humans—depending on the kind of stimulation they receive from the outside world. Indeed, when we learn anything, and even when we exercise, neurons in our brain are changed.

Quick Quiz 3.4: Neurogenesis in the Adult Brain

1. The brain’s ability to adopt new functions, reorganize itself, and make new neural connections is known as
   a. neuroplasticity
   b. neurogenesis
   c. the neuron doctrine
   d. localization of function

2. In what region of the human brain is there the most evidence of neurogenesis?
   a. frontal cortex
   b. hypothalamus
   c. amygdala
   d. hippocampus

Answers can be found at the end of the chapter.

MEASURING THE BRAIN

To be able to look into the brain as it is working was a long-time dream of philosophers and scientists. In the last few decades, realizing this wish has become possible. At least three distinct techniques are now commonly used to measure brain activity in psychological research.

Electroencephalography

Researchers use **electroencephalography (EEG)** to record the electrical activity of the brain. The procedure involves placing electrodes on a person’s scalp. The electrodes, metal disks attached to wires, are usually mounted in a fabric cap that fits snugly over the head. Typically, the person is conducting certain
The Biology of Behavior

EEG is superior to other brain imaging techniques in showing when brain activity occurs. It is not very accurate at indicating precisely where activity occurs (see Figure 3.20).

The event-related potential (ERP) is a special technique that extracts electrical activity from raw EEG data to measure cognitive processes. To examine ERPs, one gathers electrical recordings from an EEG cap on research participants who are performing cognitive or emotional tasks, such as trying to attend to an object on a computer screen, remember a list of words, or view emotionally charged slides. Typically, raw EEG data provide a summary of all the electrical activity in the brain that happens at a particular time. Generally this level of detail is fine for measuring states of wakefulness, for example. But you need more temporal precision if you want to see a brain reaction, say, to a particular stimulus, such as a flashing light or a line. To examine ERPs, researchers use a special averaging process that allows them to filter out all electrical activity except the activity that is related to the stimulus the person is processing in a controlled experiment.

Because they are based on EEG, ERPs provide excellent temporal resolution (they show brain activity linked with psychological tasks almost immediately in time) but poor spatial resolution. Spatial resolution involves how tiny an area can be pinpointed as being active at a certain time. Two other techniques provide better spatial resolution than EEG: MRI and PET.

Magnetic Resonance Imaging (MRI) and Functional MRI (fMRI)

MRI stands for magnetic resonance imaging. MRI uses magnetic fields to produce very finely detailed images of the structure of the brain and other soft tissues. In MRI, the patient lies on a platform or bed that slides into a tube surrounded by a circular magnet. The magnet, along with radio waves, is used to produce a signal that is then processed by computer. The computer then produces an image with an amazing level of detail (see Figure 3.21). MRI provides static pictures, and it is very useful for looking at structures and abnormalities in structures, such as when someone is injured. MRI does not tell us anything about activity, just structures.

A variation on MRI, functional MRI (fMRI), does, however, tell us about brain activity. Images from fMRI tell us where activity in the brain is occurring during particular tasks by tracking blood oxygen use in brain tissue, as shown in Figure 3.21. In this way, researchers can see which areas of the brain are using the most oxygen (and presumably are most active) during certain tasks (Casey, Davidson, & Rosen, 2002; Lagopoulos, 2007). When people perform different tasks while they are being scanned, the researchers can distinguish from high-resolution images which areas are active during the task. These are indirect images of activity based on how the brain uses oxygen rather than a direct “readout” of nerve impulses.
Although fMRI provides a much better measure of where activity occurs than EEG does, it is not without drawbacks. For one thing, it is very expensive. Also, it does not provide very precise measures of when activation occurs in response to a particular stimulus or task. It is not entirely clear exactly how directly fMRI images reflect underlying neural activity (Lagopoulos, 2007). Some studies suggest a fairly direct correlation with processing in certain cortical areas (Logothetis et al., 2001). As a result, fMRI findings should always be interpreted with care. The Research Process for this chapter illustrates the use of fMRI to study how people perceive faces (see Figure 3.22).

**Positron Emission Tomography (PET)**

**Positron emission tomography (PET)** measures blood flow to brain areas in the active brain (see Figure 3.21). From these measurements researchers and doctors can determine which brain areas are active during certain situations. PET involves injecting the participant or patient with a harmless radioactive form of oxygen (or glucose). The brain then takes up the oxygen during cell metabolism. Thanks to the radioactive label on the oxygen, scanners and computers can be used to create images of the brain regions using that oxygen during a certain task.
Research Process

1. Research Questions
Is any part of the brain dedicated to seeing faces and no other object? Likewise, is there a part of the brain dedicated exclusively to perceiving places (such as buildings)? If so, are these brain regions equally active when you imagine a face or place and when you actually see one?

2. Method
Previous research had found one distinct part of the brain activated when we see a face (the fusiform face area, FFA) and a different area of the brain (the parahippocampal place area, PPA) activated when we see a place or a building. O’Craven and Kanwisher (2000) wanted to confirm this result and extend it by seeing whether the activity was as strong when just imagining faces or places as it was when seeing these images.

Eight participants were placed inside an fMRI machine (see image) and then viewed images of either famous faces or familiar buildings on their university campus. For the imagining condition, participants were read the names of famous names and places and asked to close their eyes and form a “vivid mental image” of each one.

3. Results
Results confirmed the FFA showed high activity (% signal change) for faces but low activity for places, whereas the PPA showed the opposite (see figure). Moreover, the results for imagining faces and places showed the same pattern of results, only less strongly.

4. Conclusion
Different regions of the brain are dedicated to very specific kinds of visual stimuli. We know this only because fMRI technology allows us to see specific areas of brain activity when we are shown different kinds of objects and given different kinds of tasks.

---

**FIGURE 3.22**
Although the results are very informative, the use of radioactive substances means PET is not risk-free. fMRI is a much safer way to image metabolism in the brain.

The imaging techniques we have discussed so far focus on measuring the structure or activity of clusters of somas of neurons. What is known as the gray matter is the brain tissue composed of neuron cell bodies, because the soma or cell body is where cell metabolism takes place (and thus oxygen is used by the cell). But information is communicated among different areas of the brain via long fibers of myelinated axons, which are not typically well imaged by MRI or PET. Because these fibers are covered with myelin, they are called white matter. Several methods have been developed for better imaging white matter, or neural fibers. These include diffusion tensor imaging, which is a special kind of MRI that is adapted for better imaging myelinated fibers and tracts (collections of myelinated fibers). This type of imaging is important for studying the connectivity among brain areas (Hua et al., 2009).

Quick Quiz 3.5: Measuring the Brain

1. Which brain measurement technique best shows when neural activity has occurred?
   a. PET
   b. MRI
   c. EEG
   d. fMRI

2. Betty has an injury to a particular part of her brain and suddenly has trouble imagining, recognizing, and interpreting faces. What region of the brain was likely affected and which technology told us this?
   a. parahippocampal place area (PPA); MRI
   b. parahippocampal place area (PPA); fMRI
   c. fusiform face area (FFA); MRI
   d. fusiform face area (FFA); fMRI

Answers can be found at the end of the chapter.

THE ENDOCRINE SYSTEM

In the nervous system, neurons communicate information electrochemically by means of membrane changes and neurotransmitters released into the synaptic cleft. In the endocrine system, glands secrete chemicals called hormones, which travel through the bloodstream to tissues and organs all over the body and regulate body functions. Hormones also play a crucial role in regulating metabolism, growth, reproduction, mood, and other processes. Figure 3.23 depicts some of the major endocrine glands of the body.

The hypothalamus, shown in Figure 3.23, is a brain structure that controls the pituitary gland. The pituitary gland is known as the master gland of the body, because it secretes hormones that control the release of hormones from glands elsewhere in the body.

The thyroid gland sits in the neck region and releases hormones that control the rate of metabolism. Metabolism is the process by which the body converts nutritional substances into energy. The pancreas releases hormones, including insulin, that play a vital role in regulating blood sugar levels. The sex glands (ovaries and testes) release sex hormones that lead to development of sex characteristics (such as body hair and breast development), sex drive, and other aspects of sexual maturation.

The adrenal glands, which sit atop the kidneys, release hormones in response to stress and emotions. They also help regulate heart rate, blood pressure, and blood sugar. In addition, the adrenal glands produce catecholamines, a class of chemicals that includes the neurotransmitters dopamine, epinephrine, and norepinephrine.
norepinephrine, and epinephrine, which control ANS activation. Norepinephrine activates the sympathetic nervous system, increasing heart rate, rate of respiration, and blood pressure in order to support rapid action of the body. The adrenal glands also release stress hormones such as cortisol, which is responsible for maintaining the activation of bodily systems during prolonged stress.

The endocrine system works in conjunction with the nervous system and in a dynamic relationship with the brain. An example is its control of the female menstrual cycle. Each month, the hypothalamus sends signals to the pituitary to release hormones that stimulate a woman’s ovaries to develop (mature) an egg. As part of the process, the ovary itself releases hormones that prepare the womb to receive a fertilized egg. If the egg is fertilized, the ovaries send hormonal feedback to the hypothalamus, so that it will not stimulate further egg development.

Quick Quiz 3.6: The Endocrine System

1. How do hormones differ from neurotransmitters?
   a. Hormones are proteins; neurotransmitters are fats.
   b. Hormones carry messages in the bloodstream; neurotransmitters carry messages across synapses.
   c. Hormones have no effect on mood; neurotransmitters do.
   d. all of the above

2. What is the name of the stress hormone released by the adrenal glands?
   a. catecholamine
   b. insulin
   c. thyroxin
   d. cortisol

Answers can be found at the end of the chapter.
Bringing It All Together

Making Connections in the Biology of Behavior

What Esref Armagan’s Story Reveals About the Brain

This chapter opened with a profile of the blind artist Esref Armagan. Besides being a fine example of someone creatively overcoming a disability, Armagan’s story offers us a way to connect much of the material in this chapter. Let’s take a closer look.

When Armagan paints, he uses a Braille stylus (writing instrument) to sketch out his drawing by laying down bumps on paper. With his other hand, he follows the raised bumps to “see” what he has put down (Motluk, 2005). He then transfers this sketch to canvas and applies acrylic paint with his fingers, one color at a time. Armagan waits for each color to dry before applying another so that they will not blend or smear too much. No one helps him when he paints, and his paintings are entirely his own creations.

Armagan has learned much from talking with other people, such as what the typical colors of certain objects are. He always keeps his paints lined up in the same order so that he can find the right color. His sense of perspective is harder to explain. He portrays perspective with uncanny realism, far beyond what any other blind painter has ever achieved (Kennedy & Juricevic, 2006). He says he learned this from talking with others as well as from feeling his way in the world (“Biography,” n.d.).

Armagan’s skill appears to have at least some inborn basis, given how early he started without receiving any instruction. Before age 6, he would draw in dirt and scratch drawings on the furniture in his home. His parents, wanting to save their furniture, finally gave him drawing materials (Kennedy & Juricevic, 2006; Motluk, 2005)—something not usually offered to blind children. This early, automatic, and almost compulsive behavior suggests that something about how his brain was wired drove young Esref to draw, and genetics likely played a role.

What senses does Armagan use while painting? Like many blind people, Armagan relies mostly on his sense of touch. Interestingly, he needs total silence while working. In many blind people, the so-called visual centers of the brain are used to process hearing (Röder, 2006). Maybe Armagan needs silence because he cannot afford to devote the precious resources of his mind’s eye to hearing.

How can we explain Armagan’s act of painting in the context of the nervous system? As Armagan moves the stylus to create bumps on paper and moves his fingers over those bumps, the sensations from his fingertips stimulate his sensory neurons. These neurons, in turn, stimulate interneurons in different regions of the brain (discussed below), which eventually stimulate motor neurons to move his hands and fingers in precise ways to execute his painting.

Throughout this entire process, millions of neurons are firing. As Armagan moves his hands and fingers and begins to paint, the neurons send impulses to other neurons. Some of the messages are excitatory; some are inhibitory. If a neuron receives a preponderance of excitatory impulses and the membrane potential changes sufficiently, it will fire in an all-or-none fashion. At this point, the cell membrane opens channels letting potassium out and sodium in. The wave of opening and closing channels moves the impulse down the axon and stimulates the release of neurotransmitters in vesicles that are in the terminal buttons. The neurotransmitters are released into the synaptic cleft, where they bind with receptor sites in postsynaptic neurons, get taken back up into the presynaptic neuron, or degrade. The message is then relayed to the next (postsynaptic) neurons.

What neurotransmitters are most likely to be involved in painting? As Armagan sketches and paints, he voluntarily moves his arms, hands, and fingers. Voluntary motor movements of muscles use synapses involving dopamine and
acetylcholine. His attention and focus while painting, and his blocking out of auditory stimulation, increase his levels of norepinephrine as well. Additionally, the learning and memory needed for his artistry involve the effects of acetylcholine and glutamate in various parts of the brain.

There is activity throughout his brain, in brain stem structures as well as in the forebrain. As Armagan paints, as is true for anything he does, his breathing, heart rate, body temperature, and even consciousness are regulated by the medulla (see Figure 3.24). Armagan’s thalamus transfers and relays most of the sensory information coming into various parts of the brain for different kinds of processing. And there is so much information to process! As he develops new ideas for what he wants to paint, his hippocampus is active in sending those ideas to the frontal lobes for memory or to various cortices for more permanent storage.

In order to paint, Armagan needs to plan and execute the actions of painting. The frontal lobes play a key role in planning and keeping in mind the tasks needed to paint. His motor cortex controls movement of his legs, arms, hands, and fingers. His basal ganglia help carry out the commands to move the various parts of his body. Perhaps Armagan decides to put his fingers in the paint container to his left. The parietal lobes get involved in orienting his body in space, and the frontal lobes plan the action to reach for the paint pot to his left. When he is ready to move his hand, the signal from these cortical areas travels to the cerebellum to control fine movement, then to the pons, medulla, and finally to the spinal cord to the nerves that control the muscles in his hand and arm. All this occurs in an instant. His brain gets feedback on the position of the hand and makes needed adjustments: a complex interplay among the somatosensory cortex (which receives sensory input from his fingers and arms as he paints), the insula, and the cerebellum.

Armagan is one of the few blind people with the ability to accurately portray depth and perspective in his drawings and paintings. When asked to draw a cube and then rotate it once and then again, he draws it in perfect perspective, with horizontal and vertical lines converging at imaginary points in the distance (Kennedy & Juricevic, 2006). This ability to render perspective accurately in three dimensions is processed in the parietal lobes near the top and back of his brain. The visual images that Armagan forms from his sense of touch activate the same region of the brain that is active when sighted people see something: the occipital lobe.

When sighted people imagine something, their visual cortex (in the occipital lobe) is active—but in a much weaker way than when they actually look at something. When Armagan imagines an object, his visual cortex is even less active than that. But when he paints, his occipital cortex becomes so active that it cannot easily be distinguished from a sighted person’s visual cortex as he actually sees something (Begley, 2007; Motluk, 2005). Armagan’s brain appears to be seeing.

Because Armagan has been blind since birth, his visual cortex has never received any visual input (light). But that part of his brain didn’t merely die or stop functioning. In
many blind people, the visual cortex takes on hearing functions, enabling them to hear certain types of sounds better than sighted people can (Röder, 2006). Armagan’s occipital cortex indeed is very active when he paints, but he is receiving tactile (touch) and not visual input.

Furthermore, in most blind people who read Braille, the visual cortex is active in processing tactile and verbal memory function. But Armagan can’t read Braille and his visual cortex is not recruited for any aspect of language. In fact, his memory for language is rather poor. He is a very “visual” person, but his visual images are built from tactile information—just as images are during a walk through the Tactile Dome. There is evidence from neuroscientists who study blind people in general that this plasticity of the occipital lobes is the norm—it usually processes tactile information, verbal information, or both for blind people (Amedi et al., 2005). Armagan’s life, abilities, and brain illustrate that the brain is both highly plastic and specialized (Begley, 2007). The so-called visual part of his brain found something to do.

Chapter Review

GENES AND BEHAVIOR

• At least four principles of behavioral genetics are important for psychology: (1) The relationship between specific genes and behavior is complex. (2) Most specific behaviors derive from many genes. (3) Behavioral genetics employs studies of twins and adoptees to disentangle the contributions of heredity and environment to behavior. (4) The environment influences how and when genes affect behavior.

• The extent to which a characteristic is influenced by genetics is known as heritability. Researchers use twin-adoption studies and gene-by-environment designs to study heritability.

THE NERVOUS SYSTEM

• There are two kinds of cells in the central nervous system: glial cells and neurons. Glial cells provide structural support, among other important functions.

• Neurons transmit information throughout the nervous system by means of action potentials. Messages are received by the branchlike dendrites and cell bodies of neighboring neurons; these messages create changes in the membrane of the receiving neuron. If the right conditions are met, that neuron fires in an all-or-none fashion. Action potentials move down the length of the axon as channels in the membrane open and close, allowing ions to move in and out of the axon. The action potential stimulates the release of neurotransmitters from the terminal buttons into the synaptic cleft.

• Neurotransmitters bind to receptor sites on the dendrites of postsynaptic neurons, allowing an action potential to be generated if the charge threshold is surpassed. Excess neurotransmitter is either taken back into the original neuron or broken down in the synaptic cleft.

THE BRAIN

• The brain is divided into three major regions: the hindbrain, midbrain, and forebrain.

• The topmost brain structures are the cerebrum and cerebral cortex, which are the seat of abstract reasoning, planning, and higher-order thought.

• The cerebrum comprises four lobes: the frontal lobes are involved in abstract reasoning, self-control, and motor control; the temporal lobes house the auditory cortex; the parietal lobes process tactile and spatial information; and the occipital lobes house the visual cortex.

• The left and right hemispheres of the brain carry out somewhat different functions. The biggest difference between the hemispheres is language, which is usually controlled by the left hemisphere.

• One major shift in our understanding of the brain over the last 15–20 years is how much neurons and brain structures are shaped by experience. New neurons form, new dendrites grow, and new synapses are created across the life span, especially in infancy and early childhood.
MEASURING THE BRAIN
• Various methods offer glimpses into the brain and its functions. Electroencephalography (EEG) measures electrical activity from scalp readings. Magnetic resonance imaging (MRI) measures blood flow changes in the brain without the added risk of the radioactive dyes used in PET scans. The adaptation of MRI to functional MRIs (fMRI) allows researchers to determine which brain areas are active during specific tasks.

THE ENDOCRINE SYSTEM
• In the endocrine system, glands secrete chemicals called hormones, which travel in the bloodstream to tissues and organs all over the body. The pituitary gland, called the master gland of the body, controls the release of hormones from other glands in the body. The adrenal glands secrete hormones involved in sympathetic nervous system responses and stress.

BRINGING IT ALL TOGETHER: MAKING CONNECTIONS IN THE BIOLOGY OF BEHAVIOR
• The story of Esref Armagan offers a glimpse of the brain in action. For example, as Armagan moves his hands and fingers and begins to paint, the neurons send impulses to other neurons. Activation occurs in many regions of the brain. The cerebellum fine-tunes his movements by attending to whether his body is moving appropriately with the right amount of effort. The visual images that Armagan forms from his sense of touch activate the same region of the brain that is active when seeing people see something: the occipital lobe.
Quick Quiz Answers

Quick Quiz 3.1: 1. b  2. a  3. a
Quick Quiz 3.2: 1. c  2. a  3. b  4. c
Quick Quiz 3.3: 1. b  2. c  3. d
Quick Quiz 3.4: 1. a  2. d
Quick Quiz 3.5: 1. c  2. d
Quick Quiz 3.6: 1. b  2. d

Challenge Your Assumptions Answers

• Learning can change the size of your brain. True. See pp. 99 and 109–111.
• Traits that are genetically influenced are set and unchanging after conception. False. See p. 80.
• In people who are blind, vision areas of the brain do not function. False. See pp. 108 and 118–119.
• You can’t easily learn a new language as an adult. True. See p. 107.
Touring the Nervous System and the Brain

The Neuron and Synapse  ■  The Resting Potential and Action Potential
Structures and Functions in the Human Brain  ■  Lobes of the Cerebral Cortex
Visual Information in the Split Brain  ■  Central and Peripheral Nervous Systems

GOALS OF THE TOUR

1  The Neuron and Synapse. You will be able to identify parts of the neuron and synapse and describe how they communicate information.

2  The Resting Potential and Action Potential. You will be able to describe the membrane changes involved in maintaining the resting potential and in producing the action potential.

3  Structures and Functions in the Human Brain. You will be able to identify the brain’s key structures and functions.

4  Lobes of the Cerebral Cortex. You will be able to identify the location and describe the function of the four lobes of the cerebral cortex.

5  Visual Information in the Split Brain. You will be able to describe hemispheric lateralization and communication in the brain.

6  Central and Peripheral Nervous Systems. You will be able to identify the parts of the central and peripheral nervous systems and describe the body functions they control.
The Neuron and the Synapse

1. Identify parts of the neuron and synapse and describe how they communicate information.

1a Neuron
Stimulus to a neuron causes a neural impulse to travel down the axon toward dendrites of the next neuron.

1b Synapse
In the terminal button, the impulse triggers the release of neurotransmitters into the synaptic cleft.

- Presynaptic Neuron
- Postsynaptic Neuron
- Axon of the presynaptic neuron
- Terminal button
- Vesicle containing neurotransmitters
- Synaptic cleft
- Receptor with binding site
- Dendrite of postsynaptic neuron
- Direction of nerve impulse
The Resting Potential and Action Potential

2a Resting potential
In the resting neuron, the fluid outside the axon contains a higher concentration of positive ions than the inside of the axon, which contains many negatively charged anions (A–).

2a Action Potential
The action potential is an impulse of positive charge that sweeps down the axon.

The graph below depicts the electrical changes that occur during each stage of an action potential (1 resting potential, 2 depolarization, 3 repolarization, and 4 refractory period).

The Resting Potential and Action Potential

Describe the membrane changes involved in maintaining the resting potential and in producing the action potential.
Structures and Functions of the Human Brain

3 Identify the brain's key structures and functions.

3a Brain Stem Structures

- Thalamus
- Reticular formation
- Pons
- Medulla (green)
- Cerebellum
- Spinal cord

3T-4 Touring the Nervous System
Lobes of the Cerebral Cortex

Identify the location of the lobes of the cerebral cortex and describe their primary function.
Visual Information in the Split Brain

Describe hemispheric lateralization and communication in the brain.

Left hemisphere of the brain
- Main language center, especially speech and grammar
- Receives information only from the right side of the body, and controls the right side of the body as well

Right hemisphere of the brain
- Nonverbal information, such as perception, visual recognition, and emotion
- Receives information only from the left side of the body, and controls the left side of the body as well

Corpus callosum
A thick band of axons that connect brain cells in one hemisphere to the other. In healthy brains, the two sides engage in a continuous flow of information via this neural bridge and share information.
Identify the parts of the central and peripheral nervous systems and describe the body functions they control.
1. THE NEURON AND SYNAPSE
The neuron consists of a soma, dendrites, and an axon. The soma is the structure of the neuron that contains the nucleus, which consists of the genetic material including the chromosomes. The dendrites are branches of the neuron that receive information from other neurons. The axon sends information away from the soma to other neurons or cells.
When a neuron fires, it sends an electrical impulse down the axon, known as the action potential. When the impulse arrives at the axon terminal buttons, it causes the release of neurotransmitter molecules into the synapse. The synapse is the gap junction between two neurons. Neurons communicate with one another by means of chemical signals provided by neurotransmitters that cross the synapse.

The neurotransmitter released by the sending neuron enters the synaptic gap and attaches to a receptor on the postsynaptic neuron. The receptor site contains a channel that is typically closed when the receiving neuron is in the resting state (resting potential). When the neurotransmitter binds to the receptor site, the receptor channel opens to allow a particular ion to enter or leave the neuron. If a neurotransmitter causes channels to be positively charged ions like sodium (Na⁺) to open, the postsynaptic neuron will become less negative in charge. The entry of sodium will cause a change in the electrical charge (potential) of the receiving neuron that may make it more likely to generate its own action potential.

2. THE RESTING POTENTIAL AND ACTION POTENTIAL
The neuron maintains electrical properties called an electrical potential, which is a difference in the electrical charge inside and outside of the cell. This charge difference is maintained because the membrane of the neuron is selectively permeable. This means some molecules can pass through the membrane more freely than others. The membrane is not permeable to large negatively charged protein molecules that are trapped inside the neuron. Inside and outside the neuron are electrically charged particles called ions that vary in concentrations. The ions that play an important role in the function of the neuron are sodium (Na⁺), potassium (K⁺), and chloride (Cl⁻). These ions enter or leave the neuron through special channels provided by protein molecules that line the neuron.

The resting potential is the electrical property of the neuron when it is not stimulated or not sending a nerve impulse. In a typical neuron this is seen as a ~70 mV charge inside relative to the outside of the membrane. During the resting potential, the sodium channels are closed, leaving a higher concentration of sodium ions outside of the neuron membrane. The negative charge of a neuron during the resting state is largely maintained by the negatively charged protein molecules trapped inside the neuron and by the inability of positively charged sodium ions to cross the membrane into the neuron.

If the neuron receives enough excitatory messages to surpass the threshold level, an action potential will occur, sending the nerve impulse down the axon. Positively charged sodium ions enter the neuron, and potassium ions move out. The action potential jumps from one space in the axon’s myelin sheath to the next, changing membrane qualities at each space. Membrane channels for sodium close to keep sodium ions out of the neuron and potassium channels open to allow potassium to move into the neuron, restoring the resting potential.

3. STRUCTURES AND FUNCTIONS IN THE HUMAN BRAIN
The brain stem structures are embedded within the core of the brain and provide a number of vital functions for survival. These include the medulla, pons, cerebellum, reticular formation, and the thalamus.

The medulla is a brain structure just above the spinal cord. It controls a number of life-sustaining reflexes and functions including breathing, coughing, vomiting, and heart rate. The pons lies just above the medulla and is particularly involved in sleep and arousal. The cerebellum is a large structure at the base of the brain with many folds. It is traditionally known to be involved in motor coordination and balance but also plays a role in attention of visual and auditory stimuli and the timing of movements. The reticular formation is an elaborate diffuse network of neurons that runs through the core of the medulla and pons to the base of the thalamus. It plays a role in arousal, attention, sleep patterns, and stereotyped patterns such as posture and locomotion. The thalamus is a central structure in the brain that relays auditory, visual, and somatosensory (body senses) information to the cerebral cortex.

The limbic system comprises a number of brain structures involved in motivation, emotion, and memory. The hypothalamus is a small structure that is located just below the thalamus. It controls the autonomic nervous system as well as the release of hormones from the pituitary gland. It is involved in a number of functions including eating, drinking, and sexual behavior, and plays an important role in the expression of emotions and stress responses. The hippocampus is located in the temporal lobe and plays a role in learning and memory. Adjacent to the hippocampus is the amygdala, which is involved in fear and anxiety. The cingulate gyrus, a beltlike structure in the middle of the brain, is involved in attention and cognitive control.

The cerebral cortex is the outer layer of the brain and is involved in higher-order functions such as thinking, learning, consciousness, and memory.

4. LOBES OF THE CEREBRAL CORTEX

The cerebral cortex is anatomically divided into four lobes: occipital lobe, parietal lobe, temporal lobe, and frontal lobe. The occipital lobe is located in the posterior end (back region) of the cortex and is involved in processing visual information. The parietal lobe makes up the top rear section of the cortex. The parietal lobe is involved in bodily senses. The area just in front of the parietal lobe is the somatosensory cortex. It is the primary target for the touch senses of the body and information for muscle-stretch receptors and joint receptors. The temporal lobe is the large portion of each hemisphere near the temples and lies behind the frontal lobe and below the lateral fissure. It is the primary region of the cortex that processes auditory information. The frontal lobe extends from the central sulcus to the anterior limit (forward region) of the brain. The region of the frontal lobe immediately adjacent to the central sulcus is called the motor cortex because it controls fine movements. The most anterior region is called the prefrontal cortex; it is involved in higher brain functions including cognition (thought processes), recent memory, the planning of movement, and some aspects of emotion.

5. VISUAL INFORMATION IN THE SPLITT BRAIN

Lateralization refers to the division of labor between the two cerebral hemispheres of the brain. The left hemisphere receives sensory information from and controls the movements in the right side of the body. Likewise, images of objects in the right visual field are projected to the left half of the retina of each eye, which in turn sends the information to the visual cortex in the left hemisphere. The left hemisphere also contains the main language area involved in the comprehension and production of language.

The right hemisphere receives sensory information from and controls the movements in the left side of the body. Likewise, images of objects in the left visual field are projected to the right half of the retina of each eye, which in turn sends the information to the visual cortex in the right hemisphere. The right hemisphere processes nonverbal information, such as perception, visual recognition, and emotion.

In the healthy brain the two cerebral hemispheres share information with each other across the broad band of axons called the corpus callosum. In some instances the corpus callosum is surgically cut, resulting in what is called a split brain. In the split brain, information in one cerebral hemisphere is confined to that side of the brain.

6. CENTRAL AND PERIPHERAL NERVOUS SYSTEMS

The nervous system is made up of the central nervous system and the peripheral nervous system. The central nervous system is comprised of the brain and the spinal cord. The peripheral nervous system consists of all nerve fibers outside of the brain and spinal cord. The peripheral nervous system is made up of two major divisions: the somatic nervous system and the autonomic nervous system.

The somatic nervous system consists of nerve fibers conveying information from the brain and spinal cord to skeletal muscles; this information controls movement and sends information back to the brain via the spinal cord from sensory receptors located in various parts of the body.

The autonomic nervous system controls the glands and muscles of the internal organs such as the heart, digestive system, lungs, and salivary glands, and it consists of the sympathetic and the parasympathetic branches. The sympathetic branch arouses the body, mobilizes its energy during physical exercise and in stressful situations, and activates the adrenal gland to release epinephrine into the bloodstream. The parasympathetic branch calms the body and conserves and replenishes energy.