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ROBERTO MATTA
Listen to Living, 1941

A 64-year-old, right-handed man was awakened by the sense that there was something strange in his bed. Opening his eyes, he observed to his horror that there was a strange arm reaching toward his neck. The arm approached nearer, as if to strangle him, and the man let out a cry of terror. Suddenly, he realized that the arm had on its wrist a silver-banded watch, which the man recognized to be his own. It occurred to him that the arm's possessor must have stolen his watch sometime during the night. A struggle ensued, as the man attempted to wrestle the watch off of the arm. During the struggle, the man became aware that his own left arm was feeling contorted and uncomfortable. It was then that he discovered that the strange arm in fact was his own. The watch was his, and it was on his own left wrist. He was wrestling with his own arm! (Tranel, 1995, p. 885)

What could account for such bizarre behavior? It was caused by a stroke that damaged the right side of the man's brain. This made him exhibit **unilateral neglect**, which involves difficulty in attending to one side (usually the left side) of one's body and of one's immediate environment (Deouell, Haemaelaenen, & Bentin, 2000). Victims of unilateral neglect often act as though one side of their world, including one side of their bodies, does not exist. A man with unilateral neglect might shave the right side of his face, but not the left, and might eat the pork chop on the right side of his plate but not the potatoes on the left. Figure 3.1 shows self-portraits painted by an artist, Anton Raederscheidt, whose paintings illustrate the effects of unilateral neglect. As in his case, unilateral neglect is usually self-limiting, typically lasting weeks or months (Harvey & Milner, 1999). Though unilateral neglect is more often found after damage to the right side of the brain, it is sometimes found in people with damage to the left side of the brain; they show neglect for objects in the right half of their spatial world (Weintraub et al., 1996).

Such profound effects of brain damage on physical and psychological functioning indicate that abilities we often take for granted require an intact, properly functioning brain. If you have an intact brain, as you read this page your eyes inform your brain about what you are reading. At the same time, your brain interprets the meaning of that information and stores some of it in your memory. When you reach the end of a right-hand page, your brain directs your hand to turn the page. But how do your eyes inform your brain about what you are reading? How does your brain interpret and store the information it receives? And how does your brain direct the movements of your hand? The answers to these questions are provided by the field of **behavioral neuroscience**, which studies the relationship between neurological processes (typically brain activity) and psychological functions (such as memory, emotion, and perception). Some behavioral neuroscientists are particularly interested in the influence of heredity on behavior.

◆ HEREDITY AND BEHAVIOR

Interest in behavioral neuroscience is not new. William James (1890/1981), in his classic psychology textbook *The Principles of Psychology*, stressed the close association between biology and psychology. James declared, "I have felt most acutely the difficulties of understanding either the brain without the mind or the mind without the brain" (Bjork, 1988, p. 107). James was influenced by Charles Darwin's (1859/1975) theory of evolution, which holds that individuals who are biologically well adapted to their environment are more

unilateral neglect

A disorder, caused by damage to a parietal lobe, in which the individual acts as though the side of her or his world opposite to the damaged lobe does not exist.

behavioral neuroscience

The field that studies the physiological bases of human and animal behavior and mental processes.



▲ Charles Darwin (1801–1882)

"I have called this principle, by which each slight variation, if useful, is preserved, by the term Natural Selection."



**Milestones in the History of
Neuroscience**

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► **Figure 3.1**
Unilateral Neglect

These self-portraits painted by the German artist Anton Raederscheidt were painted over a period of time following a stroke that damaged the cortex of his right parietal lobe. As his brain recovered, his attention to the left side of his world returned (Wurtz, Goldberg, & Robinson, 1982).



likely to survive, reproduce, and pass on their physical traits to succeeding generations through their genes. Thus, the human brain has evolved into its present form because it helped human beings in thousands of earlier generations adapt successfully to their surroundings and survive long enough to reproduce. Because of its remarkable flexibility in helping us adapt to different circumstances, the brain that helped ancient people survive without automobiles, grocery stores, or electric lights helps people today survive in the arctic, outer space, and New York City.

Evolutionary Psychology

To what extent are you the product of your heredity, and to what extent are you the product of your environment? This issue of “nature versus nurture” has been with us since the era of ancient Greece, when Plato championed nature and Aristotle championed nurture. Plato

Anatomy of a Research Study

Do Predispositions Molded by Evolution Affect Romantic Relationships?

Rationale

This study (Buss et al., 1992) tested David Buss's belief that evolution has left its mark on human behavior, even in the area of heterosexual romance. Women can be sure that their newborns are truly theirs, but men cannot, so Buss hypothesized that men would exhibit more jealousy in response to an intimate partner's sexual infidelity than to her emotional infidelity. Because prehistoric women were, on the average, physically weaker and more responsible for caring for their children, and depended on men to support them after giving birth, Buss hypothesized that women would exhibit more jealousy in response to an intimate partner's emotional infidelity than to his sexual infidelity. Buss assumes that these differences are the product of thousands of generations of natural selection.

Method

Participants were 202 male and female undergraduate students. They were asked which of the following two alternatives would distress them more: their romantic partner forming a deep emotional attachment to someone else or that partner enjoying passionate sexual intercourse with someone else. The participants also were asked to respond to a similar dilemma in which their romantic partner either fell in love with another person or tried a variety of sexual positions with that person.

Results and Discussion

The results showed that for the first dilemma 60 percent of the male participants reported greater jealousy over their partner's potential sexual infidelity. In contrast, 83 percent of the female participants reported greater jealousy over their partner's potential emotional infidelity. The second dilemma brought out the same pattern of responses. Of course, cultural interpretations of male sexual jealousy and female emotional jealousy are possible. But the researchers pointed to the commonness of these gender differences in sexual and emotional jealousy as evidence of its possible hereditary basis.

These findings have been replicated in research studies across different cultures: men tend to be more sexually jealous and women tend to be more emotionally jealous (Buss et al., 1999; Wiederman & Kendall, 1999). But the degree of the difference in female and male responses to sexual and emotional infidelity varies across cultures and ideologies. In one study, for example, gender differences in the two kinds of jealousy were stronger in the United States than in Germany or the Netherlands (Buunk et al., 1996). Another study found that gender differences in sexual and emotional jealousy were greater among undergraduates who believed in gender inequality (Pratto & Hegarty, 2000). As you can see, research findings can be equally compatible with an evolutionary interpretation and a social-cultural interpretation (Wood & Eagly, 2000).

believed we are born with some knowledge; Aristotle believed that at birth our mind is a blank slate (or *tabula rasa*) and that life experiences provide us with knowledge.

In modern times, the argument became even more heated after Charles Darwin put forth his theory of evolution in the mid 19th century. Darwin noted that animals and human beings vary in their physical traits. Given the competition for resources (including food and water) and the need to foil predators (by defeating them or escaping from them), animals and human beings with physical traits best adapted to these purposes would be the most likely to survive long enough to produce offspring, who would likely also have those traits. As long as particular physical traits provide a survival advantage, those traits will have a greater likelihood of showing up in succeeding generations. Darwin called this process *natural selection*. Psychologists who champion **evolutionary psychology** employ Darwinian concepts in their research and theorizing. The possible role of evolution in human social relationships inspired the study by evolutionary psychologist David Buss and his colleagues Randy Larsen, Drew Westen, and Jennifer Semmelroth at the University of Michigan (Buss et al., 1992) that you can read about in the Anatomy of a Research Study feature.



Human Behavior and
Evolution Society

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evolutionary psychology

The study of the evolution of behavior through natural selection.

► “Not guilty by reason of genetic determinism, Your Honor.”

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behavioral genetics

The study of the effects of heredity and life experiences on behavior.

Human Genome Project Information

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genotype

An individual's genetic inheritance.

phenotype

The overt expression of an individual's genotype (genetic inheritance) in his or her appearance or behavior.

Behavioral Genetics

Beginning in the 1970s, psychology has seen the growth of **behavioral genetics**, which studies how heredity affects behavior. Research in behavioral genetics has found evidence of a hereditary basis for characteristics as diverse as divorce (Jocklin, McGue, & Lykken, 1996), empathy (Plomin, 1994), and intelligence (Petrill & Wilkerson, 2000).

To appreciate behavioral genetics, it helps to have a basic understanding of genetics itself. The cells of the human body contain 23 pairs of *chromosomes*, which are long strands of *deoxyribonucleic acid (DNA)* molecules. (Unlike the other body cells, the egg cell and sperm cell each contains 23 single chromosomes.) DNA molecules are ribbon-like structures composed of segments called *genes*. Genes direct the synthesis of *ribonucleic acid (RNA)*. RNA, in turn, directs the synthesis of proteins, which are responsible for the structure and function of our tissues and organs.

Though our genes direct our physical development, their effects on our behavior are primarily indirect (Mann, 1994). There are, for example, no “motorcycle daredevil genes.” Instead, genes influence physiological factors, such as hormones, neurotransmitters, and brain structures. These factors, in turn, make people somewhat more likely to engage in particular behaviors. Perhaps people destined to become motorcycle daredevils inherit a less physiologically reactive nervous system, making them experience less anxiety in dangerous situations. Moreover, given current trends in molecular genetics, behavioral geneticists are on the threshold of identifying genes that affect behavior (Plomin & Crabbe, 2000). For example, the ambitious Human Genome Project aims to identify the structure and functions of all human genes, with scientists estimating that there are more than 30,000 genes to be identified. Most researchers in behavioral genetics prefer to search for the effects of interactions among these genes, rather than single-gene effects, as influences on behavior (Wahlsten, 1999). This holds promise for the prevention and treatment of physical and psychological disorders with possible genetic bases, such as obesity (see Chapter 11) and schizophrenia (see Chapter 14).

Our outward appearance and behavior might not indicate our exact genetic inheritance. In recognition of this, scientists distinguish between our genotype and our phenotype. Your **genotype** is your genetic inheritance. Your **phenotype** is the overt expression of your inheritance in your appearance or behavior. For example, your eye color is determined by the interaction of a gene inherited from your mother and a gene inherited from your father. The brown-eye gene is *dominant*, and the blue-eye gene is *recessive*. Dominant genes take precedence over recessive genes. Traits carried by recessive genes show up in phenotypes only when recessive genes occur together. If you are blue-eyed, your genotype includes two



◀ “In extenuation, Your Honor, I would like to suggest to the court that my client was inadequately parented.”

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blue-eye genes (both recessive). If you have brown eyes, your genotype could include two brown-eye genes (both dominant) or one brown-eye gene (dominant) and one blue-eye gene (recessive).

In contrast to simple traits like eye color, most characteristics are governed by more than one pair of genes—that is, they are *polygenic*. With rare exceptions, this is especially true of genetic influences on human behaviors and abilities. Your athletic, academic, and social skills depend on the interaction of many genes, as well as your life experiences. For example, your muscularity (your phenotype) depends on both your genetic endowment (your genotype) and your dietary and exercise habits (your life experiences).

If you understand the concept of heritability, you will be able to appreciate research studies that try to determine the relative contributions of heredity and environment to human development. **Heritability** refers to the proportion of variability in a trait across a population attributable to genetic differences among members of the population (Turkheimer, 1998). For example, human beings differ in their intelligence (as measured by IQ tests). To what extent is this variability caused by heredity, and to what extent is it caused by experience? Heritability values range from 0.0 to 1.0. If heritability accounted for none of the variability in intelligence, it would have a value of 0.0. If heritability accounted for all of the variability in intelligence, it would have a value of 1.0. In reality, the heritability of intelligence, as measured by IQ tests, is estimated to be between .50 (Chipuer, Rovine, & Plomin, 1990) and .70 (Bouchard et al., 1990). This indicates that the variability in intelligence is strongly, but not solely, influenced by heredity. Environmental factors also account for much of the variability. Note that heritability applies to groups, not to individuals. The concept cannot be used, for example, to determine the relative contributions of heredity and environment to your own intelligence. Research procedures that assess the relative contributions of nature and nurture involve the study of relatives. These include studies of families, adoptees, and identical twins reared apart.

heritability

The proportion of variability in a trait across a population attributable to genetic differences among members of the population.

Family Studies

Family studies investigate similarities between relatives with varying degrees of genetic similarity. These studies find that the closer the genetic relationship (that is, the more genes that are shared) between relatives, the more alike they tend to be on a variety of traits. For example, the siblings of a person who has schizophrenia are significantly more likely to have schizophrenia than are the person’s cousins. Though it is tempting to attribute this to their degree of genetic similarity, one cannot rule out that it is instead due to their degree of environmental similarity.

The best kind of family study is the *twin study*, which compares identical (or *monozygotic*) twins to fraternal (or *dizygotic*) twins. This kind of study was introduced by Francis Galton (1822–1911), who found more similarity between identical twins than between fraternal twins—and attributed this to heredity. Identical twins, because they come from the same fertilized egg, have the same genetic inheritance. Fraternal twins, because they come from different fertilized eggs, do not. They merely have the same degree of genetic similarity as non-twin siblings. Moreover, twins, whether identical or fraternal, are born at the same time and share similar environments. Because research has found that identical twins reared in similar environments are more psychologically similar than fraternal twins reared in similar environments, it is reasonable to attribute the greater similarity of identical twins to heredity. Twin studies have been consistent across cultures in supporting the heritability of psychological characteristics, as in studies of the personality of twins in Russia (Saudino et al., 1999), sexual orientation and conformity to gender roles in Australian twins (Bailey, Dunne, & Martin, 2000), and schizophrenia in twins in Finland (Cannon et al., 1999). Nonetheless, there is an alternative, environmental explanation. Perhaps identical twins become more psychologically similar because they are treated more alike than fraternal twins are.

Adoption Studies

Superior to family studies are *adoption studies*, which measure the correlation in particular traits between adopted children and their biological parents and between those same adopted children and their adoptive parents. Adoption studies have found that adoptees are more similar to their biological parents than to their adoptive parents in traits such as body fat (Price & Gottesman, 1991), drug abuse (Cadoret et al., 1995), vocational interests (Lykken et al., 1993), and religious values (Waller et al., 1990). These findings indicate that, with regard to such traits, the genes that adoptees inherit from their biological parents affect their development more than does the environment they are provided with by their adoptive parents.

Yet the environment cannot be ruled out as an explanation for the greater similarity between adoptees and their biological parents. As explained in Chapter 4, prenatal experiences can affect children’s development. Perhaps adoptees are more like their biological parents, not because they share the same genes, but because the adoptees spent their prenatal months in their biological mother’s womb, making them subject to their mother’s drug habits, nutritional intake, or other environmental influences. Moreover, their experiences with their biological parents in early infancy, before they were adopted, might affect their development, possibly making them more similar to their biological parents.

Studies of Identical Twins Reared Apart

Perhaps the best procedure is to study *identical twins reared apart*. Research on a variety of traits consistently finds higher positive correlations between identical twins reared apart than between fraternal twins reared together. Because identical twins share identical genes, virtually identical prenatal environments, and highly similar neonatal environments, this provides strong evidence in favor of the nature side of the debate. This has been supported by a widely publicized study conducted at the University of Minnesota, which has examined similarities between identical twins who were separated in infancy and reunited later in life. As part of the University of Minnesota study of twins reared apart, researchers administered a personality test to 71 pairs of identical and 53 pairs of fraternal adult twins reared apart and 99 pairs of identical and 99 pairs of fraternal adult twins reared together. The results found that the heritability estimate for personality was 0.46, indicating that heredity plays an important, but not dominant, role in personality (Bouchard et al., 1998).

The University of Minnesota study has found some uncanny similarities in the habits, abilities, and physiological responses of the reunited twins (Bouchard et al., 1990). For example, one pair of twins at their first reunion discovered that they “both used Vademe-cum toothpaste, Canoe shaving lotion, Vitalis hair tonic, and Lucky Strike cigarettes. After that meeting, they exchanged birthday presents that crossed in the mail and proved to be identical choices, made independently in separate cities” (Lykken et al., 1992, p. 1565).

But some of these similarities might be due to coincidence or being reared in similar environments or having some contact with each other before being studied. In fact, research

on even unrelated people sometimes show moderately strong similarities in their personality traits (Wyatt, 1993). Moreover, identical twins look the same and might elicit responses from others that indirectly lead to their developing similar interests and personalities. Consider how we treat obese people, muscular people, attractive people, and people with acne. Thus, identical twins who share certain physical traits might become more similar than ordinary siblings who do not share such traits—even when reared in different cultures (Ford, 1993). As you can see, no kind of study is flawless in demonstrating the superiority of heredity over environment in guiding development.

Regardless of the influence of heredity on development, behavioral genetics researcher Robert Plomin reminds us that life experiences are also important. In one study, personality test scores of identical and fraternal twins were compared at an average of 20 years of age and then at 30 years of age. The conclusion was that the stable core of personality is strongly influenced by heredity but that personality change is overwhelmingly influenced by environment (McGue, Bacon, & Lykken, 1993). Thus, heredity might have provided you with the intellectual potential to become a Nobel Prize winner, but without adequate academic experience in childhood you might not perform well enough even to graduate from college.

STAYING ON TRACK: *Heredity and Behavior*

1. What is behavioral neuroscience?
2. Why are the greater physical, cognitive, and personality similarities among relatives than among nonrelatives not enough to demonstrate conclusively that they are the product of heredity?

Answers to Staying on Track start on p. S-1

◆ COMMUNICATION SYSTEMS

Biopsychological activity is regulated by two major bodily communication systems: the *nervous system* and the *endocrine system*. These systems regulate biopsychological functions as varied as hunger, memory, sexuality, and emotionality.

The Nervous System

The brain is part of the **nervous system**, the chief means of communication within the body. The nervous system is composed of **neurons**, cells that are specialized for the transmission and reception of information. As illustrated in Figure 3.2, the two divisions of the nervous system are the *central nervous system* and the *peripheral nervous system*.

The Central Nervous System

The **central nervous system** comprises the *brain* and the *spinal cord*. The brain, protectively housed in the skull, is so important in psychological functioning that most of this chapter and many other sections of this book are devoted to it. As you will learn, the **brain** is intimately involved in learning, thinking, language, memory, emotion, motivation, body movements, social relationships, psychological disorders, perception of the world, and even immune-system activity.

The **spinal cord**, which runs through the bony, protective spinal column, provides a means of communication between the brain and the body. Motor output from the brain travels down the spinal cord to direct activity in muscles and certain glands. Sensory input from pain, touch, pressure, and temperature receptors in the body travels up the spinal cord to the brain, informing it of the state of the body. Damage to the spinal cord can have catastrophic effects. You might know people who have suffered a spinal-cord injury in a diving, vehicular, or contact-sport accident, causing them to lose the ability to move their limbs or feel bodily sensations below the point of the injury. Emotional reactions to spinal cord injuries

nervous system

The chief means of communication in the body.

neuron

A cell specialized for the transmission of information in the nervous system.

central nervous system

The division of the nervous system consisting of the brain and the spinal cord.

brain

The structure of the central nervous system that is located in the skull and plays important roles in sensation, movement, and information processing.

spinal cord

The structure of the central nervous system that is located in the spine and plays a role in bodily reflexes and in communicating information between the brain and the peripheral nervous system.

► **Figure 3.2**
The Organization of the Nervous System

The nervous system comprises the brain, spinal cord, and nerves.

reflex

An automatic, involuntary motor response to sensory stimulation.

peripheral nervous system

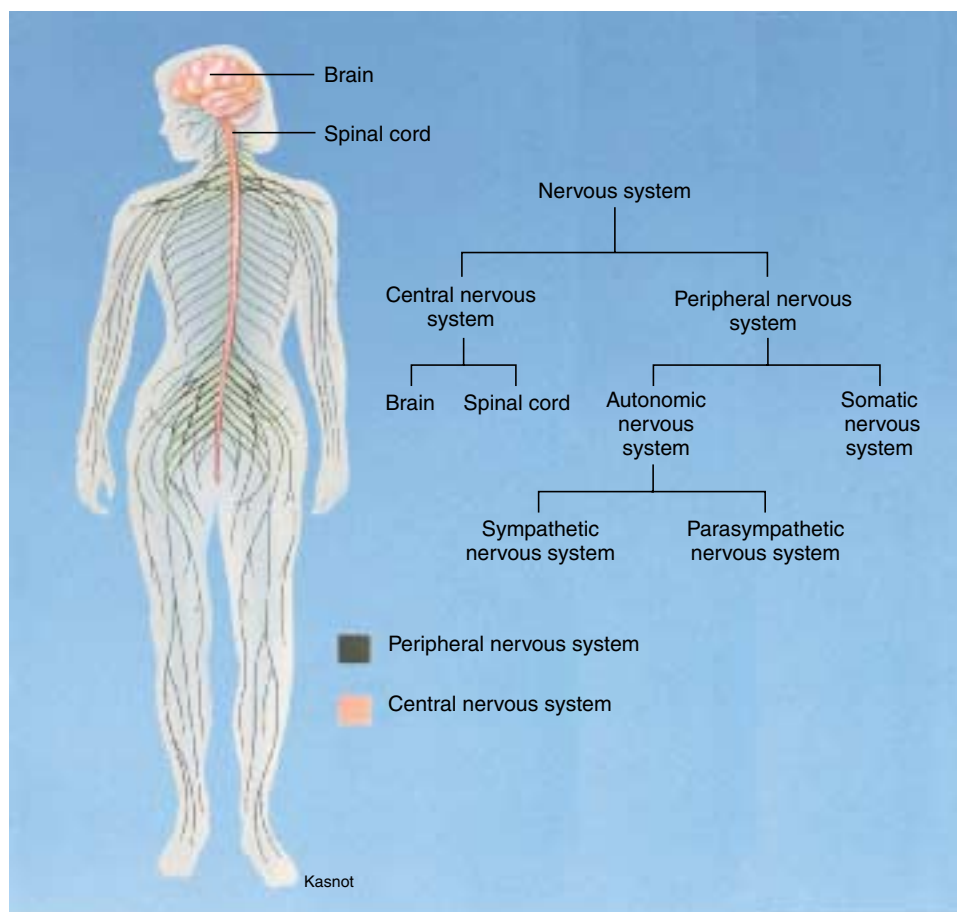
The division of the nervous system that conveys sensory information to the central nervous system and motor commands from the central nervous system to the skeletal muscles and internal organs.

nerve

A bundle of axons that conveys information to or from the central nervous system.

somatic nervous system

The division of the peripheral nervous system that sends messages from the sensory organs to the central nervous system and messages from the central nervous system to the skeletal muscles.



 **Spinal Cord Injury Links**
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▲ **Spinal Cord Damage**

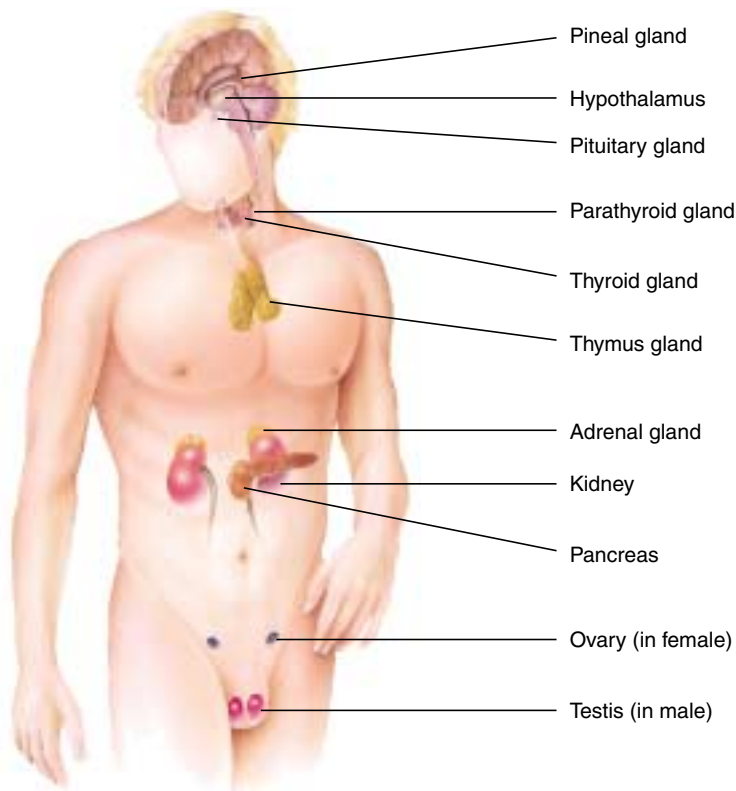
A fall from a horse broke the neck and severed the spinal cord of Christopher Reeve, famous for portraying Superman in several movies. The accident left him a quadriplegic, with little or no feeling or voluntary movement in his limbs.

show the influence of gender and culture. Two studies of people with spinal cord injuries in Southern California found that the men reported more distress over interpersonal problems than did the women (Krause, 1998). Moreover, severe depression was more common among Latinos than among European Americans or African Americans (Kemp, Krause, & Adkins, 1999). Recent research on the transplantation of healthy nerve tissue into damaged spinal cords of animals indicates that scientists might be on the threshold of discovering effective means of restoring motor and sensory functions to people who have suffered spinal cord injuries (Kim et al., 1999).

As discussed in the next section, the spinal cord also plays a role in limb reflexes. A **reflex** is an automatic, involuntary motor response to sensory stimulation. Thus, when you step on a sharp, broken shell at the beach, you immediately pull your foot away. This occurs at the level of the spinal cord; it does not require input from the brain.

The Peripheral Nervous System

The **peripheral nervous system** contains the **nerves**, which provide a means of communication between the central nervous system and the sensory organs, skeletal muscles, and internal bodily organs. The peripheral nervous system comprises the *somatic nervous system* and the *autonomic nervous system*. The **somatic nervous system** includes *sensory nerves*, which send messages from the sensory organs to the central nervous system, and *motor nerves*, which send messages from the central nervous system to the skeletal muscles. The **autonomic nervous system** controls automatic, involuntary processes (such as sweating, heart contractions, and intestinal activity) through the action of its two subdivisions: the *sympathetic nervous system* and the *parasympathetic nervous system*. The **sympathetic nervous system** arouses the body to prepare it for action, and the **parasympathetic nervous system** calms the body to conserve energy.



◀ **Figure 3.3**
The Endocrine System

Hormones secreted by the endocrine glands affect metabolism, behavior, and mental processes.

Imagine that you are playing a tennis match. Your sympathetic nervous system speeds up your heart rate to pump more blood to your muscles, makes your liver release sugar into your bloodstream for quick energy, and induces sweating to keep you from overheating. As you cool down after the match, your parasympathetic nervous system slows your heart rate and constricts the blood vessels in your muscles to divert blood for use by your internal organs. Chapter 12 describes the role of the autonomic nervous system in emotional responses and includes a diagram (Figure 12.1) illustrating its effects on various bodily organs. Chapter 16 explains how chronic activation of the sympathetic nervous system can contribute to the development of stress-related diseases.

The Endocrine System

The glands of the **endocrine system**, the other major means of communication within the body, exert their functions through chemicals called **hormones**. The endocrine glands secrete hormones into the bloodstream, which transports them to their site of action. The actions of the endocrine system are slower, longer lasting, and more diffuse than those of the nervous system. This contrasts with *exocrine glands*, such as the sweat glands and salivary glands, which secrete their chemicals onto the body surface or into body cavities. Endocrine secretions have many behavioral effects, but exocrine secretions have few. Figure 3.3 illustrates the locations of several endocrine glands. Hormones can act directly on body tissues, serve as neurotransmitters, or modulate the effects of neurotransmitters.

The Pituitary Gland

The **pituitary gland**, an endocrine gland protruding from underneath the brain, regulates many of the other endocrine glands by secreting hormones that affect their activity. This is why the pituitary is known as the “master gland.” The pituitary gland, in turn, is regulated by the brain structure called the *hypothalamus*. Feedback from circulating hormones stimulates the hypothalamus to signal the pituitary gland to increase or decrease their secretion.

Pituitary hormones also exert a wide variety of direct effects. For example, *prolactin* stimulates milk production in lactating women. Because an elevated prolactin level is also

autonomic nervous system

The division of the peripheral nervous system that controls automatic, involuntary physiological processes.

sympathetic nervous system

The division of the autonomic nervous system that arouses the body to prepare it for action.

parasympathetic nervous system

The division of the autonomic nervous system that calms the body and performs maintenance functions.

endocrine system

Glands that secrete hormones into the bloodstream.

hormones

Chemicals, secreted by endocrine glands, that play a role in a variety of functions, including synaptic transmission.

pituitary gland

An endocrine gland that regulates many of the other endocrine glands by secreting hormones that affect the secretion of their hormones.

associated with both infertility and psychological stress, prolactin might be involved in stress-related infertility. This indicates that women who are highly anxious about their inability to become pregnant might enter a vicious cycle in which their anxiety increases the level of prolactin, which in turn makes them less likely to conceive (Edelmann & Golombok, 1989). This might explain anecdotal reports of couples who, after repeatedly failing to conceive a child, finally adopt a child, only to have the woman become pregnant soon after—perhaps because her anxiety decreased after the adoption.

Growth hormone, another pituitary hormone, aids the growth and repair of bones and muscles. A child who secretes too much growth hormone might develop *giantism*, marked by excessive growth of the bones. A child who secretes insufficient growth hormone might develop *dwarfism*, marked by stunted growth. Giantism and dwarfism do not impair intellectual development. Though it might seem logical to administer growth hormone to increase the height of very short children who are not diagnosed with dwarfism, this is unwise because the long-term side effects are unknown (Tauer, 1994).

Other Endocrine Glands

Among the other psychologically relevant endocrine glands are the *adrenal glands* and the *gonads*. The **adrenal glands**, which lie on the kidneys, secrete important hormones. The *adrenal cortex*, the outer layer of the adrenal gland, secretes hormones, such as *aldosterone*, that regulate the excretion of sodium and potassium, which contribute to proper neural functioning. The adrenal cortical hormone *cortisol* helps the body respond to stress by stimulating the liver to release sugar. People under chronic stress, perhaps from jobs in which they have little control over their workload, might show an increase in their secretion of cortisol (Steptoe et al., 2000).

In response to stimulation by the sympathetic nervous system, the *adrenal medulla*, the inner core of the adrenal gland, secretes *epinephrine* and *norepinephrine*, which function as both hormones and neurotransmitters. Epinephrine increases heart rate; as noted earlier, norepinephrine is the neurotransmitter in the sympathetic nervous system that arouses the body to take action. For example, married couples (especially wives) show increases in epinephrine and norepinephrine during conflicts with their spouses (Kiecolt-Glaser et al., 1996).

The **gonads**, the sex glands, affect sexual development and behavior. The **testes**, the male gonads, secrete *testosterone*, which regulates the development of the male reproductive system and secondary sex characteristics. The **ovaries**, the female gonads, secrete *estrogens*, which regulate the development of the female reproductive system and secondary sex characteristics. The ovarian hormone *progesterone* regulates changes in the uterus that can maintain pregnancy. During prenatal development sex hormones also affect certain structures and functions of the brain. The effects of sex hormones, including their possible role in psychological gender differences (Berenbaum & Snyder, 1995), are discussed in Chapters 4 and 11.

Anabolic steroids, synthetic forms of testosterone, have provoked controversy during the past few decades. They have been used by athletes, bodybuilders, and weightlifters to promote muscle development, increase endurance, and boost self-confidence. Yet studies have shown inconsistent effects of steroids on physical strength. For example, it is unclear whether anabolic steroids directly increase strength or do so through a placebo effect, in which users work out more regularly and more vigorously simply because they have faith in the effectiveness of steroids (Maganaris, Collins, & Sharp, 2000). Moreover, anabolic steroids appear to have dangerous side effects, including increased aggressiveness. For example, male weightlifters who go on and off steroids are more verbally and physically abusive toward their wives and girlfriends when they are using steroids than when they are not (Choi & Pope, 1994).

adrenal glands

Endocrine glands that secrete hormones that regulate the excretion of minerals and the body's response to stress.

gonads

The male and female sex glands.

testes

The male gonads, which secrete hormones that regulate the development of the male reproductive system and secondary sex characteristics.

ovaries

The female gonads, which secrete hormones that regulate the development of the female reproductive system and secondary sex characteristics.



Anabolic Steroids

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STAYING ON TRACK: *Communication Systems*

1. What are the divisions of the nervous system?
2. What is the difference between exocrine glands and endocrine glands?
3. What are the effects of adrenal hormones?

Answers to Staying on Track start on p. S-1.

◆ THE NEURON

You are able to read this page because *sensory neurons* are relaying input from your eyes to your brain. You will be able to turn the page because *motor neurons* from your spinal cord are sending commands from your brain to the muscles of your hand. **Sensory neurons** send messages to the brain or spinal cord. **Motor neurons** send messages to the glands, the cardiac muscle, and the skeletal muscles, as well as to the smooth muscles of the arteries, small intestine, and other internal organs. Illnesses that destroy motor neurons, such as *amyotrophic lateral sclerosis* (also known as Lou Gehrig’s disease, after the great baseball player struck down by it), cause muscle paralysis (Andreassen et al., 2000).

The nervous system contains 10 times more *glial cells* than neurons. **Glial cells** provide a physical support structure for the neurons (*glial* comes from the Greek word for “glue”). Glial cells also supply neurons with nutrients, remove neuronal metabolic waste, and help regenerate damaged neurons in the peripheral nervous system. Recent research indicates that glial cells might even facilitate the transmission of messages by neurons (Coyle & Schwarcz, 2000).

To appreciate the role of neurons in communication within the nervous system, consider the functions of the spinal cord. Neurons in the spinal cord convey sensory messages from the body to the brain and motor messages from the brain to the body. In 1730 the English scientist Stephen Hales demonstrated that the spinal cord also plays a role in limb reflexes. He decapitated a frog (to eliminate any input from the brain) and then pinched one of its legs. The leg reflexively pulled away. Hales concluded the pinch had sent a signal to the spinal cord, which in turn sent a signal to the leg, eliciting its withdrawal. We now know that this limb-withdrawal reflex involves sensory neurons that convey signals from the site of stimulation to the spinal cord, where they transmit their signals to **interneurons** in the spinal cord. The interneurons then send signals to motor neurons, which stimulate flexor muscles to contract and pull the limb away from the source of stimulation—making you less susceptible to injury.

To understand how neurons communicate information, it will help to become familiar with the structure of the neuron (see Figure 3.4). The **soma** (or *cell body*) contains the nucleus, which directs the neuron to act as a nerve cell rather than as a fat cell, a muscle cell, or any other kind of cell. The **dendrites** (from the Greek word for “tree”) are short, branching fibers that receive neural impulses. The dendrites are covered by bumps called *dendritic spines*, which provide more surface area for the reception of neural impulses from other neurons. The **axon** is a single fiber that sends neural impulses. Axons range from a tiny fraction

sensory neuron

A neuron that sends messages from sensory receptors to the central nervous system.

motor neuron

A neuron that sends messages from the central nervous system to smooth muscles, cardiac muscle, or skeletal muscles.

glial cell

A kind of cell that provides a physical support structure for the neurons, supplies them with nutrition, removes neuronal metabolic waste materials, facilitates the transmission of messages by neurons, and helps regenerate damaged neurons in the peripheral nervous system.

interneuron

A neuron that conveys messages between neurons in the brain or spinal cord.

soma

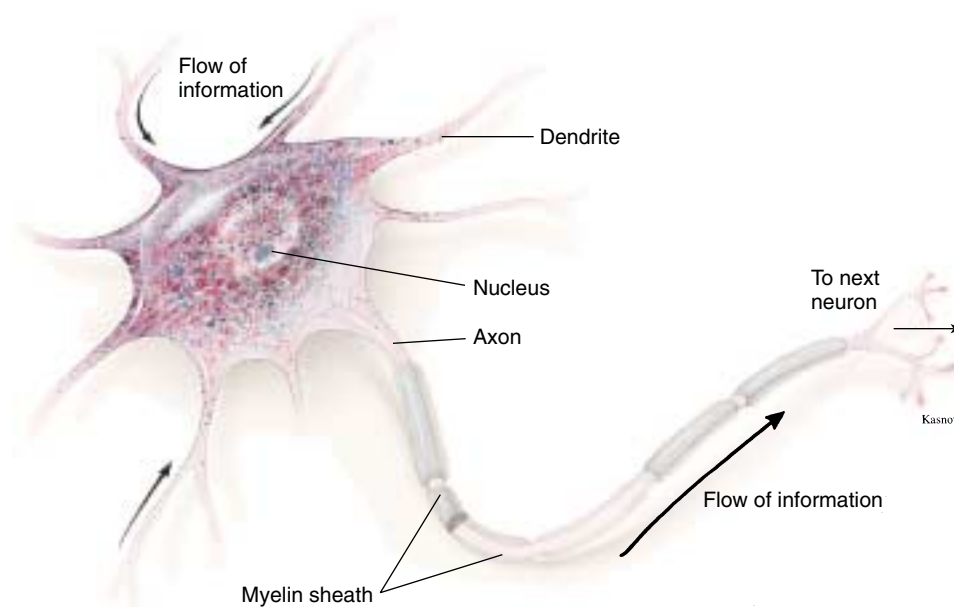
The cell body, the neuron’s control center.

dendrites

The branchlike structures of the neuron that receive neural impulses.

axon

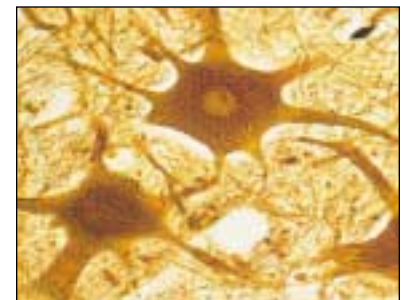
The part of the neuron that conducts neural impulses to glands, muscles, or other neurons.



◀ Figure 3.4

The Neuron

Both the drawing and the photograph show the structure of the motor neuron. Neurons have dendrites that receive signals from other neurons or sensory receptors, a cell body that controls cellular functions, and an axon that conveys signals to skeletal muscles, internal organs, or other neurons.



of an inch (as in the brain) to more than 3 feet in length (as in the legs of a 7-foot-tall basketball player). Just as bundles of wires form telephone cables, bundles of axons form the nerves of the peripheral nervous system. A nerve can contain motor neurons or sensory neurons, or both.

The Neural Impulse

How does the neuron convey information? It took centuries of investigation by some of the most brilliant minds in the history of science to find the answer. Before the neuron was discovered in the 19th century, scientists were limited to studying the functions of nerves. In these studies, they typically were influenced by their other research interests. The first significant discovery regarding nerve conduction came in 1786, when Italian physicist Luigi Galvani (1737–1798) gave demonstrations hinting that the nerve impulse is electrical in nature. Galvani found that by touching the leg of a freshly killed frog with two different metals, such as iron and brass, he could create an electrical current that made the leg twitch. He believed he had discovered the basic life force—electricity. Some of Galvani’s followers, who hoped to use electricity to raise the dead, obtained the fresh corpses of hanged criminals and stimulated them with electricity. To the disappointment of these would-be resurrectors, they failed to induce more than the flailing of limbs (Hassett, 1978). Not much later, another of Galvani’s contemporaries, Mary Shelley, applied what she called “galvanism” (apparently, the use of electricity) to revive the dead in her classic novel, *Frankenstein*.

Though Galvani and his colleagues failed to demonstrate that electricity was the basic life force, they put scientists on the right track toward understanding how neural impulses are conveyed in the nervous system. But it took almost two more centuries of research before scientists identified the exact mechanisms. We now know that neuronal activity, whether involved in hearing a doorbell, throwing a softball, or recalling a childhood memory, depends on electrical-chemical processes, beginning with the *resting potential*.

The Resting Potential

In 1952, English scientists Alan Hodgkin and Andrew Huxley, using techniques that let them study individual neurons, discovered the electrical-chemical nature of the processes that underlie **axonal conduction**, the transmission of a *neural impulse* along the length of the axon. In 1963 Hodgkin and Huxley won the Nobel Prize for physiology and medicine for their discovery (Lamb, 1999). Hodgkin and Huxley found that in its inactive state, the neuron maintains an electrical **resting potential**, produced by differences between the *intracellular fluid* inside of the neuron and the *extracellular fluid* outside of the neuron. These fluids contain *ions*, which are positively or negatively charged molecules. In regard to the resting potential, the main positive ions are *sodium* and *potassium*, and the main negative ions are *proteins* and *chloride*.

The *neuronal membrane*, which separates the intracellular fluid from the extracellular fluid, is *selectively permeable* to ions. This means that some ions pass back and forth through tiny *ion channels* in the membrane more easily than do others. Because ions with like charges repel each other and ions with opposite charges attract each other, you might assume the extracellular fluid and intracellular fluid would end up with the same relative concentrations of positive ions and negative ions. But, because of several complex processes, the intracellular fluid ends up with an excess of negative ions and the extracellular fluid ends up with an excess of positive ions. This makes the inside of the resting neuron negative relative to the outside, so the membrane is said to be *polarized*, just like a battery. For example, at rest the inside of a motor neuron has a charge of -70 millivolts relative to its outside. (A millivolt is one one-thousandth of a volt.)

The Action Potential

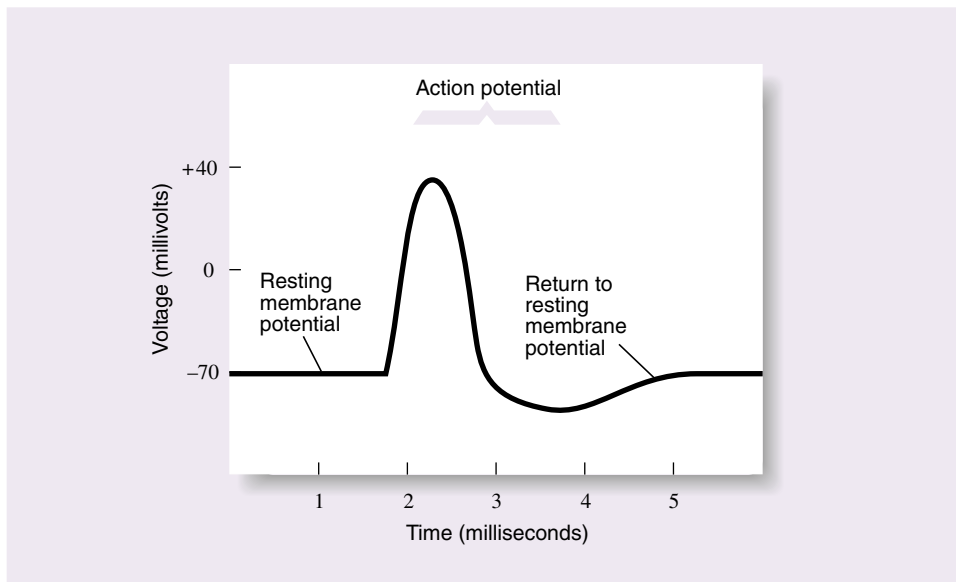
When a neuron is stimulated sufficiently by other neurons or by a sensory organ, it stops “resting.” The neuronal membrane becomes more permeable to positively charged sodium ions, which, attracted by the negative ions inside, rush into the neuron. This makes the inside of the neuron less electrically negative relative to the outside, a process called *depolarization*.

axonal conduction

The transmission of a neural impulse along the length of an axon.

resting potential

The electrical charge of a neuron when it is not firing a neural impulse.



◀ **Figure 3.5**
The Action Potential

During an action potential, the inside of the axon becomes electrically positive relative to the outside, but quickly returns to its normal resting state, with the inside again electrically negative relative to the outside.

As sodium continues to rush into the neuron, and the inside becomes less and less negative, the neuron reaches its *firing threshold* (about -60 millivolts in the case of a motor neuron) and an *action potential* occurs at the point where the axon leaves the cell body.

An **action potential** is a change in the electrical charge across the axonal membrane, with the inside of the membrane becoming more electrically positive than the outside and reaching a charge of $+40$ millivolts. Once an action potential has occurred, that point on the axonal membrane immediately restores its resting potential through a process called *repolarization*. This occurs, in part, because the sudden excess of positively charged sodium ions inside the axon repels the positive potassium ions, driving many of them out of the axon. This loss of positively charged ions helps return the inside of the axon to its negatively charged state relative to the outside. The restored resting potential is also maintained by chemical “pumps” that transport sodium and potassium ions across the axonal membrane, returning them to their original concentrations. Figure 3.5 illustrates the electrical changes that occur during the action potential.

If an axon fails to depolarize enough to reach its firing threshold, no action potential occurs—not even a weak one. If you have ever been under general anesthesia, you became unconscious because you were given a drug that prevented the axons in your brain that are responsible for the maintenance of consciousness from depolarizing enough to fire off action potentials (Nicoll & Madison, 1982). When an axon reaches its firing threshold and an action potential occurs, a neural impulse travels the entire length of the axon at full strength, as sodium ions rush in at each successive point along the axon. This is known as the **all-or-none law**. It is analogous to firing a gun: If you do not pull the trigger hard enough, nothing happens; but if you do pull the trigger hard enough, the gun fires and a bullet travels down the entire length of its barrel.

Thus, when a neuron reaches its firing threshold, a neural impulse travels along its axon, as each point on the axonal membrane depolarizes (producing an action potential) and then repolarizes (restoring its resting potential). This process of depolarization/repolarization is so rapid that an axon might conduct up to 1,000 neural impulses a second. The loudness of sounds you hear, the strength of your muscle contractions, and the level of arousal of your brain all depend on the number of neurons involved in those processes and the rate at which they conduct neural impulses.

The speed at which the action potential travels along the axon varies from less than 1 meter per second in certain neurons to more than 100 meters per second in others. The speed depends on several factors, most notably whether sheaths of a white fatty substance called **myelin** (which is produced by glial cells) are wrapped around the axon (Miller, 1994). At frequent intervals along myelinated axons, tiny areas are nonmyelinated. These are called

action potential

A series of changes in the electrical charge across the axonal membrane that occurs after the axon has reached its firing threshold.

all-or-none law

The principle that once a neuron reaches its firing threshold, a neural impulse travels at full strength along the entire length of its axon.

myelin

A white fatty substance that forms sheaths around certain axons and increases the speed of neural impulses.



▲ **Santiago Ramón y Cajal (1852–1934)**

“For all those who are fascinated by the bewitchment of the infinitely small, there wait in the bosom of the living being millions of palpitating cells which, for the surrender of their secret, and with it the halo of fame, demand only a clear and persistent intelligence to contemplate, admire, and understand them.”

synaptic transmission

The conveying of a neural impulse between a neuron and a gland, muscle, sensory organ, or another neuron.

synapse

The junction between a neuron and a gland, muscle, sensory organ, or another neuron.

nodes. In myelinated axons, such as those forming much of the brain and spinal cord, as well as the motor nerves that control our muscles, the action potential jumps from node to node, instead of traveling from point to point along the entire axon. This explains why myelinated axons conduct neural impulses faster than nonmyelinated axons.

If you were to look at a freshly dissected brain, you would find that the inside appeared mostly white and the outside appeared mostly gray, because the inside contains many more myelinated axons. You would be safe in concluding that the brain’s white matter conveyed information faster than its gray matter. Some neurological disorders are associated with abnormal myelin conditions. In the disease *multiple sclerosis*, portions of the myelin sheaths in neurons of the brain and spinal cord are destroyed, causing muscle weakness, sensory disturbances, memory loss, and cognitive deterioration as a result of the disruption of normal axonal conduction (Bitsch et al., 2000).

To summarize, a neuron maintains a *resting potential* during which its inside is electrically negative relative to its outside. Stimulation of the neuron makes positive sodium ions rush in and *depolarize* the neuron (that is, make the inside less negative relative to the outside). If the neuron depolarizes enough, it reaches its *firing threshold* and an *action potential* occurs. During the action potential, the inside of the neuron becomes electrically positive relative to the outside. Because of the *all-or-none law*, a *neural impulse* is conducted along the entire length of the axon at full strength. Axons covered by a *myelin sheath* conduct impulses faster than other axons. After an action potential has occurred, the axon *repolarizes* and restores its resting potential.

Synaptic Transmission

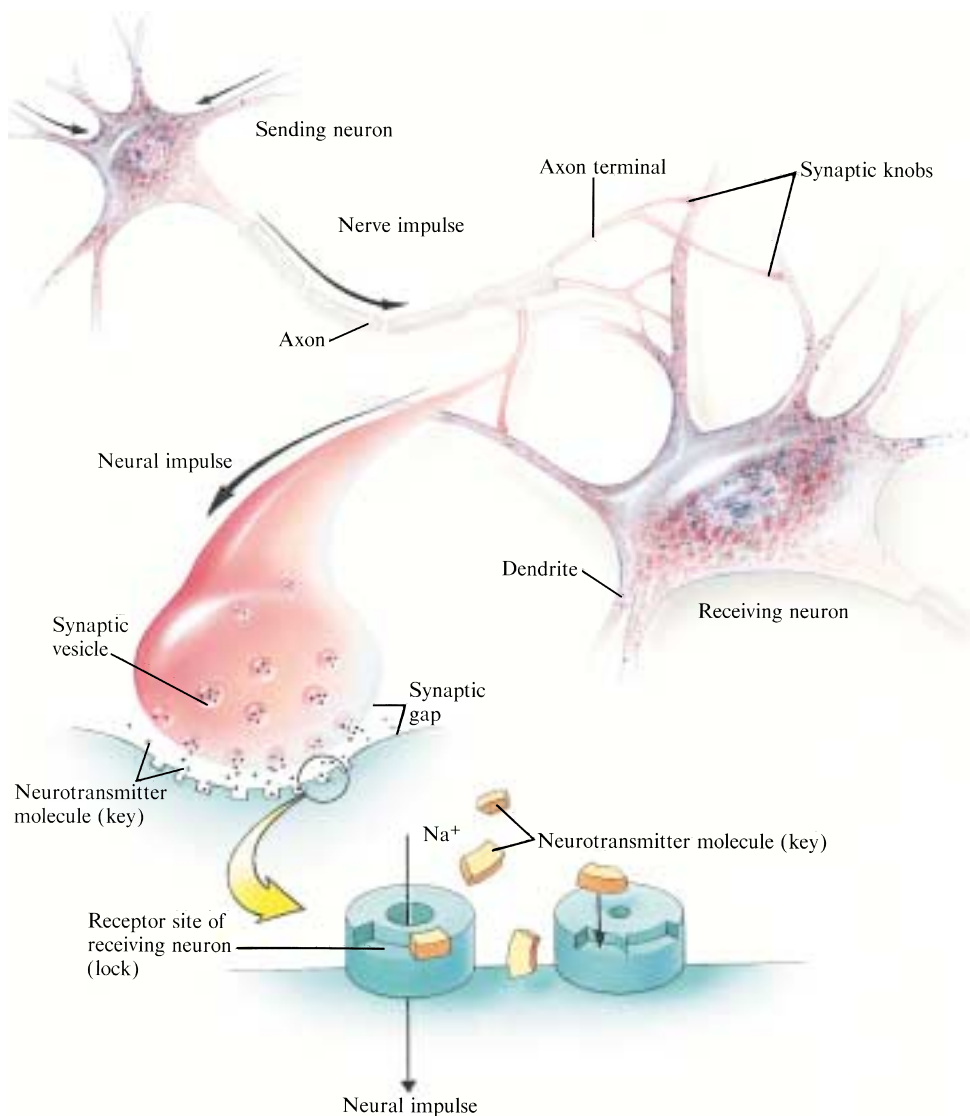
If all the neuron did was conduct a series of neural impulses along its axon, we would have an interesting, but useless, phenomenon. The reason we can see a movie, feel a mosquito bite, think about yesterday, or ride a bicycle is because neurons can communicate with one another by the process of **synaptic transmission**—communication across gaps between neurons. Many psychological processes, such as detecting the direction of a sound by determining the slight difference in the arrival time of sound waves at the two ears, require rapid and precisely timed synaptic transmission (Sabatini & Regehr, 1999).

The question of how neurons communicate with one another provoked a heated debate in the late 19th century. Spanish anatomist Santiago Ramón y Cajal (1852–1934) argued that neurons were separate from one another (Koppe, 1983). He won the debate by showing that neurons do not form a continuous network (Ramón y Cajal, 1937/1966). In 1897, the English physiologist Charles Sherrington (1857–1952) had coined the term **synapse** (from the Greek word for “junction”) to refer to the gaps that exist between neurons. Synapses also exist between neurons and glands, between neurons and muscles, and between neurons and sensory organs.

Mechanisms of Synaptic Transmission

As is usually the case with scientific discoveries, the observation that neurons were separated by synapses led to still another question: How could neurons communicate with one another across these gaps? At first, some scientists assumed that the neural impulse simply jumped across the synapse, just as sparks jump across the gap in a spark plug. But the correct answer came in 1921—in a dream.

The dreamer was Otto Loewi (1873–1961), an Austrian physiologist who had been searching without success for the mechanism of synaptic transmission. Loewi awoke from his dream and carried out the experiment it suggested. He removed the beating heart of a freshly killed frog, along with the portion of the *vagus nerve* attached to it, and placed it in a solution of salt water. By electrically stimulating the vagus nerve, he made the heart beat slower. He then put another beating heart in the same solution. Though he had not stimulated its vagus nerve, the second heart also began to beat slower. If you had made this discovery, what would you have concluded? Loewi concluded, correctly, that stimulation of the vagus nerve of the first heart had released a chemical into the solution. It was this chemical, which he later identified as *acetylcholine*, that slowed the beating of both hearts.



◀ **Figure 3.6**
Synaptic Transmission Between Neurons
 When a neural impulse reaches the end of an axon, it stimulates synaptic vesicles to release neurotransmitter molecules into the synapse. The molecules diffuse across the synapse and interact with receptor sites on another neuron, causing sodium ions to leak into that neuron. The molecules then disengage from the receptor sites and are broken down by enzymes or taken back into the axon.

Acetylcholine is one of a group of chemicals called **neurotransmitters**, which transmit neural impulses across synapses. Neurotransmitters are stored in round packets called *synaptic vesicles* in the intracellular fluid of bumps called *synaptic knobs* that project from the end branches of axons. The discovery of the chemical nature of synaptic transmission led to a logical question: How do neurotransmitters facilitate this transmission? Subsequent research revealed the processes involved (see Figure 3.6):

- First, when a neural impulse reaches the end of an axon, it induces a chemical reaction that makes some synaptic vesicles release neurotransmitter molecules into the synapse.
- Second, the molecules diffuse across the synapse and reach the dendrites of another neuron.
- Third, the molecules attach to tiny areas on the dendrites called *receptor sites*.
- Fourth, the molecules interact with the receptor sites to excite the neuron; this slightly depolarizes the neuron by permitting sodium ions to enter it. But for a neuron to depolarize enough to reach its firing threshold, it must be excited by neurotransmitters released by many neurons. To further complicate the process, a neuron can also be affected by neurotransmitters that inhibit it from depolarizing. Thus, a neuron will fire an action potential only when the combined effects of *excitatory neurotransmitters* sufficiently exceed the combined effects of *inhibitory neurotransmitters*.

neurotransmitters

Chemicals secreted by neurons that provide the means of synaptic transmission.



▲ **Curare, Acetylcholine, and Hunting**
 Natives of the Amazon jungle use curare-tipped darts to paralyze, and thereby suffocate, their prey. Curare blocks receptor sites for the neurotransmitter acetylcholine, causing flaccid paralysis of the muscles.



▲ Parkinson's Disease

Actor Michael J. Fox is an advocate for Parkinson's research. In September, 2000 he testified on Capitol Hill with other people suffering from Parkinson's disease in support of federal funding for medical research.

Alzheimer's disease

A brain disorder characterized by difficulty in forming new memories and by general mental deterioration.

Parkinson's disease

A degenerative disease of the dopamine pathway, which causes marked disturbances in motor behavior.

- Fifth, neurotransmitters do not remain attached to the receptor sites, continuing to affect them indefinitely. Instead, after the neurotransmitters have done their job, they are either broken down by chemicals called *enzymes* or taken back into the neurons that had released them—in a process called *reuptake*.

Neurotransmitters and Drug Effects

Of the neurotransmitters, acetylcholine is the best understood. In the peripheral nervous system, this is the neurotransmitter at synapses between the neurons of the parasympathetic nervous system and the organs they control, such as the heart. Acetylcholine also is the neurotransmitter at synapses between motor neurons and muscle fibers, where it stimulates muscle contractions. *Curare*, a poison Amazon Indians put on the darts they shoot from their blowguns, paralyzes muscles by preventing acetylcholine from attaching to receptor sites on muscle fibers. The resulting paralysis of muscles, including the breathing muscles, causes death by suffocation.

In the brain, acetylcholine helps regulate memory processes (Levin & Simon, 1998). The actions of acetylcholine can be impaired by drugs or diseases. For example, chemicals in marijuana inhibit acetylcholine release involved in memory processes, so people who smoke it might have difficulty forming memories (Carta, Nava, & Gessa, 1998). **Alzheimer's disease**, a progressive brain disorder that strikes in middle or late adulthood, is associated with the destruction of acetylcholine neurons in the brain (Albert & Drachman, 2000). Because Alzheimer's disease is marked by the inability to form new memories, a victim might be able to recall her third birthday party but not what she ate for breakfast this morning. Alzheimer's disease also is associated with severe intellectual and personality deterioration. Though we have no cure for Alzheimer's disease, treatments that increase levels of acetylcholine in the brain—most notably drugs that do so by preventing its breakdown and deactivation in synapses—delay the mental deterioration that it brings (Francis et al., 1999).

Since the discovery of acetylcholine, dozens of other neurotransmitters have been identified. Your ability to perform smooth voluntary movements depends on brain neurons that secrete the neurotransmitter *dopamine*. **Parkinson's disease**, which is marked by movement disorders, is caused by the destruction of dopamine neurons in the brain. Drugs, such as L-dopa, that increase dopamine levels provide some relief from Parkinson's disease symptoms (Schrug et al., 1998). Based on recent research findings, there also is hope that the transplantation of healthy dopamine-secreting neural tissue into the brains of Parkinson's victims will be effective in treating the disorder (Barker & Dunnett, 1999).

Dopamine has psychological, as well as physical, effects. Positive moods are maintained, in part, by activity in dopamine neurons (Kumari et al., 1998). Elevated levels of dopamine activity are found in the serious psychological disorder called *schizophrenia*. Drugs that block dopamine activity alleviate some of the symptoms of schizophrenia (Reynolds, 1999); and drugs, such as amphetamines, that stimulate dopamine activity can induce symptoms of schizophrenia (Castner & Goldman-Rakic, 1999).

Our moods vary with the level of the neurotransmitter *norepinephrine* in the brain. A low level is associated with depression. Many antidepressant drugs work by increasing norepinephrine levels in the brain (Anand & Charney, 2000). Like norepinephrine, the neurotransmitter *serotonin* is implicated in depression. In fact, people who become so depressed that they try suicide often have unusually low levels of serotonin (Mann et al., 2000). Drugs that boost the level of serotonin in the nervous system relieve depression (Heiser & Wilcox, 1998). Antidepressant drugs called *selective serotonin reuptake inhibitors*, such as Prozac, relieve depression by preventing the reuptake of serotonin into the axons that release it, thereby increasing serotonin levels in the brain (Racagni & Brunello, 1999).

Some neurotransmitters are amino acids. The main inhibitory amino acid neurotransmitter is *gamma aminobutyric acid* (or GABA). GABA promotes muscle relaxation and reduces anxiety (Crestani et al., 1999). So-called tranquilizers, such as Valium, relieve anxiety by promoting the action of GABA (Costa, 1998). As discussed in Chapter 8, the main excitatory amino acid neurotransmitter, *glutamic acid*, helps in the formation of memories (Newcomer et al., 1999).

Endorphins

Another class of neurotransmitters comprises small proteins called *neuropeptides*. The neuropeptide *substance P* has sparked interest because of its apparent role in the transmission of pain impulses, as in migraine headaches (Nakano et al., 1993) and sciatic nerve pain (Malmberg & Basbaum, 1998). During the past few decades, neuropeptides called **endorphins** have been the subject of much research and publicity because of their possible roles in relieving pain and inducing feelings of euphoria.

The endorphin story began in 1973, when Candace Pert and Solomon Snyder of Johns Hopkins University discovered opiate receptors in the brains of animals (Pert & Snyder, 1973). Opiates are pain-relieving drugs (or *narcotics*)—including morphine, codeine, and heroin—derived from the opium poppy. Pert and Snyder became interested in conducting their research after finding hints in previous research studies by other scientists that animals might have opiate receptors. Pert and Snyder removed the brains of mice, rats, and guinea pigs. Samples of brain tissue then were treated with radioactive morphine and naloxone, a chemical similar in structure to morphine that blocks morphine’s effects. A special device detected whether the morphine and naloxone had attached to receptors in the brain tissue.

Pert and Snyder found that the chemicals had bound to specific receptors (opiate receptors). If you had been a member of Pert and Snyder’s research team, what would you have inferred from this observation? Pert and Snyder inferred that the brain must manufacture its own opiatelike chemicals. This would explain why it had evolved opiate receptors, and it seemed a more likely explanation than that the receptors had evolved to take advantage of the availability of opiates such as morphine in the environment. Pert and Snyder’s findings inspired the search for opiatelike chemicals in the brain.

The search bore fruit in Scotland when Hans Kosterlitz and his colleagues found an opiatelike chemical in brain tissue taken from animals (Hughes et al., 1975). They called this chemical *enkephalin* (from Greek terms meaning “in the head”). Enkephalin and similar chemicals discovered in the brain were later dubbed “endogenous morphine” (meaning “morphine from within”). This was abbreviated into the now-popular term *endorphin*. Endorphins function as both neurotransmitters and *neuromodulators*—neurochemicals that affect the activity of other neurotransmitters. For example, endorphins serve as neuromodulators by inhibiting the release of substance P, thereby blocking pain impulses.

Once researchers had located the receptor sites for the endorphins and had isolated endorphins themselves, they then wondered: Why has the brain evolved its own opiatelike neurochemicals? Perhaps the first animals blessed with endorphins were better able to function in the face of pain caused by diseases or injuries, making them more likely to survive long enough to reproduce and pass this physical trait on to successive generations (Levinthal, 1988). Evidence supporting this speculation has come from both human and animal experiments.



▲ Candace Pert

“Our brains probably have natural counterparts for just about any drug you could name.”

endorphins

Neurotransmitters that play a role in pleasure, pain relief, and other functions.



◀ The Runner’s High

The euphoric “exercise high” experienced by long-distance runners, such as these athletes competing at the Sydney Olympics, might be caused by the release of endorphins.

In one experiment, researchers first recorded how long mice would allow their tails to be exposed to radiant heat from a lightbulb before the pain made them flick their tails away from it. Those mice then were paired with more aggressive mice, which attacked and defeated them. The losers' tolerance for the radiant heat was then tested again. The results showed that the length of time the defeated mice would permit their tails to be heated had increased, which suggests that the aggressive attacks had raised their endorphin levels. But when the defeated mice were given naloxone, which (as mentioned earlier) blocks the effects of morphine, they flicked away their tails as quickly as they had done before being defeated. The researchers concluded that the naloxone had blocked the pain-relieving effects of the endorphins (Miczek, Thompson, & Shuster, 1982). Other studies have likewise found that endorphins are associated with pain relief in animals (Spinella et al., 1999).

Endorphin levels also rise in response to vigorous exercise (Harbach et al., 2000), perhaps accounting for the "exercise high" reported by many athletes, including runners, swimmers, and bicyclists. This was supported by a study that found increased endorphin levels after aerobic dancing (Pierce et al., 1993). Further support came from a study of bungee jumpers. After jumping, their feelings of euphoria showed a positive correlation with changes in their endorphin levels (Hennig, Laschewski, & Opper, 1994).

STAYING ON TRACK: *The Neuron*

1. What are the major structures of the neuron?
2. What is the basic process underlying neural impulses?

Answers to Staying on Track start on p. S-2.

◆ THE BRAIN

"Tell me, where is fancy bred, in the heart or in the head?" (*The Merchant of Venice*, act 3, scene 2). The answer to this question from Shakespeare's play might be obvious to you. You know that your brain, and not your heart, is your feeling organ—the site of your mind. But you have the advantage of centuries of research, which have made the role of the brain in all psychological processes obvious even to nonscientists. Of course, the cultural influence of early beliefs can linger. Just imagine the response of a person who received a gift of Valentine's Day candy in a box that was brain-shaped instead of heart-shaped.

The ancient Egyptians associated the mind with the heart and discounted the importance of the apparently inactive brain. In fact, when the pharaoh Tutankhamen ("King Tut") was mummified to prepare him for the afterlife, his heart and other bodily organs were carefully preserved, but his brain was discarded. The Greek philosopher Aristotle (384–322 B.C.) also

 The Whole Brain Atlas
www.mhhe.com/sdorow5

► The Human Brain



believed the heart was the site of the mind, because when the heart stops, mental activity stops (Laver, 1972). But the Greek physician-philosopher Hippocrates (460–377 B.C.), based on his observations of the effects of brain damage, did locate the mind in the brain:

► Some people say that the heart is the organ with which we think and that it feels pain and anxiety. But it is not so. Men ought to know that from the brain and from the brain alone arise our pleasures, joys, laughter, and tears. (quoted in Penfield, 1975, p. 7)

Techniques for Studying the Brain

Later in this chapter you will learn about the function of the different substructures of the brain. But how did scientists discover them? Today, they rely on *clinical case studies*, *experimental manipulation*, *recording of electrical activity*, and *brain imaging*. But some techniques that scientists have used for studying the brain have fallen out of favor, as described in the Thinking Critically About Psychology and the Media feature.



What Can We Infer from the Size of the Brain?

- "Research on Einstein's Brain Finds Size Does Matter" (CBC Newsworld, June 19, 1999)
- "Einstein Was Bigger Where It Counts, Analysis Shows" (Sydney Morning Herald, June 18, 1999)
- "Peek into Einstein's Brain" (Discovery Online, June 18, 1999)
- "The Roots of Genius" (Newsweek, June 24, 1999)
- "Part of Einstein's Brain 15 Percent Bigger Than Normal" (National Public Radio, June 18, 1999).

As you can gather from these headlines, the international media responded with excitement when researchers at McMaster University in Ontario, Canada, announced that the brain of scientific genius Albert Einstein was anatomically distinct. That is, a particular region of it, the parietal lobe, was larger than that same region in other people.

The media reports were based on a study of Einstein's preserved brain published in *The Lancet*, a respected British medical journal. Einstein, who is famous for his theory of relativity, is considered one of the outstanding scientists in history. The reports attributed his scientific genius to that unusually large region of his brain—a region associated with spatial and mathematical ability. It seemed to be a matter of common sense: if you know the function of a brain structure, and that structure is unusually large in a particular person, then that person must have excelled in that function. But attempts to assess intellectual and personality functions by studying the size (and shape) of specific areas of the brain are not new—and typically have been fruitless, as in the case of the practice known as **phrenology** (Greek for "science of the mind").

The Misguided "Science" of Phrenology

"You need to have your head examined!" is a refrain heard by many people whose ideas and behavior upset other people. Today, this is simply a figure of speech, but for most of the 19th century and well into the early 20th century it was common practice for people to—literally—have their heads examined. This pseudoscience, phrenology, was perhaps the most dramatic example of the commonsense practice of inferring personal characteristics from the size and shape of the brain.

Phrenology began when the respected Viennese physician-anatomist Franz Joseph Gall (1758–1828) proclaimed that particular regions of the brain controlled specific psychological functions. Gall not only believed that specific brain sites controlled specific mental faculties, but assumed that the shape of specific sites on the skull indicated the degree of development of the brain region beneath it. To Gall it was simply a matter of common sense to assume that a bumpy site would indicate a highly developed brain region; a flat site would indicate a less developed brain region.

But what did Gall use as evidence to support his practice? Much of his evidence came from his own casual observations. For example, as a child he had noted, with



The History of Phrenology
on the Web

www.mhhe.com/sdorow5

phrenology

A discredited technique for determining intellectual abilities and personality traits by examining the bumps and depressions of the skull.

some envy, that classmates with good memories had bulging eyes. He concluded that their eyes bulged because excess brain matter pushed them out of their sockets. This led to the commonsense conclusion that memory ability is controlled by the region of the brain just behind the eyes. Thus, phrenology was supported by commonsense reasoning about isolated cases, which is frowned upon by scientists because of its unreliability. Though phrenology had its scientific shortcomings and disappeared in the early 20th century, it sparked interest in the localization of brain functions (Miller, 1996).

The Furor over Einstein's Brain

But what of Einstein's brain? If it did not make scientific sense to infer the size of brain areas and the degree of development of their associated functions from the shape of the skull, is it any more scientifically credible to infer brain functions from the size of particular brain structures? When Einstein died in 1955 at the age of 76 in Princeton, New Jersey, his body was cremated and his ashes spread over the nearby Delaware River, but his brain had been removed and was kept by the pathologist, Thomas Harvey, who did the autopsy. Harvey took the brain with him when he moved to Wichita, Kansas, where he kept it in two mason jars. Most of it had been cut into sections that looked like cubes of tofu.

Over the years, Harvey had mailed small sections of the brain to scientists who wished to study its microscopic structure. But the 1999 study was the first to examine the structure of the brain as a whole. The researchers compared Einstein's brain with the preserved brains of 35 men and 56 women who were presumably of normal intelligence when they died. Einstein's brain was the same weight and overall size as those of the other men, including 8 who died at about the same age as Einstein. Though Sandra Witelson, the neuroscientist who led the research team, found that Einstein's brain was normal in size, she found more specific differences between Einstein's brain and those of the other men. The lower portion of the parietal lobe was 15 percent wider than normal. This led Witelson to conclude there might have been more neural connections in that region of Einstein's brain.

"That kind of shape was not observed in any of our brains and is not depicted in any atlas of the human brain," noted Witelson (Ross, 1999, p. A-1). Because research has indicated that the parietal region is involved in spatial and mathematical functions, Witelson inferred that this might account for Einstein's superiority as a physicist and mathematician—especially given that Einstein always insisted he did his scientific thinking spatially, not verbally.

But what can we make of this research report? Witelson warned that overall brain size is not a valid indicator of differences in intelligence. But she noted that the more specific anatomical differences between Einstein's brain and the others might indicate that mathematical genius is, at least to some extent, inborn. "[W]hat this is telling us is that environment isn't the only factor" (Ross, 1999, p. A-1). Nonetheless, Witelson added that she would not discount the importance of the environment in governing brain development. Perhaps Einstein was born with a brain similar to those of the people his was compared to, but a lifetime of thinking scientifically and mathematically (not to mention other experiences, such as diet and personal health habits) altered his brain and created distinctive anatomical differences between it and the others.

The media will always seek the most interesting, controversial research studies to report. Scientific consumers are well advised to go beyond popular reports and articles and think critically about what they claim, perhaps even reading some of the scientific literature itself when it relates to topics of personal importance. One of the goals of this textbook is to help you become that kind of critical consumer of information—whether the information is presented by a scientist or a news reporter.

Clinical Case Studies

For thousands of years human beings have noticed that when people suffer brain damage from accidents or injuries, they might experience physical and psychological changes. Physicians and scientists sometimes conduct *clinical case studies* of such people. For example, later in the chapter you will read about a clinical case study of Phineas Gage, a man who lived on after a 3-foot-long metal rod pierced his brain. Neurosurgeon Oliver Sacks has

written several books based on clinical case studies of patients who suffered brain damage that produced unusual—even bizarre—symptoms, including a man who lost the ability to recognize familiar faces. This disorder, *prosopagnosia*, is discussed in Chapter 5.

Experimental Manipulation

Clinical case studies involve individuals who have suffered brain damage from illness or injury. In contrast, techniques that involve *experimental manipulation* involve purposefully damaging the brain, electrically stimulating the brain, or observing the effects of drugs on the brain.

When scientists use brain lesioning, they destroy specific parts of animal brains and, after the animal has recovered from the surgery, look for changes in behavior. Since the early 19th century, when the French anatomist Pierre Flourens formalized this practice, researchers who employ this technique have learned much about the brain. As described in Chapter 11, for example, researchers in the late 1940s demonstrated that destroying a specific part of the brain structure called the *hypothalamus* would make a deprived rat starve itself even in the presence of food, whereas destroying another part of the hypothalamus would make a rat insatiable and overeat until it became obese.

Some researchers, instead of destroying parts of the brain to observe the effects on behavior, use electrical stimulation of the brain (ESB). They use weak electrical currents to stimulate highly localized sites in the brain and observe any resulting changes in behavior. Perhaps the best-known research using ESB was conducted by neurosurgeon Wilder Penfield, who, in the course of operating on the brains of people with severe epilepsy, meticulously stimulated the surface of the brain. As discussed later in the chapter, Penfield thereby discovered that activity in specific brain sites controls specific body movements and that specific sites are related to sensations from specific body sites.

Some researchers, instead of using ESB, observe the behavioral effects of drugs on the brain. Earlier in this chapter, you learned that animal subjects, when given the drug naloxone, do not show a reduction in pain following attack. Because naloxone blocks the effects of opiates, this supported research implicating endorphins as the body's own natural opiates. In a discussion later in this chapter, you will learn of a technique that involves injecting a barbiturate into an artery serving the left or right side of the brain and then observing any resulting effects. When the drug affects the left side of the brain, but rarely when it affects the right side, the person will lose the ability to speak. This supports research indicating that the left half of the brain regulates speech in most people.

Recording Electrical Activity

Consider the **electroencephalograph (EEG)**, which records the patterns of electrical activity produced by neuronal activity in the brain. The EEG has a peculiar history, going back to a day at the turn of the 20th century when an Austrian scientist named Hans Berger fell off a horse and narrowly escaped serious injury. That evening he received a telegram informing him that his sister felt he was in danger.

The telegram inspired Berger to investigate the possible association between *mental telepathy* (the alleged, though scientifically unverified, ability of one mind to communicate with another by extrasensory means) and electrical activity from the brain (La Vague, 1999). In 1924, after years of experimenting on animals and his son Klaus, Berger succeeded in perfecting a procedure for recording electrical activity in the brain. He attached small metal disks called *electrodes* to Klaus's scalp and connected them with wires to a device that recorded changes in the patterns of electrical activity in his brain.

Though Berger failed to find physiological evidence in support of mental telepathy, he found that specific patterns of brain activity are associated with specific mental states, such as coma, sleep, and wakefulness (Gloor, 1994). He also identified two distinct rhythms of electrical activity. He called the relatively slow rhythm associated with a relaxed mental state the *alpha rhythm* and the relatively fast rhythm associated with an alert, active mental state the *beta rhythm*. Berger also used the EEG to provide the first demonstration of the stimulating effect of cocaine on brain activity. He found that cocaine increased the relative proportion of the beta rhythm in EEG recordings (Herning, 1985).

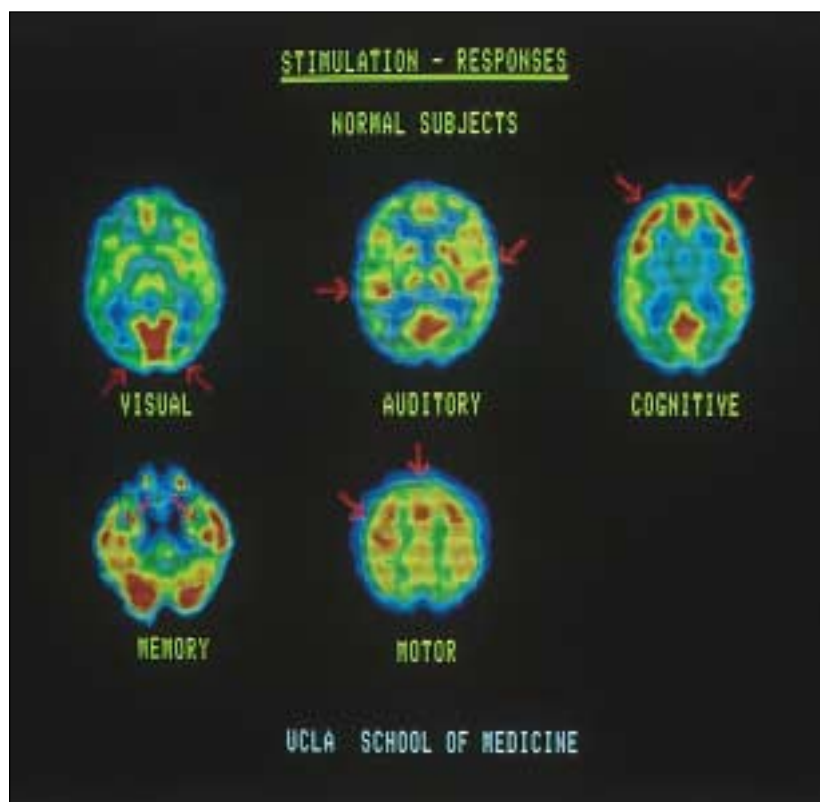
electroencephalograph (EEG)

A device used to record patterns of electrical activity produced by neuronal activity in the brain.

► Figure 3.7

The PET Scan

The red areas of these PET scans reveal the regions of the brain that have absorbed the most glucose, indicating that they are the most active regions during the performance of particular tasks (Phelps & Mazziotta, 1985).



Berger's method of correlating EEG activity with psychological processes is still used today. In one study, for example, researchers determined the EEG patterns that accompanied mental fatigue in white-collar workers. The ultimate aim of the researchers was to maximize workers' productivity by determining the optimal length of work periods and rest breaks (Okogbaa, Shell, & Filipusic, 1994). The EEG even has been used to distinguish differences in brain-wave patterns in responses of listeners to different kinds of music (Panksepp & Bekkedal, 1997).

Brain-Imaging Techniques

The computer revolution has given rise to a major breakthrough in the study of the brain: brain-imaging techniques. Brain imaging involves scanning the brain to provide pictures of brain structures or "maps" of ongoing activity in the brain. Brain imaging has been used to assess brain abnormalities in psychological disorders (Gordon, 1999), brain activity while performing arithmetic thinking (Dehaene et al., 1999), and brain processes involved in storing memories (Glanz, 1998).

Perhaps the most important kind of brain scan to psychologists is **positron-emission tomography (PET)**, which lets them measure ongoing activity in particular regions of the brain. In using the PET scan, researchers inject radioactive glucose (a type of sugar) into a participant. Because neurons use glucose as a source of energy, the most active region of the brain takes up the most radioactive glucose. The amount of radiation emitted by each region is measured by a donut-shaped device that encircles the head. This information is analyzed by a computer, which generates color-coded pictures showing the relative degree of activity in different brain regions. As illustrated in Figure 3.7, PET scans are useful in revealing the precise patterns of brain activity during the performance of motor, sensory, and cognitive tasks (Phelps & Mazziotta, 1985). For example, a study of severe stutterers as they read aloud used the PET scan to identify brain pathways that might be involved in stuttering (De Nil et al., 2000). The PET scan has also found lasting alterations in the functioning of particular brain structures in users of the illegal drug Ecstasy, also known as MDMA (Obrocki et al., 1999).

positron-emission tomography (PET)

A brain-scanning technique that produces color-coded pictures showing the relative activity of different brain areas.

Two other brain-scanning techniques, which are more useful for displaying brain structures than for displaying ongoing brain activity, are **computed tomography (CT)** and **magnetic resonance imaging (MRI)**. The CT scan takes many X rays of the brain from a variety of orientations around it. Detectors then record how much radiation has passed through the different regions of the brain. A computer uses this information to compose a picture of the brain. The MRI scan exposes the brain to a powerful magnetic field, and the hydrogen atoms in the brain align themselves along the magnetic field. A radio signal then disrupts the alignment. When the radio signal is turned off, the atoms align themselves again. A computer analyzes these changes, which differ from one region of the brain to another, to compose an even more detailed picture of the brain. Figure 3.8 illustrates an MRI image.

Traditional CT and MRI scans have been useful in detecting structural abnormalities. For example, degeneration of brain neurons in people with Alzheimer's disease has been verified by CT scans and MRI scans (Wahlund, 1996). In the past few years, a technique called *functional MRI* has joined the PET scan as a tool for measuring ongoing activity in the brain. This ultrafast version of the traditional MRI detects increases in blood flow to brain regions that are more active at the moment. Functional MRI has been used to study brain activity involved in processes such as eating (Liu et al., 2000) and short-term memory (D'Esposito et al., 1998).

A more recent version of computed tomography, **single photon emission computed tomography (SPECT)**, does more than provide images of brain structures; it creates images of regional cerebral blood flow. SPECT has been used in assessing brain activity in sensory processes such as hearing (Ottaviani et al., 1997), cognitive activities such as language (McMackin et al, 1998), and psychological disorders such as schizophrenia (Chen & Ho, 2000).

The electrical activity produced by neuronal action potentials induces changing magnetic fields. Changes in these magnetic fields can be detected by the **superconducting quantum interference device**, or **SQUID**, a recent addition to the behavioral neuroscientist's arsenal of brain-imaging techniques. SQUID uses these changes in magnetic fields to trace pathways of brain activity associated with different processes such as hearing or movement. SQUID even has been used to reveal the pattern of brain activity involved in memory processing (Glanz, 1998).

Functions of the Brain

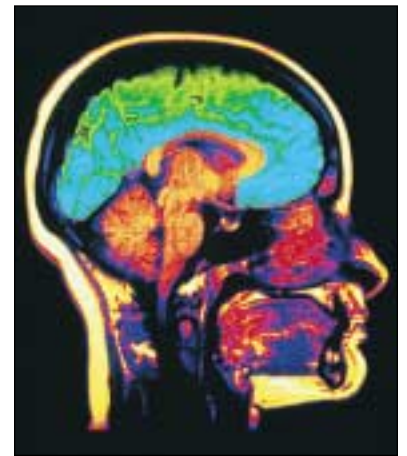
The human brain's appearance does not hint at its complexity. Holding it in your hands, you might not be impressed by either its 3-pound weight or its walnutlike surface. You might be more impressed to learn it contains billions of neurons. And you might be astounded to learn that any given brain neuron might communicate with thousands of others, leading to an enormous number of pathways for messages to follow in the brain. Moreover, the brain is not homogeneous. It has many separate structures that interact to help you perform the myriad of activities that let you function in everyday life.

Though the functions of brain structures are similar across human beings, there are cultural differences in brain functioning (Shrivastava & Rao, 1997). For example, culturally disadvantaged preschool children in Mexico have been found to display brain-wave patterns different from those of nondisadvantaged children (Otero, 1997). When discussing brain functions, it is customary to categorize areas of the brain as the *brain stem*, the *limbic system*, and the *cerebral cortex* (see Figure 3.9).

The Brain Stem

Your ability to survive from moment to moment depends on your *brain stem*, located at the base of the brain. The brain stem includes the *medulla*, the *pons*, the *cerebellum*, the *reticular formation*, and the *thalamus*.

The Medulla. Of all the brain stem structures, the most crucial to your survival is the **medulla**, which connects the brain and spinal cord. At this moment your medulla is regulating your breathing, heart rate, and blood pressure. Because the medulla supports basic life functions, the absence of neurological activity in the medulla is sometimes used as a



▲ **Figure 3.8**
The MRI Scan

The illustration shows a color-enhanced MRI scan of a healthy human brain presenting a high-definition view of the brain stem.

computed tomography (CT)

A brain-scanning technique that relies on X rays to construct computer-generated images of the brain or body.

magnetic resonance imaging (MRI)

A brain-scanning technique that relies on strong magnetic fields to construct computer-generated images of the brain or body.

single photon emission computed tomography (SPECT)

A brain-imaging technique that creates images of cerebral blood flow.

superconducting quantum interference device (SQUID)

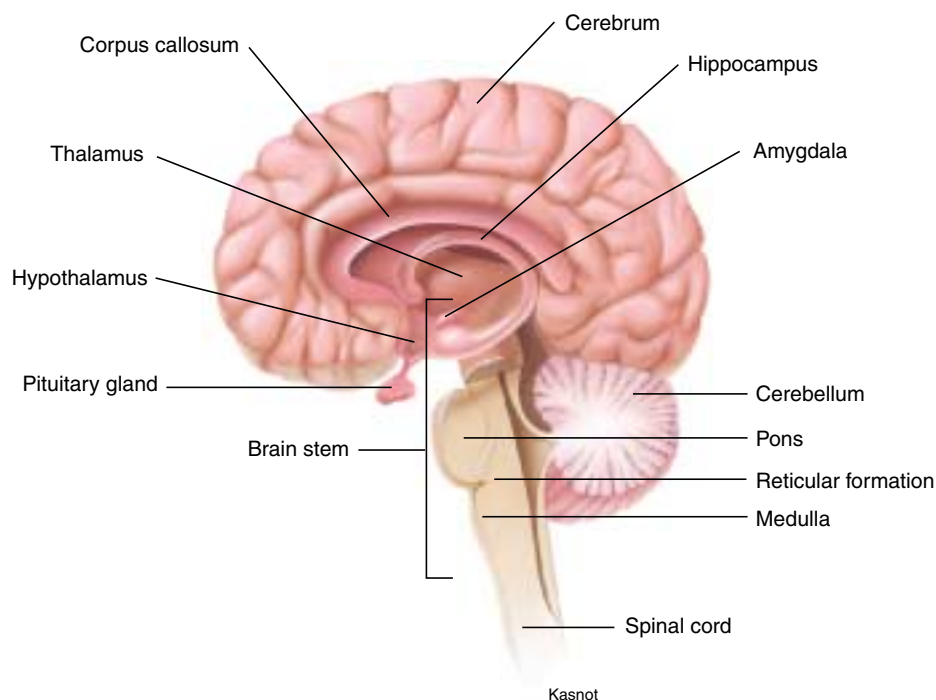
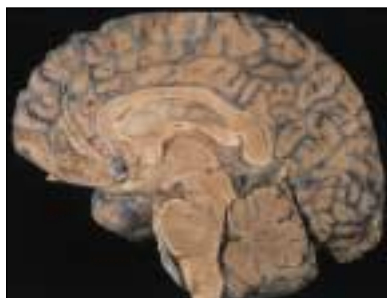
A brain-imaging technique that uses changes in magnetic fields to trace pathways of brain activity associated with processes such as hearing or movement.

medulla

A brain stem structure that regulates breathing, heart rate, blood pressure, and other life functions.

► **Figure 3.9**
The Structure of the Human Brain

The structures of the brain stem, limbic system, and cerebral cortex serve a variety of life-support, sensorimotor, and cognitive functions.



sign of brain death by physicians (Sonoo et al., 1999). When called upon, your medulla also stimulates coughing, vomiting, or swallowing. By inducing vomiting, for example, the medulla can prevent people who drink too much alcohol too fast from poisoning themselves. The medulla is also important in regulating the transmission of pain impulses (Urban, Coutinho, & Gebhart, 1999).

pons

A brain stem structure that regulates the sleep-wake cycle.

cerebellum

A brain stem structure that controls the timing of well-learned movements.

reticular formation

A diffuse network of neurons, extending through the brain stem, that helps maintain vigilance and an optimal level of brain arousal.

The Pons. Just above the medulla lies a bulbous structure called the **pons**. As explained in Chapter 6, the pons helps regulate the sleep-wake cycle through its effect on consciousness (Shouse et al., 2000). Surgical anesthesia induces unconsciousness by acting on the pons (Ishizawa et al., 2000). And if you have ever been the unfortunate recipient of a blow to the head that knocked you out, your loss of consciousness was caused by the blow’s effect on your pons (Hayes et al., 1984).

The Cerebellum. The pons (which means “bridge” in Latin) connects the **cerebellum** (meaning “little brain”) to the rest of the brain. The cerebellum controls the timing of well-learned sequences of movements that are too rapid to be controlled consciously, as in running a sprint, singing a song, or playing the piano (Kawashima et al., 2000). As you know from your own experience, you can disrupt normally automatic sequences of movements by trying to control them. Pianists who think of each key they are striking while playing a well-practiced piece would be unable to maintain proper timing. Recent research indicates that the cerebellum might even affect the smooth timing and sequencing of mental activities, such as the use of language (Fabbro, 2000). Damage to the cerebellum can disrupt the ability to perform skills that we take for granted, such as timing the opening of the fingers in throwing a ball (Timmann, Watts, & Hore, 1999).

The Reticular Formation. The brain stem also includes the **reticular formation**, a diffuse network of neurons that helps regulate vigilance and brain arousal. The role of the reticular formation in maintaining vigilance is shown by the “cocktail party phenomenon,” in which you can be engrossed in a conversation but still notice when someone elsewhere in the room says something of significance to you, such as your name. Thus, the reticular formation acts as a filter, letting you attend to an important stimulus while ignoring irrelevant ones (Shapiro, Caldwell, & Sorensen, 1997). Experimental evidence supporting the role of the

reticular formation in brain arousal came from a study by Giuseppe Moruzzi and Horace Magoun in which they awakened sleeping cats by electrically stimulating the reticular formation (Moruzzi & Magoun, 1949).

The Thalamus. Capping the brain stem is the egg-shaped **thalamus**. The thalamus functions as a sensory relay station, sending taste, bodily, visual, and auditory sensations on to other areas of the brain for further processing. The visual information from this page is being relayed by your thalamus to areas of your brain that process vision, and, at this moment the thalamus is processing impulses that will inform your brain if part of your body feels cold (Davis et al., 1999) or is in pain (Bordi & Quartaroli, 2000). The one sense whose information is not relayed through the thalamus is smell. Sensory information from smell receptors in the nose goes directly to areas of the brain that process odors.

The Limbic System

Surrounding the thalamus is a group of structures that constitute the **limbic system**. The word *limbic* comes from the Latin for “border,” indicating that the limbic structures form a border between the higher and lower structures of the brain. The limbic system interacts with other brain structures to promote the survival of the individual and, as a result, the continuation of the species. Major components of the limbic system include the *hypothalamus*, the *amygdala*, and the *hippocampus*.

The Hypothalamus. Just below the thalamus, on the underside of the brain, lies the **hypothalamus** (in Greek the prefix *hypo-* means “below”), a structure that is important to a host of functions. The hypothalamus helps regulate eating, drinking, emotion, sexual behavior, and body temperature. It exerts its influence by regulating the secretion of hormones by the pituitary gland and by signals sent along neurons to bodily organs controlled by the autonomic nervous system.

The importance of the hypothalamus in emotionality was discovered by accident. Psychologists James Olds and Peter Milner (1954) of McGill University in Montreal inserted fine wire electrodes into the brains of rats to study the effects of electrical stimulation of the reticular formation. They had already trained the rats to press a lever to obtain food rewards. When a wired rat now pressed the lever, it obtained mild electrical stimulation of its brain. To the experimenters’ surprise, the rats, even when hungry or thirsty, ignored food and water in favor of pressing the lever—sometimes thousands of times an hour, until they dropped from exhaustion up to 24 hours later (Olds, 1956). Olds and Milner examined brain tissue from the rats and discovered that they had mistakenly inserted the electrodes near the hypothalamus and not into the reticular formation. They concluded they had discovered a “pleasure center.” Later research studies showed that the hypothalamus is but one structure in an interconnected group of brain structures that induce feelings of pleasure when stimulated.

The Amygdala. The **amygdala** of the limbic system continuously evaluates information from the immediate environment, such as facial expressions and tone of voice, and helps elicit appropriate emotional responses (Killcross, 2000). If you saw a pit bull dog running toward you, your amygdala would help you quickly decide whether the dog was vicious, friendly, or simply roaming around. Depending on your evaluation of the situation, you might feel happy and pet the dog, feel afraid and jump on top of your desk, or feel relief and go back to studying.

In the late 1930s, Heinrich Klüver and Paul Bucy (1937) found that lesions of the amygdala in monkeys led to “psychic blindness,” an inability to evaluate environmental stimuli properly. The monkeys indiscriminately examined objects by mouth, tried to mate with members of other species, and acted fearless when confronted by a snake. Human beings who suffer amygdala damage can also exhibit symptoms of Klüver-Bucy syndrome (Hayman et al., 1998).

The Hippocampus. Whereas your amygdala helps you evaluate information from your environment, the limbic system structure that is most important in helping you form memories of that information (including what you are now reading) is the **hippocampus** (Nadel

thalamus

A brain stem structure that acts as a sensory relay station for taste, body, visual, and auditory sensations.

limbic system

A group of brain structures that, through their influence on emotion, motivation, and memory, promote the survival of the individual and, as a result, the continuation of the species.

hypothalamus

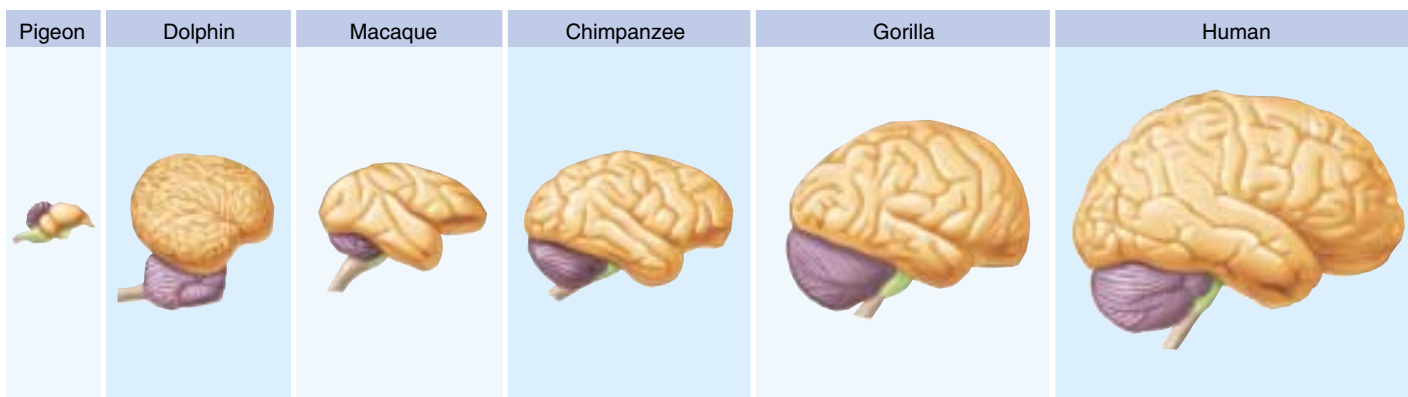
A limbic system structure that, through its effects on the pituitary gland and the autonomic nervous system, helps to regulate aspects of motivation and emotion, including eating, drinking, sexual behavior, body temperature, and stress responses.

amygdala

A limbic system structure that evaluates information from the immediate environment, contributing to feelings of fear, anger, or relief.

hippocampus

A limbic system structure that contributes to the formation of memories.



■ Cerebrum
 ■ Cerebellum
 ■ Brain stem

▲ Figure 3.10

The Evolution of the Brain

Animals that are more cognitively complex have evolved brains that are larger in proportion to their body sizes. Their cerebral cortex is also larger in proportion to the size of their other brain structures, which creates a more convoluted brain surface.

cerebral cortex

The outer covering of the brain.

cerebral hemispheres

The left and right halves of the cerebrum.

primary cortical areas

Regions of the cerebral cortex that serve motor or sensory functions.

association areas

Regions of the cerebral cortex that integrate information from the primary cortical areas and other brain areas.

frontal lobe

A lobe of the cerebral cortex responsible for motor control and higher mental processes.

motor cortex

The area of the frontal lobes that controls specific voluntary body movements.

& Moscovitch, 1998). Much of what we know about the hippocampus comes from case studies of people who have suffered damage to it. The most famous study is of a man known as “H. M.” (Scoville & Milner, 1957), whose hippocampus was surgically removed in 1953—when he was 27—to relieve his uncontrollable epileptic seizures. Since the surgery, H. M. has formed few new memories, though he can easily recall events and information from before his surgery. You can read more about the implications of his case in regard to memory in Chapter 8. Damage to the hippocampus has been implicated in the memory loss associated with Alzheimer’s disease. Victims of this disease suffer from degeneration of the neurons that serve as pathways between the hippocampus and other brain areas (Laakso et al., 2000).

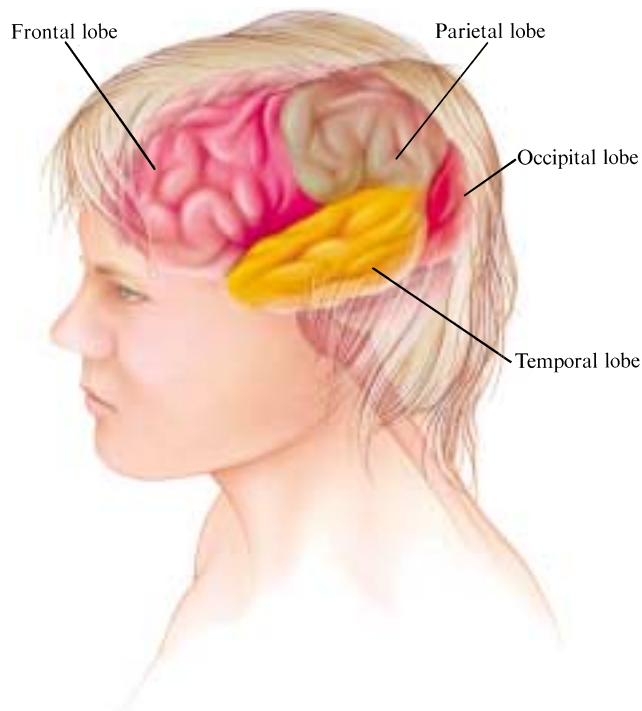
The Cerebral Cortex

Covering the brain is the crowning achievement of brain evolution—the **cerebral cortex**. *Cortex* means “bark” in Latin. And just as the bark is the outer layer of the tree, the cerebral cortex is the thin, 3-millimeter-thick outer layer of the uppermost portion of the brain called the *cerebrum*. The cerebral cortex of human beings and other mammals has evolved folds called *convolutions*, which, as shown in Figure 3.10, give it the appearance of kneaded dough. The convolutions permit more cerebral cortex to fit inside the skull. This is necessary because evolution has assigned so many complex brain functions to the mammalian cerebral cortex that the brain has, in a sense, outgrown the skull in which it resides. If the cerebral cortex were smooth instead of convoluted, the human brain would have to be enormous to permit the same amount of surface area. The brain would be encased in a skull so large that it would give us the appearance of creatures from science fiction movies.

The cerebrum is divided into left and right halves called the **cerebral hemispheres**. Figure 3.11 shows that the cerebral cortex covering each hemisphere is divided into four regions, or *lobes*: the *frontal lobe*, the *temporal lobe*, the *parietal lobe*, and the *occipital lobe*. The lobes have **primary cortical areas** that serve motor or sensory functions. The lobes also have **association areas** that integrate information from the primary cortical areas and other brain areas in activities such as speaking, problem solving, and recognizing objects.

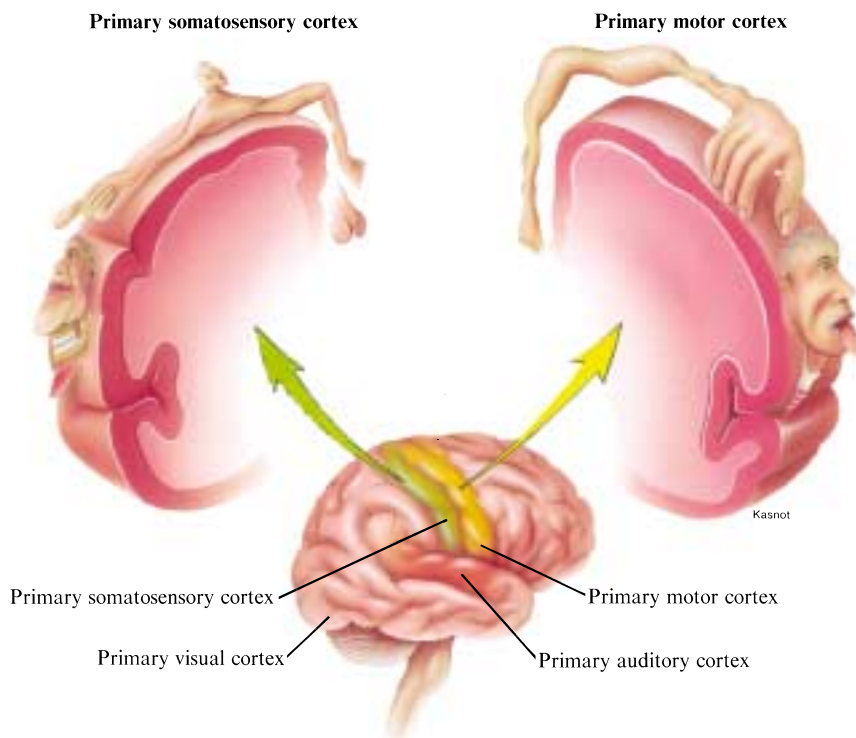
Motor Areas. Your tour begins in 1870, when the German physicians Gustav Fritsch and Eduard Hitzig (1870/1960) published their findings that electrical stimulation of a strip of cerebral cortex along the rear border of the right or left **frontal lobe** of a dog induced limb movements on the opposite side of the body. This is known as *contralateral control*. The area they stimulated is called the **motor cortex**. They were probably the first to demonstrate conclusively that specific sites on the cerebral cortex control specific body movements (Breathnach, 1992).

Figure 3.12 presents a “map” of the motor cortex of the frontal lobe, represented by a *motor homunculus* (*homunculus* is a Latin term meaning “small human”). Each area of the motor cortex controls a particular contralateral body movement. Certain sites on the motor cortex even show activity merely in anticipation of particular arm movements (Hyland,



◀ **Figure 3.11**
The Lobes of the Brain

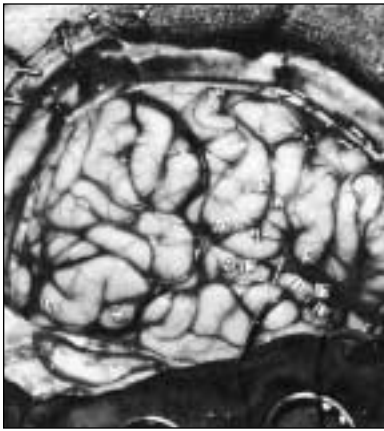
The cerebral cortex covering each cerebral hemisphere is divided into four lobes: the frontal lobe, the temporal lobe, the parietal lobe, and the occipital lobe.



◀ **Figure 3.12**
The Motor Cortex and the Somatosensory Cortex

Both the motor cortex and the somatosensory cortex form distorted, upside-down maps of the contralateral side of the body.

1998). Note that the motor homunculus is upside down, with the head represented at the bottom and the feet represented at the top. You might also be struck by the disproportionate sizes of the body parts on the motor homunculus—each body part is represented in proportion to the precision of its movements, not in proportion to its actual size. Because your fingers move with great precision in manipulating objects, the region of the motor cortex devoted to your fingers is disproportionately large relative to the regions devoted to body parts that move with less precision, such as your arms.



▲ Mapping the Brain

Wilder Penfield mapped the cerebral cortex while performing brain surgery on patients with epilepsy. The numbered tags on the exposed brain indicate sites that produced particular movements or mental experiences when electrically stimulated.

parietal lobe

A lobe of the cerebral cortex responsible for processing bodily sensations and perceiving spatial relations.

somatosensory cortex

The area of the parietal lobes that processes information from sensory receptors in the skin.

temporal lobe

A lobe of the cerebral cortex responsible for processing hearing.



▲ Wilder Penfield (1891–1976)

“The mind remains, still, a mystery that science has not solved.”

Sensory Areas. The primary cortical areas of the frontal lobes control movements; the primary cortical areas of the other lobes process sensory information. You will notice in Figure 3.12 that the primary cortical area of the **parietal lobes** runs parallel to the motor cortex of the frontal lobes. This area is called the **somatosensory cortex**, because it processes information related to bodily senses such as pain, touch, and temperature. Certain sites even respond when the individual merely anticipates being touched (Drevets et al., 1995). As in the case of the motor cortex, the somatosensory cortex forms a distorted, upside-down homunculus of the body and receives input from the opposite side of the body. Each body part is represented on the *sensory homunculus* in proportion to its sensory precision rather than its size. This is why the region devoted to your highly sensitive lips is disproportionately large relative to the region devoted to your less sensitive back.

How do we know that a motor homunculus and a sensory homunculus exist on the cerebral cortex? We know because of research conducted by neurosurgeon Wilder Penfield (1891–1976), of the Montreal Neurological Institute, in the course of brain surgery to remove defective tissue causing epileptic seizures. Of his many contributions, his most important was the “Montreal procedure” for surgically removing scar tissue that caused epilepsy. In applying the procedure, he made the first use of Hans Berger’s EEG, by comparing brain activity before and after surgery to see if it had been successful in abolishing the abnormal brain activity that had triggered his patients’ seizures.

In using the Montreal procedure, Penfield made an incision through the scalp, sawed through a portion of the skull, and removed a large flap of bone—exposing the cerebral cortex. His patients required only a local anesthetic at the site of the scalp and skull incisions, because incisions in the brain itself do not cause pain. This let the patients remain awake during surgery and converse with him.

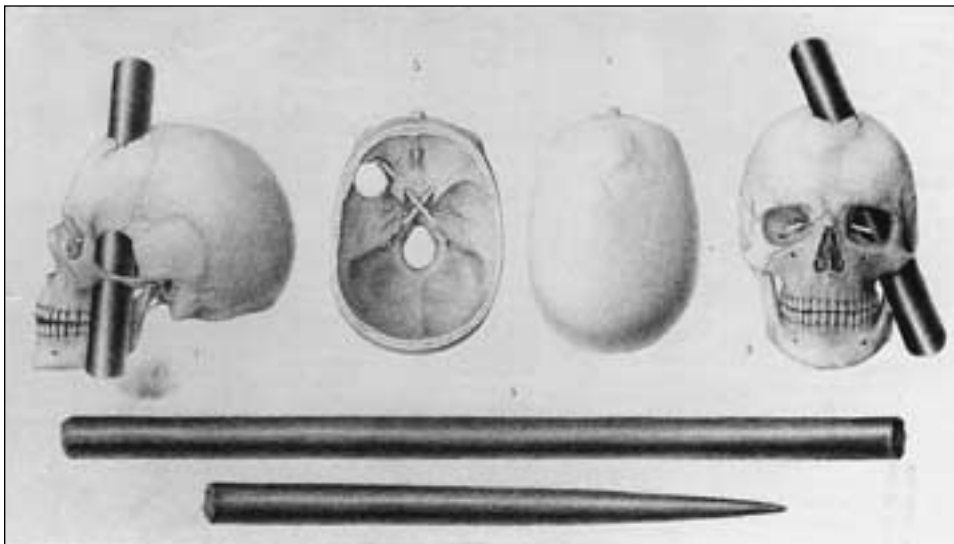
Penfield then administered a weak electrical current to the exposed cerebral cortex. He did so for two reasons. First, he wanted to induce an *aura* that would indicate the site that triggered the patient’s seizures. An *aura* is a sensation (such as an unusual odor) that precedes a seizure. Second, he wanted to avoid cutting through parts of the cerebral cortex that serve important functions.

Penfield found that stimulation of a point on the right frontal lobe might make the left forefinger rise, and that stimulation of a point on the left parietal lobe might make the patient report a tingling feeling in the right foot. After stimulating points across the entire cerebral cortex of many patients, Penfield found that the regions governing movement and bodily sensations formed the distorted upside-down maps of the body shown in Figure 3.12. His discovery has been verified by research on animals as well as on human beings. For example, stimulation of points on the cerebral cortex of baboons produces similar distorted “maps” of the body (Waters et al., 1990).

The **temporal lobes** have their own primary cortical area, the **auditory cortex**. Particular regions of the auditory cortex are responsible for processing sounds of particular frequencies (Schreiner, 1998). This enables the temporal lobes to analyze sounds of all kinds, including speech (Binder et al., 2000). When you listen to a symphony, certain areas of the auditory cortex respond more to the low-pitched sound of a tuba, while other areas respond more to the high-pitched sound of a flute.

At the back of the brain are the **occipital lobes**, which contain the **visual cortex**. This region integrates input from your eyes into a visual “map” of what you are viewing (Swindale, 2000). Because of the nature of the pathways from your eyes to your visual cortex, visual input from objects in your *right visual field* is processed in your left occipital lobe, and visual input from objects in your *left visual field* is processed in your right occipital lobe. Damage to a portion of an occipital lobe can produce a blind spot in the contralateral visual field. In some cases, damage can produce visual hallucinations, such as the perception of parts of objects that are not actually present (Anderson & Rizzo, 1994).

Association Areas. In reading about the brain, you might have gotten the impression that each area functions independently of the others. That is far from the truth. Consider the association areas that compose most of the cerebral cortex. These areas combine information from other areas of the brain. For example, the association areas of the frontal lobes integrate



◀ **Phineas Gage's Skull and the Tamping Rod That Pierced His Frontal Lobes**

information involved in thinking, planning, and problem solving. The unusually large association areas of the human cerebral cortex provide more area for processing information. This contributes to human beings' greater flexibility in adapting to diverse circumstances.

Some of the evidence supporting the importance of the association areas of the frontal lobes in emotion and personality has come from case studies of people with damage to it, most notably the case of Phineas Gage (Harlow, 1993). On a fall day in 1848, Gage, the 25-year-old foreman of a Vermont railroad crew laying track, was clearing away rocks. While he was using an iron tamping rod to pack a gunpowder charge into a boulder, a spark ignited the gunpowder. The resulting explosion hurled the rod into Gage's left cheek, through his frontal lobes, and out the top of his skull.

Miraculously, Gage survived, recuperated, and lived 12 more years, with little impairment of his intellectual abilities. But there were dramatic changes in his personality and emotionality. Instead of remaining the friendly, popular, hardworking man he had been before the accident, he became an ornery, disliked, irresponsible bully. Gage's friends believed he had changed so radically that "he was no longer Gage."

The case study of Phineas Gage implies that the frontal lobe structures damaged by the tamping rod might be important in emotion and personality. But as explained in Chapter 2, it is impossible to determine causality from a case study. Perhaps Gage's emotional and personality changes were caused not by the brain damage itself, but instead by Gage's psychological response to his traumatic accident or by changes in how other people responded to him. Nonetheless, the frontal lobe's importance in emotion and personality has been supported by subsequent scientific research (Luv, Collins, & Tucker, 2000).

As in the case of Phineas Gage, damage to the frontal lobes causes the person to become less inhibited, which produces emotional instability, inability to plan ahead, and socially inappropriate behavior (Macmillan, 2000). This indicates the association areas of the frontal lobes are especially important in helping us adapt our emotions and behavior to diverse situations. A case study of a 50-year-old man with frontal lobe damage similar to Gage's showed intact cognitive abilities but difficulty inhibiting his behavior and trouble in behaving responsibly (Dimitrov et al., 1999).

Language Areas. The integration of different brain areas underlies many psychological functions. Consider the process of speech, one of the most distinctly human abilities. Speech depends on the interaction of the association cortex of the frontal and temporal lobes. In most left-handed people and almost all right-handed people, the left cerebral hemisphere is superior to the right in processing speech. The speech center of the frontal lobe, **Broca's area**, is named for its discoverer, the French surgeon and anthropologist Paul Broca (1824–1880). In 1861 Broca treated a 51-year-old man named Leborgne, who was given the nickname "Tan"

auditory cortex

The area of the temporal lobes that processes sounds.

occipital lobe

A lobe of the cerebral cortex responsible for processing vision.

visual cortex

The area of the occipital lobes that processes visual input.



The Phineas Gage Information Page

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Broca's area

The region of the frontal lobe responsible for the production of speech.



▲ Tan's Brain

Tan's brain, preserved for more than a century, shows the damage to Broca's area in the left frontal lobe that destroyed his ability to speak.

Wernicke's area

The region of the temporal lobe that controls the meaningfulness of speech.

because he had a severe speech disorder that made *tan* the only syllable he could pronounce clearly. After Tan died of an infection, Broca performed an autopsy and found damage to a small area of the left frontal lobe of his brain. Broca concluded that this area controls speech. Tan's speech disorder is now called *Broca's aphasia*. (*Aphasia* is the Greek word for "speechless.") Broca's observation was confirmed in later autopsies of the brains of people who had speech disorders similar to Tan's. CT scans have also verified that damage to Broca's area in living people is, indeed, associated with Broca's aphasia (Breathnach, 1989).

What is the nature of Broca's aphasia? Though its victims retain the ability to comprehend speech, they speak in a telegraphic style that can be comprehended only by listeners who pay careful attention. For example, when one victim of Broca's aphasia was asked about a family dental appointment, he said, "Monday . . . Dad and Dick . . . Wednesday nine o'clock . . . doctors and teeth" (Geschwind, 1979, p. 186). The speaker expressed the important thoughts but failed to express the connections between them. Nonetheless, you probably got the gist of the statement.

Speech also depends on a region of the temporal lobe cortex called **Wernicke's area**, named for the German physician Karl Wernicke. In contrast to Broca's area, which controls the production of speech, Wernicke's area controls the meaningfulness of speech. In 1874, Wernicke reported that patients with damage to the rear margin of the left temporal lobe spoke fluently but had difficulty comprehending speech and made little or no sense to even the most attentive listener. This became known as *Wernicke's aphasia*.

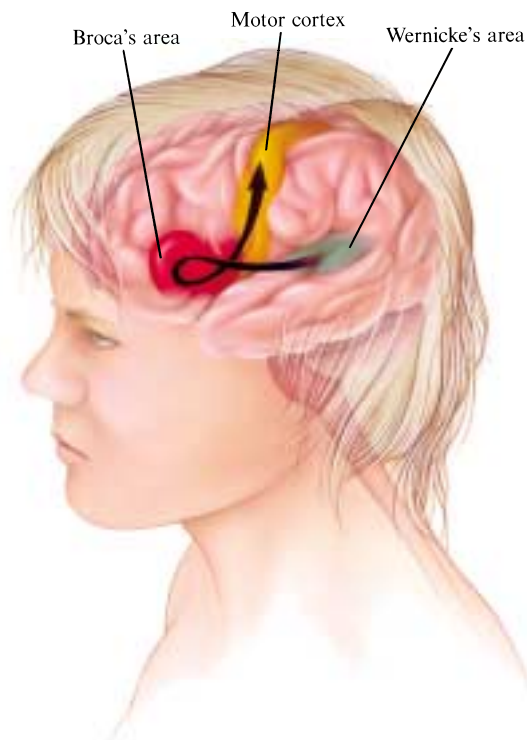
Consider the following statement by a victim of Wernicke's aphasia that is supposed to describe a picture of two boys stealing cookies behind a woman's back: "Mother is away here working her work to get her better, but when she's looking the two boys looking in the other part. She's working another time" (Geschwind, 1979, p. 186). The statement seems more grammatical than the telegraphic speech of the victim of Broca's aphasia, but it is impossible to comprehend—it is virtually meaningless.

The consensus among researchers is that speech production requires the interaction of Wernicke's area, Broca's area, and the motor cortex (Geschwind, 1979). Wernicke's area selects the words that will convey your meaning and communicates them to Broca's area. Broca's area then selects the muscle movements to express those words and communicates them to the region of the motor cortex that controls the speech muscles. Finally, the motor cortex communicates these directions through motor nerves to the appropriate muscles, and you speak the intended words. As you can see, speaking phrases as simple as *let's go out for pizza* involves the interaction of several areas of your brain (see Figure 3.13).

Cerebral Hemispheric Specialization

You may have noted reports in the popular media alleging that the cerebral hemispheres control different psychological functions, leading to the notion of "left-brained" and "right-brained" people. Though most researchers would not assign complete responsibility for any psychological function to just one hemisphere, they have reached agreement on some of the psychological functions for which each hemisphere is primarily responsible. The left hemisphere is somewhat superior at performing verbal, mathematical, analytical, and rational functions, and the right hemisphere is somewhat superior at performing nonverbal, spatial, holistic, and emotional functions (Springer & Deutsch, 1998). Some researchers believe we have evolved hemispheric specialization because it makes us more efficient in carrying out multiple activities at the same time, such as eating while remaining vigilant to potential threats (Rogers, 2000). Though each hemisphere has its own strengths, the hemispheres do not work in isolation. For example, the left hemisphere generally controls the production of speech, but the right hemisphere gives speech its appropriate emotional intonation (Snow, 2000).

But hemispheric specialization might differ between ethnic groups. A study comparing left- and right-hemispheric EEG patterns of natives of northeast Russia and immigrants to that region found significant differences between them during performance of tasks involving mental arithmetic and imagining a natural landscape (Rotenberg & Arshavsky, 1997). Moreover, there is some evidence of gender differences in cerebral lateralization. In one study, for example, men showed greater lateralization of language to the left hemisphere



◀ **Figure 3.13**
Speech and the Brain
 Wernicke's area, Broca's area, and the motor cortex interact in producing speech.

than did women (Jaeger et al., 1998). The size of this gender difference is small (Hiscock et al., 1995), however. In fact, other researchers have failed to find a gender difference at all (Frost et al., 1999).

Because about 90 percent of human beings are right-handed and, as a consequence, the manufactured environment favors right-handers, left-handers have some difficulties functioning in the everyday world. For example, left-handers have difficulty operating control panels designed for right-handers, especially under stressful conditions that can cause confusion, as in airplane cockpits. Because of this, human-factors engineers must consider left-handed people when designing control consoles (Garonzik, 1989). Nonetheless, left-handedness has some advantages. For example, a disproportionate number of competitive athletes are left handed, apparently because it provides a tactical advantage in sport competition (Grouios et al., 2000).

Because right-handedness is prevalent in virtually all cultures, heredity is evidently more important than life experiences in determining handedness and cerebral lateralization of functions. Additional evidence of this comes from research findings that even newborns show evidence of cerebral lateralization of psychological functions (Fein, 1990) and fetuses show a preference for sucking their right thumb while in the womb (Hepper, Shahidullah, & White, 1991). Yet cultural factors can override hereditary tendencies, as revealed in a survey of natives of the Amazon region of Colombia. All of the persons in the survey reported that they were right-handed. The researchers who did the survey concluded that those who had been born with initial tendencies toward left-handedness became right-handed as a result of cultural pressures to do so (Bryden, Ardila, & Ardila, 1993).

Perhaps the most controversial issue in recent years regarding handedness is whether right-handed people tend to live longer than left-handed people. There is no controversy about one fact: There are proportionately fewer left-handers among older adults than among younger adults. But as you will soon see, this does not necessarily mean that right-handers live longer. Two of the main proponents of the belief that right-handers do, in fact, live longer have been Stanley Coren and Diane Halpern.

Coren, a psychologist at the University of British Columbia, and Halpern, a psychologist at California State University at San Bernardino, pointed to earlier studies indicating that the percentage of right-handers was greater in older age groups (Coren & Halpern, 1991).

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► **Figure 3.14**
Handedness and Longevity

As the graph indicates, when comparing different age groups the proportion of left-handers in the population decreases as the age of the group increases. Whereas about 15 percent of young adults are right-handers, almost none of those above age 80 are left-handers. It is unclear whether this decline reflects the greater longevity of right-handers or the forced change from left-handedness to right-handedness in some members of older age groups earlier in their lives.

Source: Coren, S. (1992). *The left-hander syndrome*. New York: Free Press.

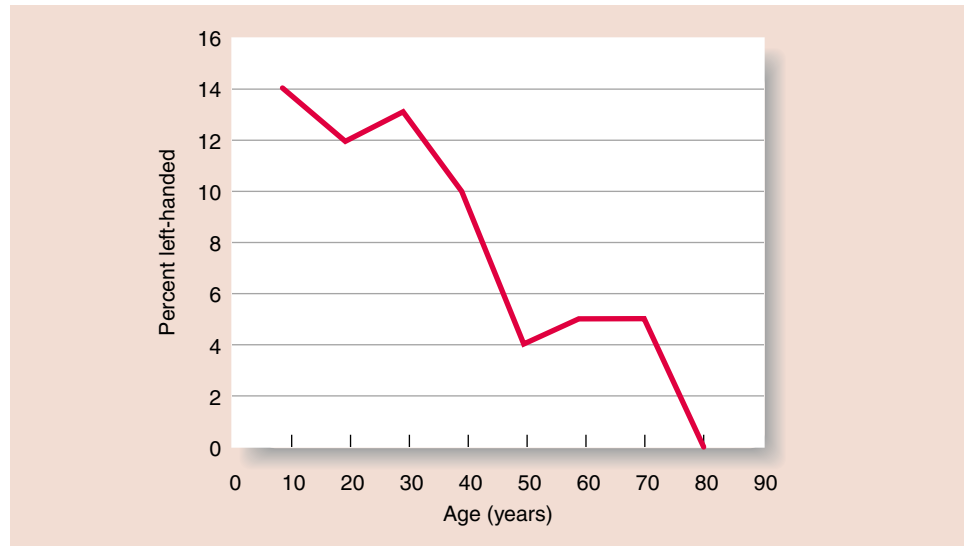


Figure 3.14 illustrates the drastic change in the percentage of left-handers from younger age groups to older ones (Porac & Coren, 1981). Note that by age 80 there are virtually no left-handers in the population! To assess this handedness effect, Halpern and Coren (1988) conducted an archival study of longevity in professional baseball players, using the *Baseball Encyclopedia* as their source of data on more than 2,000 players. They found that, on the average, right-handers lived 8 months longer than left-handers. This inspired them to replicate that study to determine if their findings would generalize to people other than baseball players.

Coren and Halpern sent brief questionnaires to the next of kin of 2,875 persons who recently had died in two counties in southern California. The questionnaires asked questions about the deceased’s handedness regarding writing, drawing, and throwing. Each person’s age at death was obtained from death certificates. Despite the apparent intrusion of the questionnaires into the lives of grieving relatives, 1,033 questionnaires were returned. Of these, 987 were usable. Coren and Halpern determined whether the deceased had been right-handed or left-handed.

The results were startling: right-handers lived an average of 9 years longer than left-handers. Thus, this study found a much larger longevity gap than the study of baseball players found. Coren and Halpern attributed the gap to the earlier deaths of left-handers (the *elimination hypothesis*) rather than to cultural pressures to become right-handed (the *modification hypothesis*) affecting older generations more than younger ones. Coren and Halpern found that the most important factors accounting for this were a greater tendency for left-handers to have accidents, immune disorders, and evidence of neurological defects. For example, a Canadian study of people hospitalized for head injuries caused by automobile accidents found that victims were disproportionately left-handers (MacNiven, 1994).

Research findings have not consistently supported Coren and Halpern’s findings. Even the allegedly longer life spans of right-handed baseball players have been called into question. A large-scale study of more than 5,000 professional baseball players found that left-handers actually lived an average of 8 months longer than right-handers (Hicks et al., 1994). Coren and Halpern’s explanations for the apparent longevity difference favoring right-handers also have been called into question. For example, a study in the Netherlands found no relationship between accident proneness and handedness among undergraduate students (Merckelbach, Muris, & Kop, 1994). Moreover, research has been inconsistent on the relationship between handedness and immune disorders, with some even showing that right-handers are more susceptible to them (Bryden, 1993). And there is conflicting evidence about the greater likelihood of neurological disorders in left-handers (Bishop, 1990).

The strongest response to Coren and Halpern has come from Lauren Harris of Michigan State University, who believes the modification hypothesis is a better explanation for the



▲ **Stanley Coren and Diane Halpern**
 “The absence of left-handedness in older age groups may be due to the elimination of this set of individuals through selective mortality.”

decline in left-handers across the life span (Harris, 1993). According to Harris, today's older adults grew up at a time when left-handers were forced to use their right hands or simply chose to conform to a right-handed world. In contrast, over the past few decades left-handedness has lost its stigma, resulting in more left-handers remaining left-handed.

This was supported by a study in Norway. In keeping with Coren and Halpern's findings, the researchers found that about 15.2 percent of 21- to 30-year-olds were left-handed and only 1.7 percent of those more than 80 years old were left-handed. But the researchers found that the apparent decline in left-handedness across the life span was, in reality, due to the fact that many left-handers in earlier generations had switched to being right-handed (Hugdahl et al., 1993). Despite these findings, which contradict their position, Halpern and Coren (1993) insist that most scientifically sound studies support their belief that left-handers tend to die younger.

Several questions remain to be answered, but the main one is this: If we follow groups of young people as they grow older, will the left-handers tend to die sooner than the right-handers? If they do, it would support Coren and Halpern's explanation. If they do not, it would support Harris's explanation. Of course, this would take many decades to determine.

In addition to their interest in handedness, cerebral-laterality researchers study the psychological functions of the left and right hemispheres. They do so by studying the damaged brain, the intact brain, and the split brain.

Evidence of Hemispheric Specialization from the Damaged Brain. As you read earlier in the chapter, the earliest source of knowledge about cerebral hemispheric specialization was the study of unilateral brain damage; that is, damage to one cerebral hemisphere. If damage to one hemisphere of the brain produces symptoms that differ from symptoms produced by damage to the other hemisphere, researchers conclude that the damaged hemisphere plays more of a role in that function than does the other hemisphere.

Paul Broca, after finding that a specific kind of language disorder consistently followed damage to the left hemisphere, concluded that language depended more on the left hemisphere than on the right hemisphere (Harris, 1999). More recent research on brain damage has found that both hemispheres are involved in language, but that their particular roles differ. For example, though the left hemisphere is more important for the production and comprehension of speech, the right hemisphere is more important for processing aspects of speech unrelated to the spoken words themselves. For example, damage to the right hemisphere produces greater deterioration in the ability to interpret the speaker's tone of voice than does damage to the left hemisphere (Ross, Thompson, & Yenkosky, 1997).

Evidence of Hemispheric Specialization from the Intact Brain. Psychologists interested in hemispheric specialization have devised several methods for studying the intact brain. One of the chief methods has participants perform tasks while an EEG records the electrical activity of their cerebral hemispheres. Studies have found that people produce greater electrical activity in the left hemisphere while performing verbal tasks, such as solving verbal analogy problems, and greater electrical activity in the right hemisphere while performing spatial tasks, such as mentally rotating geometric forms (Loring & Sheer, 1984). Research using functional MRI has demonstrated activity in the language areas of the left hemisphere even in people using American Sign Language. But American Sign Language also involves greater involvement of the right hemisphere than does English (Bavelier et al., 1998).

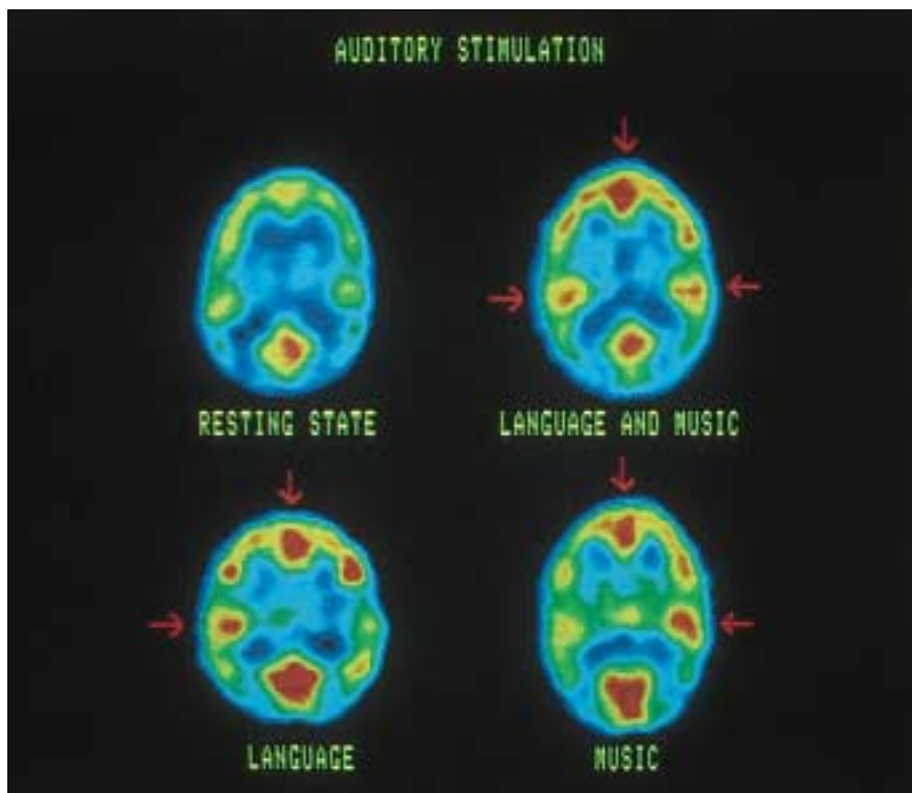
A more recent approach to studying hemispheric specialization in the intact brain uses the PET scan to create color-coded pictures of the relative activity in regions of the left hemisphere and right hemisphere. Figure 3.15 shows the results of one such study. Another approach, the **Wada test**, studies human participants in whom a hemisphere has been anesthetized in the course of brain surgery to correct a neurological defect (Izac & Banoczi, 1999). This is done by injecting a barbiturate anesthetic into either the right or the left carotid artery, which provides oxygenated blood to the associated cerebral hemisphere. The injection anesthetizes that hemisphere. As you might expect, anesthetization of the left hemisphere, but only rarely of the right hemisphere, induces temporary aphasia—the patient has difficulty speaking (Mueller et al., 1998).

Wada test

A technique in which a cerebral hemisphere is anesthetized to assess hemispheric specialization.

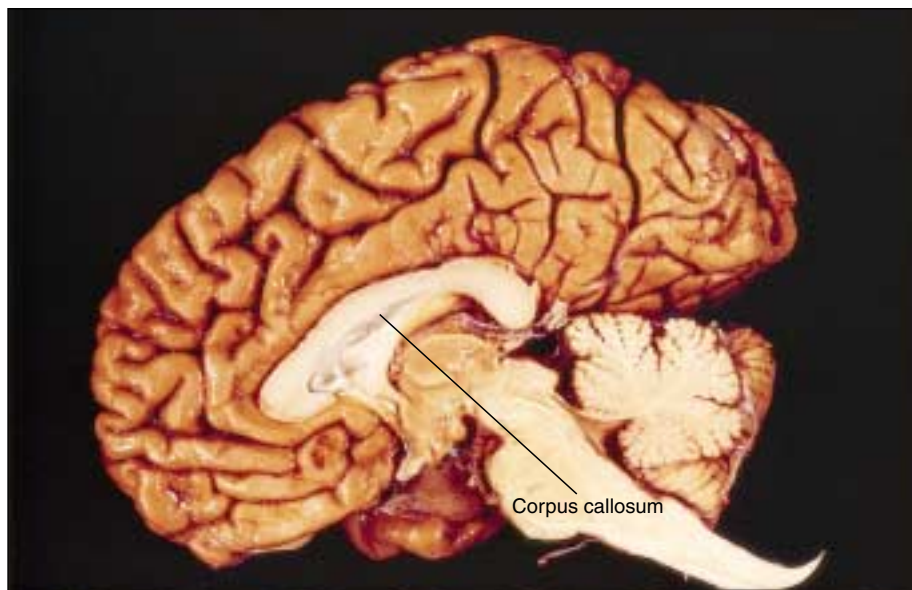
► **Figure 3.15**
The PET Scan and Hemispheric Specialization

The red areas of these PET scans show that the left hemisphere is more active when we listen to speech and the right hemisphere is more active when we listen to music (Phelps & Mazziotta, 1985).



► **Figure 3.16**
Split-Brain Surgery

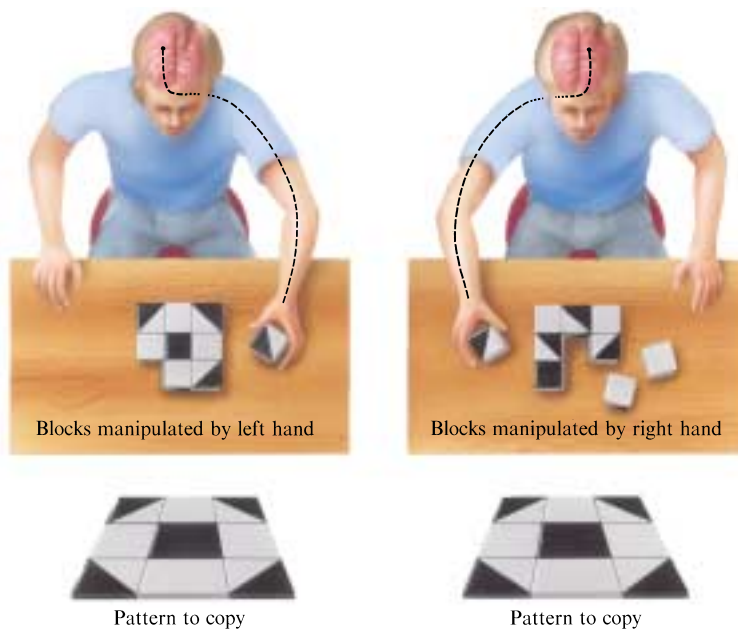
Severing the corpus callosum disconnects the cerebral hemispheres from each other. Note that in “split-brain” surgery, the entire brain is not split. That would cut through the brain stem structures that control vital functions, causing immediate death.



split-brain research

Research on hemispheric specialization that studies individuals in whom the corpus callosum has been severed.

Evidence of Hemispheric Specialization from the Split Brain. Studies of damaged brains and intact brains have provided most of the evidence regarding cerebral hemispheric specialization, but the most fascinating approach has been **split-brain research**. This involves people whose hemispheres have been surgically separated from each other. Though split-brain research is only a few decades old, the idea was entertained in 1860 by Gustav Fechner, who was introduced in Chapter 1 as a founder of psychology. Fechner claimed that people who survived the surgical separation of their cerebral hemispheres would have two separate minds in one head (Springer & Deutsch, 1998). Decades later English psychologist William McDougall argued that such an operation would not divide the mind, which he considered



◀ **Figure 3.17**
A Split-Brain Study

Gazzaniga (1967) had a split-brain patient arrange multicolored blocks to match a design printed on a card in front of him. The patient's left hand performed better than his right, because the left hand is controlled by the right hemisphere, which is superior at perceiving spatial relationships. You would be able to perform a block-design task equally well with either your right or your left hand, because your intact corpus callosum would let information from your spatially superior right hemisphere help your left hemisphere control your right hand.

indivisible. McDougall even volunteered to test Fechner's claim by having his own cerebral hemispheres surgically separated if he ever became incurably ill.

Though McDougall never had split-brain surgery, it was performed on patients in the early 1960s, when neurosurgeons Joseph Bogen and Phillip Vogel severed the **corpus callosum** of epileptic patients to reduce seizure activity that had not responded to drug treatments. As illustrated in Figure 3.16, the corpus callosum is a thick bundle of axons that provides the means of communication of information between the cerebral hemispheres (Gazzaniga, 2000). Split-brain surgery works by preventing seizure activity in one hemisphere from spreading to the other. Split-brain patients behave normally in their everyday lives, but special testing procedures have revealed an astonishing state of affairs: Their left and right hemispheres can no longer communicate with each other (Reuter-Lorenz & Miller, 1998). Each acts independently of the other.

Roger Sperry (1982) and his colleagues, most notably Jerre Levy and Michael Gazzaniga, have been pioneers in split-brain research. In a typical study of a split-brain patient, information is presented to one hemisphere and the participant is asked to give a response that depends more on one hemisphere than on the other. In one study (Gazzaniga, 1967), a split-brain patient performed a block-design task in which he had to arrange multicolored blocks so that their upper sides formed a pattern that matched the pattern printed on a card in front of him. This is illustrated in Figure 3.17. When the participant performed with his left hand, he did well, but when he performed with his right hand, he did poorly. Can you figure out why that happened?

Because the left hand is controlled by the right hemisphere, which is superior in perceiving spatial relationships, such as those in designs, he performed well with his left hand. And because the right hand is controlled by the left hemisphere, which is inferior in perceiving spatial relationships, he performed poorly with his right hand—even though he was right-handed. At times, when his right hand was having a hard time completing the design, his left hand would sneak up on it and try to help. This led to a bizarre battle for control of the blocks—as if each hand belonged to a different person.

Despite the dramatic findings of split-brain studies, Jerre Levy (1983) believes that researchers, including Gazzaniga (1983), have exaggerated the extent to which each hemisphere regulates particular psychological processes, especially the supposed superiority of the left hemisphere. As always, only additional scientific research will resolve the Levy-Gazzaniga debate, which, you might note, is an example of the continual controversy over the degree to which psychological functions are localized in particular areas of the brain.

corpus callosum

A thick bundle of axons that provides a means of communication between the cerebral hemispheres, which is severed in so-called split-brain surgery.



▲ Jerre Levy

"Although the right hemisphere is nonlinguistic (except in unusual or pathological cases), the evidence is overpowering that it is active, responsive, highly intelligent, thinking, conscious, and fully human with respect to its cognitive depth and complexity."

STAYING ON TRACK: *The Brain*

1. What are the functions of the brain stem, the limbic system, and the cerebral cortex?
2. What roles do Broca's and Wernicke's area play in speech production?
3. What evidence is there for hemispheric specialization based on split-brain research?

Answers to Staying on Track start on p. S-2.

Chapter Summary

HEREDITY AND BEHAVIOR

- The field of behavioral neuroscience studies the relationships between physiological processes and psychological functions.
- Psychologists who champion evolutionary psychology employ Darwinian concepts in their research and theorizing.
- Scientists who study behavioral genetics are interested in how heredity affects behavior.
- Heritability refers to the proportion of variability in a trait across a population attributable to genetic differences among members of the population
- Research procedures that assess the relative contributions of nature and nurture involve studies of families, adoptees, and identical twins reared apart.

COMMUNICATION SYSTEMS

- The nervous system is composed of cells called neurons and serves as the main means of communication within the body.
- The nervous system is divided into the central nervous system, which comprises the brain and the spinal cord, and the peripheral nervous system, which comprises the nerves of the somatic nervous system and the autonomic nervous system.
- The autonomic nervous system is subdivided into the sympathetic nervous system, which arouses the body, and the parasympathetic nervous system, which conserves energy.
- Hormones, secreted into the bloodstream by endocrine glands, also serve as a means of communication within the body.
- Most endocrine glands are regulated by hormones secreted by the pituitary gland, which, in turn, is regulated by the hypothalamus.
- Hormones participate in functions as diverse as sexual development and responses to stress.

THE NEURON

- The nervous system carries information along sensory neurons, motor neurons, and interneurons, as in the limb-withdrawal reflex mediated by the spinal cord.
- The neuron generally receives signals through its dendrites and sends signals along its axon.
- The axon maintains a resting potential during which it is electrically negative on the inside relative to its outside, as a result of a higher concentration of negative ions inside.
- Sufficient stimulation of the neuron causes the axon to depolarize (become less electrically negative) and reach its firing threshold.

- This produces an action potential, which causes a neural impulse to travel along the entire length of the axon.
- The neural impulses stimulate the release of neurotransmitter molecules into the synapse. The molecules cross the synapse and attach to receptor sites on glands, muscles, or other neurons. These molecules exert either an excitatory or an inhibitory influence.
- In recent years, the neurotransmitters known as endorphins have inspired research because of their role in pain relief and euphoria.

THE BRAIN

- The functions of the brain have been revealed by clinical case studies, experimental manipulation, recording of electrical activity, and brain-imaging techniques.
- The medulla regulates vital functions, such as breathing; the pons regulates arousal and attention; and the cerebellum controls the timing of well-learned sequences of movements.
- The reticular formation regulates brain arousal and helps maintain vigilance.
- The thalamus relays sensory information (except smell) to various regions of the brain for further processing.
- Within the limbic system, the hypothalamus regulates the pituitary gland, as well as emotion and motives such as eating, drinking, and sex.
- The amygdala continuously evaluates the immediate environment for potential threats, and the hippocampus processes information into memories.
- The cerebral cortex covers the brain and is divided into the frontal, temporal, parietal, and occipital lobes.
- Well-defined areas of the lobes regulate movements and process sensory information.
- Most areas of the cerebral cortex are association areas devoted to integrating information from different brain areas, such as those devoted to speech.
- Each cerebral hemisphere has psychological functions at which it excels, though both hemispheres influence virtually all functions.
- Studies of the degree of activity in each hemisphere, of the effects of damage to one hemisphere, and of people whose hemispheres have been surgically disconnected show that the left hemisphere is typically superior at verbal tasks and the right hemisphere is typically superior at spatial tasks.

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Thought Questions

1. How do psychologists interested in behavioral genetics use studies of identical twins reared apart to assess the role of heredity in human development?
2. How would you determine whether the joy of a student who earns a 4.00 grade-point average is associated with an increase in endorphin levels?

3. Why do some psychologists believe that phrenology was an important but misguided approach to the localization of brain functions?
4. How does split-brain research provide evidence that the left cerebral hemisphere predominates in speech and the right cerebral hemisphere predominates in spatial relations?

Possible Answers to Thought Questions start on p. P-1

OLC Preview



For additional quizzing and a variety of interactive resources, visit the book's Online Learning Center at www.mhhe.com/sdorow5.