Key Question Chapter Outline

How Are Genes and Behavior Linked?

Evolution and Natural Selection
Genetics and Inheritance

How Does the Body Communicate Internally?

The Neuron: Building Block of the Nervous System
Divisions of the Nervous System
The Endocrine System

How Does the Brain Produce Behavior and Mental Processes?

Windows on the Brain
Three Layers of the Brain
Lobes of the Cerebral Cortex
The Cooperative Brain
Cerebral Dominance
The Split Brain: "I've Half a Mind to . . ."

Biopsychology: The State of the Art

CORE CONCEPTS

Evolution has fundamentally shaped psychological processes because it favors genetic variations that produce adaptive behavior.

The brain coordinates the body's two communications systems, the nervous system and the endocrine system, which use similar chemical processes to communicate with targets throughout the body.

The brain is composed of many specialized modules that work together to create mind and behavior.

Psychology in Your Life

Choosing Your Children's Genes

Within your lifetime, parents may be able to select genetic traits for their children. What price will we pay for these choices?

How Psychoactive Drugs Affect the Nervous System

Chemicals used to alter thoughts and feelings usually affect the actions of hormones or neurotransmitters. In so doing, they may also stimulate unintended targets, where they produce unwanted side effects.

Brain Damage and Behavior

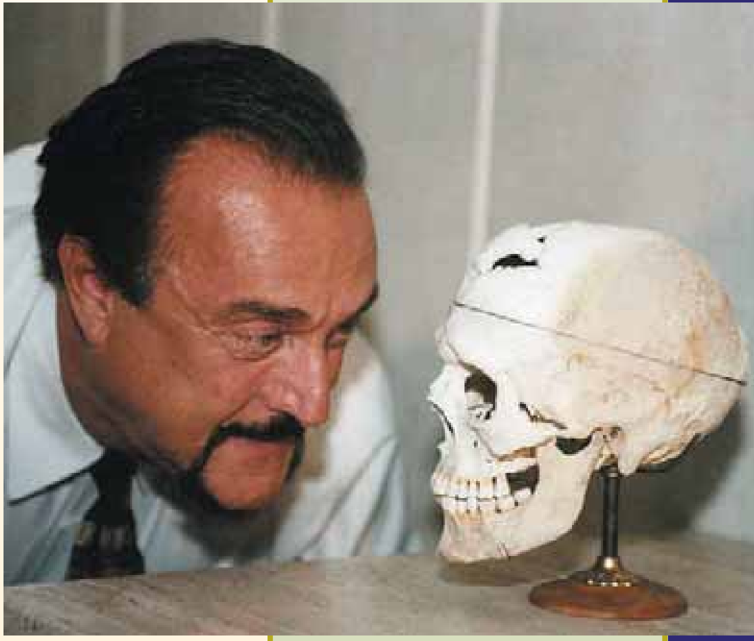
Everyone knows somebody who has suffered brain damage from an accident, a tumor, or a stroke. The symptoms suggest which part of the brain was damaged.

USING PSYCHOLOGY TO LEARN PSYCHOLOGY
Putting Your Knowledge of the Brain to Work

Chapter

3

Biopsychology and the Foundations of Neuroscience



I HADN'T NOTICED DAD dragging the toe of his right foot ever so slightly as he walked. But my mother noticed it on their nightly tour of the neighborhood, when he wasn't keeping up with her brisk pace. I just figured that he was slowing down a bit in his later years.

Dad, too, casually dismissed his symptom, but Mom was persistent. She scheduled an appointment with the doctor. In turn, the doctor scheduled a brain scan that showed a remarkably large mass—a tumor—on the left side of Dad's brain. You can see what the neurologist saw in Figure 3.1—an image taken ear-to-ear through the head.

When I saw the pictures, I knew immediately what was happening. The tumor was located in an area that would interfere with tracking the position of the foot. As I remembered learning in my introductory psychology class, each side of the brain communicates with the opposite side of the body—so it made sense that the tumor showing so clearly on the left side of Dad's brain (right side of the image) was affecting communications with his right foot.

The neurologist also told us that the diseased tissue was not in the brain itself. Rather, it was in the saclike layers surrounding the brain and spinal cord. That was good news, in an otherwise bleak report. Still, the mass was growing and putting pressure on the brain. The recommendation was surgery—which occurred after an anxious wait of a few weeks.

During this difficult time, I remember feeling grateful for my professional training. As a psychologist, I knew something about the brain, its disorders, and treatments.

● **FIGURE 3.1** MRI Image of a Brain Tumor

This image, showing a side-to-side section toward the back of the head, reveals a large mass on the left side of the brain, in a region involved with tracking the position of the right foot. Visible at the bottom is a cross section of the cerebellum. Also visible are the folds in the cerebral cortex covering the brain. Near the center, you can see two of the brain's ventricles (hollow spaces filled with cerebrospinal fluid), which are often enlarged, as they are here, in Alzheimer's disease. The scan is of the father of one of your authors.

This allowed me to shift perspectives—from son to psychologist and back again. It helped me deal with the emotions that rose to the surface when I thought about the struggle for the organ of my father's mind.

Sadly, the operation did not produce the miraculous cure for which we had hoped. Although brain surgery is performed safely on thousands of patients each year—many of whom receive immense benefits in the quality and lengths of their lives—one has to remember that it is a procedure that is usually done on very sick people. In fact, the operation did give Dad some time with us that he may otherwise not have had.

—RJ

You, too, probably know someone—a relative or a friend—who has suffered a brain injury. It might have involved a tumor, an auto accident, a combat wound, encephalitis (inflammation of the brain), a stroke, or some other trauma, including a difficult birth. This chapter is a tribute to the scores of thousands who have incurred such injuries and allowed themselves to be studied by scientists trying to understand how the brain works. In the following pages, you will learn about the resulting discoveries, as we explore the physical basis of mind and behavior.

What do we know about the brain? In the simplest terms, it is about the size of a grapefruit, it weighs about 3 pounds, and it has a pinkish-gray and wrinkled surface. But such bland facts give us no hint of the brain's amazing structure and capabilities. The home of some 100 billion nerve cells, each making connections with up to 10 thousand other nerve cells, the human brain is the most complex structure known. Its intricate circuitry makes our largest computers seem primitive by comparison. Indeed, its cells outnumber all the stars in the galaxy.

At birth, the brain has an extra supply of nerve cells, and many surplus ones die in the first few years of our lives. By adolescence the number stabilizes. Although our brains generate some new nerve cells throughout our lives, the total remains essentially constant once we reach adulthood (Barinaga, 2003a; Gage, 2003; Kempermann & Gage, 1999). This neural stability may be essential for the continuity of learning and memory over a long lifetime (Rakic, 1985). Even so, the nerve cells in our brains do continue to expire at a low rate: A mere 200,000 will die every day of your adult life (Dowling, 1992). Fortunately, because we start out with so many and generate some new ones along the way, we end up with more than 98% of our supply after 70 years.

As for its capabilities, the brain uses its vast nerve circuitry to regulate all our body functions, control our behavior, generate our emotions and desires, and process the experiences of a lifetime. In addition—and unlike any ordinary computer—the brain has circuits capable of producing emotions, motives, and insights. This dazzling array of abilities may seem to involve something far more than a mere knot of nervous tissue lying inside our heads—and it does! Yet when disease, drugs, or accidents destroy brain cells, the biological basis of the human mind becomes apparent. We are then forced to recognize that biology underlies all human sensation and perception, learning and memory, passion and pain, reason—and even madness.

Most remarkable of all, the human brain has the ability to think about itself. This is one of the fascinations for researchers in **biopsychology,** a rapidly growing specialty that lies at the intersection of biology, behavior, and mental processes. Increasingly, biopsychologists are collaborating with cognitive psychologists, biologists, computer scientists, chemists, neurologists, linguists and others interested in the connection between brain and mind—how the circuitry of the brain produces mental processes and behavior. The result is a vibrant interdisciplinary field known as **neuroscience** (Kandel & Squire, 2000).

In this chapter, you will see that biopsychologists and other neuroscientists have made many discoveries that have practical applications in everyday life. For example, we now know that sleep patterns are controlled by specific parts of the brain—with the result that we now have effective treatments for a variety of sleep disorders. Likewise, the attraction of certain psychoactive drugs, such as cocaine, heroin, and methamphetamine, makes sense only when we understand how these drugs interact with chemicals made in the brain. And, as we pointed out earlier, a little knowledge of biopsychology will be helpful when someone you know sustains brain damage as the result of an accident, stroke, or Alzheimer's disease.

CONNECTION: CHAPTER 5

Neuroscientists have discovered the causes and treatments for many *sleep disorders.*

We will begin our exploration of biopsychology and neuroscience at the most basic level—by considering the twin domains of *genetics* and *evolution,* both of which have shaped our bodies and minds. Then we will examine the *endocrine system* and the *nervous system,* the two communication channels carrying messages throughout the body. Finally, we will focus on the brain itself. As we follow this path, please keep in mind that we are not asking you to undertake a mere academic exercise: You will be learning how biological processes shape your every thought, feeling, and action.

■ **Biopsychology** The specialty in psychology that studies the interaction of biology, behavior, and mental processes.

■ **Neuroscience** A relatively new interdisciplinary field that focuses on the brain and its role in psychological processes.

KEY QUESTION

HOW ARE GENES AND BEHAVIOR LINKED?

Just as fish have an inborn knack for swimming and most birds are built for flight, we humans also have *innate* (inborn) abilities. At birth, the human brain is already "programmed" for language, social interaction, self-preservation, and many other functions, as we can see in the interaction between babies and their caregivers. Babies "know," for example, how to search for the breast and how to communicate through coos and cries. We'll look more closely at the menu of innate human behaviors in our discussion of human development (Chapter 4), but for now, this is the question: How did such potential come to be woven into the brain's fabric?

The scientific answer rests on the concept of **evolution,** the process by which succeeding generations of organisms change as they adapt to changing environments. We can observe evolution in action on a microscopic level, when an antibiotic doesn't work because a strain of bacteria has evolved a resistance. Over much longer time spans, generations of larger and more complex organisms also change, as they adapt to changing climates, competitors, diseases, and food supplies. In our species, for example, change has favored large brains suited to language, complex problem solving, and social interaction.

Our Core Concept for this section makes this evolutionary process the link between genetics and behavior.

CORE CONCEPT

Evolution has fundamentally shaped psychological processes because it favors genetic variations that produce adaptive behavior.

The idea of evolution is both simple and powerful. In this section we begin our explanation of evolution with the story of Charles Darwin, who gave the idea of evolutionary change to the world. Then we will consider an idea Darwin never knew: how *genetics* produces the molecular machinery that makes evolution work—and ultimately influences all our psychological processes.

Evolution and Natural Selection

Although he had trained for both medicine and the ministry, Charles Darwin decided that biology was his calling. So, in 1831, he signed on as a naturalist aboard HMS *Beagle,* a British research vessel commissioned to survey the coastline of South America. Returning five years later with numerous specimens and detailed records of the many unusual life-forms and fossils he had found, Darwin also brought home the radical idea of a relationship among species. Struck by the similarities among the various animals and plants he studied, Darwin concluded that all creatures, including humans, share a common ancestry.

He knew this notion flew in the face of accepted scholarship, as well as the religious doctrine of creationism. Thus, in his famous book, *On the Origin of Species* (1859), Darwin carefully made the case for the evolution of life. And controversial it was. The essential features of his argument, however, withstood withering attacks, and eventually the theory of evolution created a fundamental change in the way people saw their relationship to other living things (Keynes, 2002; Mayr, 2000).

What was the evidence that led Darwin to his radical conclusion about the evolution of organisms? Again and again on the voyage, he had observed organisms that were exquisitely adapted to their environments: flowers that attracted certain insects, birds with beaks perfectly suited to cracking certain

■ **Evolution** The gradual process of biological change that occurs in a species as it adapts to its environment.

seeds. He had also observed *variation* among individuals within a species: Some finches, for example, had bigger, stronger beaks than others, just as some humans are taller than others or have better eyesight (Weiner, 1994). Such variations gave some individuals an advantage over others in the struggle for survival and reproduction. This, then, suggested a mechanism for evolution: a "weeding out" process that he called **natural selection.** By means of natural selection, those individuals best adapted to the environment are more likely to flourish and reproduce; those that are poorly adapted will tend to leave fewer progeny, and their line may die out. (You may have heard this described as "survival of the fittest," a term Darwin disliked.) For the fortunate individuals whose ancestors had accumulated new traits that allowed them to adapt and survive, the result "would be the formation of a new species," claimed Darwin (1859).

Applied to psychology, evolution makes sense of many things that would otherwise seem arbitrary. For example, evolutionary psychologists have pointed out that human *phobias* (extreme and incapacitating fears) almost always involve stimulation that signaled danger to our ancestors (snakes, lightning, blood), rather than dangerous conditions of more recent origin (radiation, electricity, automobiles). In the same way, the fact that we spend about a third of our lives asleep makes much more sense in an evolutionary context (sleep kept our ancestors out of trouble in the dark) than it does as an adaptive behavior in a modern world with artificial lights. Evolution also explains certain innate preferences and distastes, such as the attractiveness of sweets and fatty foods (good sources of valuable calories for our ancestors) and a dislike for bitter-tasting substances (often a sign of poisons).

"Evolution" is, of course, an emotionally loaded term, and many people misunderstand its real meaning. For example, some believe that Darwin's theory says humans "come from monkeys." But neither Darwin nor any other evolutionary scientist has ever said that. Rather, they say we had a common ancestor millions of years ago—a big difference. Another evolutionary misconception holds that behavior can alter hereditary traits. But giraffes didn't get long necks from stretching to reach leaves high in the trees. Instead, the doctrine of natural selection says that the ancestors of modern giraffes were variants that had a survival advantage over their shorter-necked cousins. Over time, then, the longer-necked trait came to dominate the population. In the same way, evolving human traits, such as a big brain adapted for language, gave our ancestors an advantage in the competitive struggle for survival and reproduction (Buss et al., 1998).

We should be clear that the basic principles of evolution, while still controversial in some quarters, have been accepted by virtually all scientists for more than a century. That said, we should note that evolutionary theory is a controversial newcomer to psychology. It is not that psychologists dispute Darwin—most do not. Rather, the controversy centers on whether an evolutionary approach places too much emphasis on *nature,* the biological basis of psychology, and not enough emphasis on *nurture,* the role of learning. This *nature–nurture controversy* is a long-standing issue in psychology that we will meet again and again throughout this book. Sometimes it is also called the *heredity vs. environment* issue.

In later chapters we will discuss specific evolutionary explanations that have been advanced to explain aggression, jealousy, sexual orientation, physical attraction and mate selection, parenting, cooperation, temperament, morality, and (always a psychological hot potato) gender differences. But for now, let us turn our attention to the biological underpinnings of evolutionary change.

CONNECTION: CHAPTERS 7 AND 9

The *nature–nurture controversy* is a prominent issue in developmental psychology and in intelligence testing.

■ **Natural selection** The driving force behind evolution, by which the environment "selects" the fittest organisms.

Genetics and Inheritance

Remarkably, Darwin knew nothing of genetics. Although he correctly described how natural selection works, he lived long before scientists understood the biology behind evolutionary change. From our perspective, some 150 years after Darwin, we know that the individual variations that caught his attention arise from random genetic differences among individuals.

In principle, the genetic code is quite simple. Much as the microscopic pits in a CD encode information that can become pictures or music, your *genes* encode information that can become your inherited traits. Consider your own unique combination of traits. Your height, weight, facial features, and hair color, for example, all originate in the encoded genetic "blueprint" inherited from your parents and inscribed in every cell nucleus in your body. Psychologists have shown that many of our psychological characteristics, too, are influenced by genetics, including basic temperament, tendency to fears, and certain behavior patterns (Pinker, 2002).

Yet, despite your genetic heritage, you are a unique individual—different from either of your parents. One source of difference lies in your experience, in the environment in which you grew up—distinct in time and, perhaps, in place from that of your parents. The other main source of difference between you and your parents comes from heredity—the random combination of traits that each parent passed on to you from past generations in their own family lines. These include the color of your hair, eyes, and skin, as well as aspects of your personality. This hybrid inheritance produced your unique **genotype,** the genetic pattern that makes you different from anyone else on earth.

If the genotype is the "blueprint," then the resulting physical structure is the **phenotype.** All your physical characteristics make up your phenotype, including not only your visible traits but also the chemistry and "wiring" of your brain. We should hasten to point out that although the phenotype is based in biology, it is not completely determined by heredity. Heredity never acts alone but always in partnership with the environment, which includes such biological influences as nutrition, disease, and stress. For example, poor medical care that results in a birth defect counts as an environmental influence on the phenotype.

Now, with these ideas about heredity, environment, genotypes, and phenotypes fresh in mind, let's turn to the details of heredity and individual variation that Darwin never knew.

Chromosomes, Genes, and DNA In the film *Jurassic Park,* scientists recovered the genetic code for dinosaurs and created an island full of reptilian problems. The story, of course, was science fiction, yet the film rested on an important scientific fact: Every cell nucleus in the body carries a complete set of biological instructions for building the organism. For humans, these instructions are contained in 23 pairs of chromosomes, which, under a high-powered microscope, look like tiny twisted threads. Zooming in for a close look, we find that each chromosome consists of a long and tightly coiled chain of **DNA** (deoxyribonucleic acid), a molecule that just happens to be especially well suited to storing this biological information.

Genes are the "words" that make up the organism's instruction manual. Encoded in discrete segments of DNA, each gene contributes to the operation of the organism by specifying a single protein. Thousands of such proteins, in turn, serve as the building blocks for the organism's physical characteristics (the phenotype) and the regulation of the body's internal operations. Genes, because they are not precisely the same in each individual, are also the biological source of the variation that caught Darwin's attention.

■ **Genotype** An organism's genetic makeup.

■ **Phenotype** An organism's observable physical characteristics.

■ **DNA** A long, complex molecule that encodes genetic characteristics. DNA is an abbreviation for *deoxyribonucleic acid.*

■ **Gene** Segment of a chromosome that encodes the directions for the inherited physical and mental characteristics of an organism. Genes are the functional units of a chromosome.

The genes occur in sequence on the **chromosomes,** like a string of words in a coded sentence. But the chromosomes are much more than mere genetic paragraphs. They also contain "punctuation" that indicates where each gene begins and ends, along with instructions specifying how and when the genes are to be expressed (Gibbs, 2003). Although these instructions are not yet well understood, genetic scientists have shown that the instructions for gene expression are crucial to the proper functioning of every cell in our bodies. Errors in gene expression can lead to physical and developmental problems, including mental retardation. At the extreme, flawed gene expression can produce fatal diseases.

On a still smaller scale (now we're getting beyond the power of microscopes to resolve), genes are composed of even smaller molecular units called *nucleotides* that serve as individual "letters" in the genetic "words." But instead of a 26-letter alphabet, the genetic code uses just four nucleotides, even though a particular gene may require hundreds of nucleotides to specify a particular protein.

Physically, the nucleotides fit together in pairs, rather like the opposing teeth in a zipper. Then, when a protein is needed, the nucleotides in the appropriate segment of DNA "unzip," forming a jagged pattern, or template, from which the protein is built. (See Figure 3.2.)

Chromosome Tightly coiled threadlike structure along which the genes are organized, like beads on a necklace. Chromosomes consist primarily of DNA.

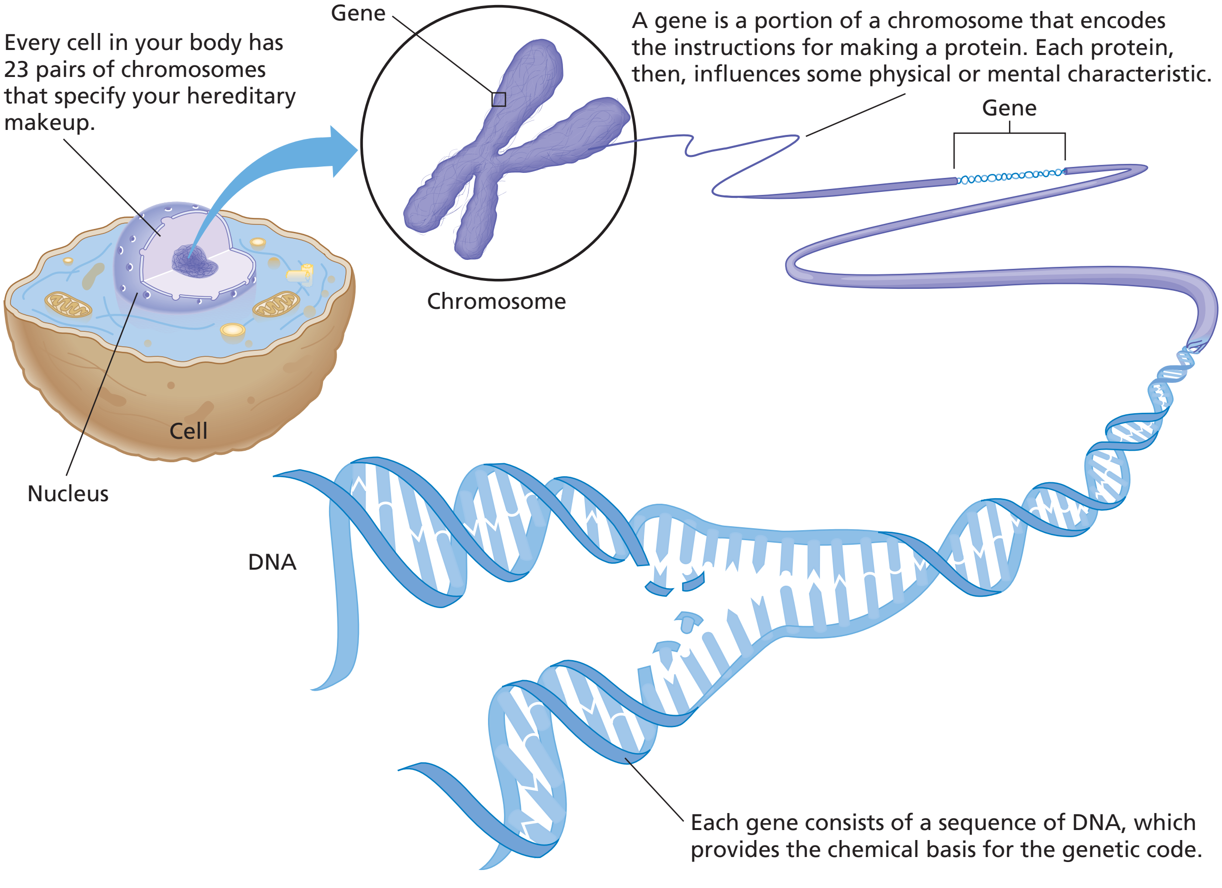


FIGURE 3.2 DNA, Genes, and Chromosomes

A chromosome is composed mainly of a tightly coiled strand of DNA, an incredibly long molecule. Each chromosome contains thousands of genes, along with instructions for the "when" and "how" of gene expression. Genes themselves are segments of DNA. Each gene contains instructions, coded in the four-nucleotide alphabet, for making a protein. The Human Genome Project recently identified the sequence of nucleotides in all 23 pairs of our chromosomes.

How many genes does it take to make a human? According to current estimates, the complete package of human DNA contains approximately 30,000 genes—surprisingly few, in view of the human organism's complexity (Netting & Wang, 2001; Pennisi, 2003). Together with their supplemental instructions, your genes reside on 46 chromosomes, arranged in 23 pairs. One in each pair came from your mother, with the remaining 23 being your father's genetic contribution. As if that weren't complicated enough, duplicate copies of all this genetic information are crammed inside the billions of cell nuclei throughout your body. It's much the same as a large corporation that relies on many individual computers, each of which requires its own copy of the operating system software.

Two of the 46 chromosomes warrant special mention: the **sex chromosomes.** Named X and Y for their shape, these chromosomes carry genes encoding for a male or a female phenotype. We all inherit one X chromosome from our biological mothers. In addition, we receive either an X (for females) or a much smaller Y (for males) from our biological fathers. When they pair up, two X chromosomes (XX) contain the code for femaleness, while an XY pair codes for maleness. In this sense, then, the chromosomes we get from our fathers determine our biological sex.

It is important to note that you do not inherit copies of *all* your father's and mother's genes. Rather you get half of each, randomly shuffled—which explains why siblings all have slightly different genotypes (unless they are identical twins). This random shuffling and recombining of parental genes produces the variation that Darwin viewed as the raw material for evolution.

Genetic Explanations for Psychological Processes Most of the foregoing discussion of heredity and genetics could apply equally to fruit flies and butterflies, hollyhocks and humans. All organisms follow the same basic laws of heredity. The differences among different species arise, then, from different genetic "words" spelled with the same four letters of life's universal four-letter alphabet.

And what does all this have to do with psychology? Simply put, genes influence our psychological characteristics as well as our physical traits. In later chapters we will explore the extent to which genes affect such diverse human attributes as intelligence, personality, mental disorders, reading and language disabilities, and (perhaps) sexual orientation. (See Bouchard, 1994; Caspi et al., 2002; DeAngelis, 1997; Gelernter, 1994; Hamer, 1997; Lai et al., 2001; Plomin, Owen, & McGuffin, 1994; Plomin & Rende, 1991; Saudino, 1997.) Even our fears can have some genetic basis (Hariri et al., 2002). But, because genetic psychology is still a field in its infancy, we don't yet know how or to what extent genes are involved in most psychological processes (Hamer, 2002; Plomin, 2003.)

In only a few cases can we hold a single gene responsible for a psychological disorder. For example, just one abnormal gene has been linked to a rare pattern of impulsive violence found in several members of a Dutch family (Brunner et al., 1993). Most other genetically influenced disorders appear to involve multiple genes, often on more than one chromosome (Boomsma, Anokhin, & de Geus, 1997; Plomin, 2000). Experts think it likely that multiple genes contribute, for example, to schizophrenia, a severe mental disorder, and to Alzheimer's disease, a form of dementia. (See Morrison-Bogorad & Phelps, 1997; Plomin, Owen, & McGuffin, 1994; Skoog et al., 1993; St. George-Hyslop, 2000.)

So, does this mean that heredity determines our psychological destiny? Will you grow up to be like your Uncle Henry? Not to worry. To reiterate: Heredity never acts alone. *Both* heredity and environment always work together to

CONNECTION: CHAPTER 12

Schizophrenia is a psychotic disorder that affects about one out of 100 persons.

■ **Sex chromosomes** The X and Y chromosomes that determine our physical sex characteristics.

influence our behavior and mental processes (Pinker, 2002). Even identical twins, who share the same genotype, display individual differences in appearance and personality that result from their distinct experiences, such as exposure to different people, places, chemicals, and diseases. Moreover, studies show that when one identical twin acquires a psychological disorder known to have a genetic basis (schizophrenia, for example), the other twin does not necessarily develop the same disorder. This is the takeaway message: *Never attribute psychological characteristic to genetics alone* (Ehrlich, 2000a, b; Mauron, 2001).

An example of the interaction between heredity and environment—and one of the rays of hope that emanate from biopsychology—can be seen in a condition called *Down syndrome.* Associated with an extra chromosome 21, this disorder includes markedly impaired physical development, as well as mental retardation. Only a few years ago, people with Down syndrome faced bleak and unproductive lives, shut away in institutions, where they depended almost wholly on others to fulfill their basic needs. Now, a better understanding of the disorder, along with a deeper appreciation for the interaction between genetics and environment, has changed that outlook. Although no cure has been found, today we know that people with Down syndrome are capable of considerable learning, despite their genetic impairment. With special programs that teach life skills, those with Down syndrome now learn to care for themselves, work, and establish some personal independence.

PSYCHOLOGY IN YOUR LIFE: CHOOSING YOUR CHILDREN'S GENES

Scientists already have the ability to control and alter the genetics of animals, like Dolly, the late and famous fatherless sheep that was cloned from one of her mother's cells. But what are the prospects for genetic manipulation in people? Scientists working on the Human Genome Project have recently completed a "first draft" of the human genetic code (Pennisi, 2001). The rest of the 21st century will see us mining this data for insight into the genetic basis for many physical and mental disorders. High on the list will be disorders that affect millions: cancer, heart disease, schizophrenia, and Alzheimer's disease. But not all the promise of human genetics lies in the future. We can already sample fetal cells and search for certain genetic disorders, such as Down syndrome. Data drawn from the Human Genome Project will greatly expand this ability. Psychologists also expect it to teach us something about the genetic basis for human differences in abilities, emotions, and resistance to stress (Kosslyn et al., 2002).

Right now, with a little clinical help, parents can select the sex of a child with a fair degree of certainty. And, within your lifetime, parents may be able to select specific genes for their children, much as you select the components of a deli sandwich. It is likely that we will learn to alter the DNA in a developing fetus in order to add or delete certain physical and mental traits (Henig, 1998). This might be done by infecting the fetus with a harmless virus containing desirable genes that will alter or replace the genetic blueprint in every cell of the body. Another approach might involve injecting *stem cells* ("generic" cells that have not fully committed themselves to becoming a particular type of tissue) that have desirable genetic characteristics (Doetsch, 2002). But what will be the price of this technology?

This developing genetic knowledge will surely create some new problems, as well as promises. Take *cloning,* for example. While most people do not favor the cloning of entire humans, the possibility exists of cloning specific organs or tissues—again from stem cells, a procedure currently under severe restrictions by the U.S. government. Proponents point out that cloned organs could potentially cure heart, liver, and kidney failure, as well as diabetes and arthritis (Pool, 1998). But one difficulty arises from the source of cells for such research. Because donor embryos most often come from extras produced during *in vitro* fertilization procedures, many people oppose this work (Wheeler, 1999). Eventually, perhaps, we will learn to build a new organ out of the recipient's own cells.

There will be psychological issues, as well. Undoubtedly, parents in this brave new genetic world will want their children to be smart and good looking—but, we might wonder, by what standards will intelligence and looks be judged? And what will be the costs? Will everyone be able to place an order for their children's genes—or only the very wealthy? You can be certain that the problems we face will be simultaneously biological, psychological, political, and ethical (Fackelmann, 1998; Patenaude, Guttmacher, & Collins, 2002).

In general, the more we learn about behavior genetics, the more clearly we can see the powerful biological forces that shape human potential and life experience. We can also glimpse the problems to be faced when we learn to manipulate these genetic forces. Already, psychologists are called on to provide guidance about how genetic knowledge can best be applied (Bronheim, 2000; Plomin, 1997; Plomin & McClearn, 1993), particularly in helping people assess genetic risks in connection with family planning. We invite you to grapple with these issues by answering the following questions:

- If you could select three genetic traits for your children, which ones would you select?
- How would you feel about raising children you have adopted or fostered but to whom you are not genetically related?
- If a biological child of yours might be born disabled or fatally ill because of your genetic heritage, would you have children anyway? What circumstances or conditions would affect your decision?
- If you knew you might carry a gene responsible for a serious medical or behavioral disorder, would you want to be tested before having children? And would it be fair for a prospective spouse to require you to be tested before conceiving children? Or would it be fair for the state to make such a requirement?

These questions, of course, have no "right" answers; but the answers you give will help you define your stand on some of the most important issues we will face in the 21st century.

CHECK YOUR UNDERSTANDING

1. **RECALL:** Which of the following processes are involved in natural selection, the driving force behind evolution? (More than one may be correct.)
   - **a.** Individuals best adapted to the environment have a survival advantage.
   - **b.** Some individuals reproduce more successfully than others.
   - **c.** The offspring of some individuals survive in greater numbers than do those of others.
   - **d.** Individuals that are poorly adapted tend to have fewer offspring.
   - **e.** All are correct.

2. **RECALL:** Which of the following is a characteristic that might be a part of your phenotype?
   - **a.** your height and eye color
   - **b.** the members of your family
   - **c.** what you have learned in school
   - **d.** the childhood diseases you have had
   - **e.** your genetic makeup

3. **RECALL:** Which of the following statements expresses the correct relationship?
   - **a.** Genes are made of chromosomes.
   - **b.** DNA is made of chromosomes.
   - **c.** Nucleotides are made of genes.
   - **d.** Genes are made of DNA.
   - **e.** Phenotype dictates genotype.
4. **ANALYSIS:** In purely evolutionary terms, which one would be a measure of your own success as an organism?
   - **a.** your intellectual accomplishments
   - **b.** the length of your life
   - **c.** the number of children you have
   - **d.** the contributions that you make to the happiness of humanity
   - **e.** your ability to find food and water
5. **UNDERSTANDING THE CORE CONCEPT:** Behavior consistently found in a species is likely to have a genetic basis that evolved because the behavior has been adaptive. Which of the following human behaviors illustrates this concept?
   - **a.** driving a car
   - **b.** sending astronauts to the moon
   - **c.** Down syndrome
   - **d.** language
   - **e.** thinking

ANSWERS: 1. e 2. a 3. d 4. c 5. d

KEY QUESTION

HOW DOES THE BODY COMMUNICATE INTERNALLY?

You are driving on a winding mountain road, and suddenly a car is coming directly at you. At the last instant, you and the other driver swerve in opposite directions. Your heart pounds—and it keeps pounding for several minutes after the danger has passed. Externally, you have avoided a potentially fatal accident. Internally, your body has responded to two kinds of messages from its two communication systems.

One of these is the fast-acting *nervous system,* with its extensive network of nerve cells that carries messages in pulses of electrical and chemical energy throughout the body. It is this network that first comes to your rescue in an emergency, carrying the orders that accelerate your heart and tense your muscles for action. The other communication network, the slower-acting *endocrine system,* sends follow-up messages that support and sustain the emergency response initiated by the nervous system. To do this, the endocrine glands, including the pituitary, thyroid, adrenals, and gonads, use the chemical messengers we call *hormones.* Coincidentally, communication between nerve cells also relies on chemicals that are suspiciously similar to hormones, as we shall see.

It is important to understand that the two internal message systems cooperate to arouse us not only in stressful situations, such as the narrowly avoided auto accident, but in happier emotional circumstances, such as when you receive an unexpected "A" on a test or fall in love. They also work together when we are in states of low arousal, to keep the vital body functions operating smoothly. This cooperation between the endocrine system and the nervous system is coordinated by the nervous system's chief executive, the brain—which brings us to our Core Concept:

CORE CONCEPT

The brain coordinates the body's two communications systems, the nervous system and the endocrine system, which use similar chemical processes to communicate with targets throughout the body.

Why is this notion important for your understanding of psychology? For one thing, these two communication systems are the biological bedrock for all our thoughts, emotions, and behaviors. For another, when the biology goes awry, the result can be a variety of unfortunate effects on the brain and mental functions, such as stroke, Alzheimer's disease, and schizophrenia. Still another reason for studying the biology behind the body's internal communications is that it helps us understand how drugs, such as caffeine, alcohol, and Prozac, can change the chemistry of the mind.

We will begin our tour of these vital communication systems with a close look at the building block of the nervous system: the *neuron.* Next, we will see how networks of neurons, each having similar functions, work together as components of the *nervous system.* Then we will consider the *endocrine system,* a network of glands that operates in parallel with the nervous system to send information throughout the body. Finally, in the last section of the chapter, we will probe the mysteries of that "great raveled knot" of neurons: the *brain* itself.

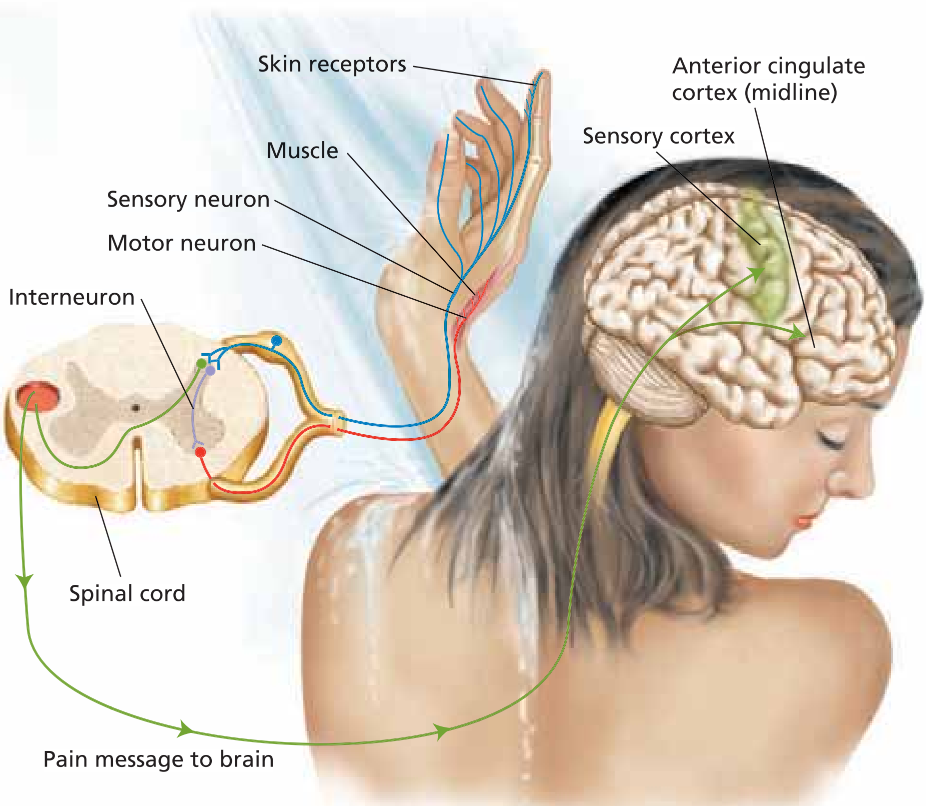
The Neuron: Building Block of the Nervous System

On the most basic level, every part of the nervous system is made of the same components, called *nerve cells* or neurons. In simplest terms, a **neuron** is merely a cell specialized to receive, process, and transmit information to other cells. And neurons do that very efficiently. A typical neuron may receive information from a thousand other neurons and, within a fraction of a second, "decide" to pass it along at speeds up to 100 meters per second to a thousand more neurons—sometimes as many as 10,000 (Pinel, 2003).

■ **Neuron** Cell specialized to receive and transmit information to other cells in the body—also called a *nerve cell.* Bundles of many neurons are called *nerves.*

■ **Sensory neuron** Nerve cell that carries messages from sense receptors toward the central nervous system. Also called an *afferent neuron.*

Types of Neurons While neurons vary in shape and size, they all have essentially the same structure, and they all send messages in essentially the same way. Still, biopsychologists distinguish three major classes of neurons according to their location and function: *sensory neurons, motor neurons,* or *interneurons.* (See Figure 3.3.) **Sensory neurons,** or *afferent neurons,* act like one-way



● **FIGURE 3.3** Sensory Neurons, Motor Neurons, and Interneurons

Information about the water temperature in the shower is carried by thousands of *sensory neurons* (afferent neurons) from the sense organs to the central nervous system. In this case, the message enters the spinal cord and is relayed, by *interneurons,* to the brain. There, the information is assessed and a response is initiated (turn the water temperature down!). These instructions are sent to the muscles by means of *motor neurons* (efferent neurons). Large bundles of the message-carrying fibers from these neurons are called *nerves.*

streets that carry traffic from the sense organs *toward* the brain. Accordingly, afferent neurons treat the brain to all your sensory experience, including vision, hearing, taste, touch, smell, pain, and balance. For example, when you test the water temperature in the shower with your hand, afferent neurons carry the message toward the brain. By contrast, **motor neurons,** or *efferent neurons,* form the one-way routes that transport messages *away* from the brain to the muscles, organs, and glands. So, in our shower example, the motor neurons deliver the message from the brain that tells your hand just how much to move the shower control knob.

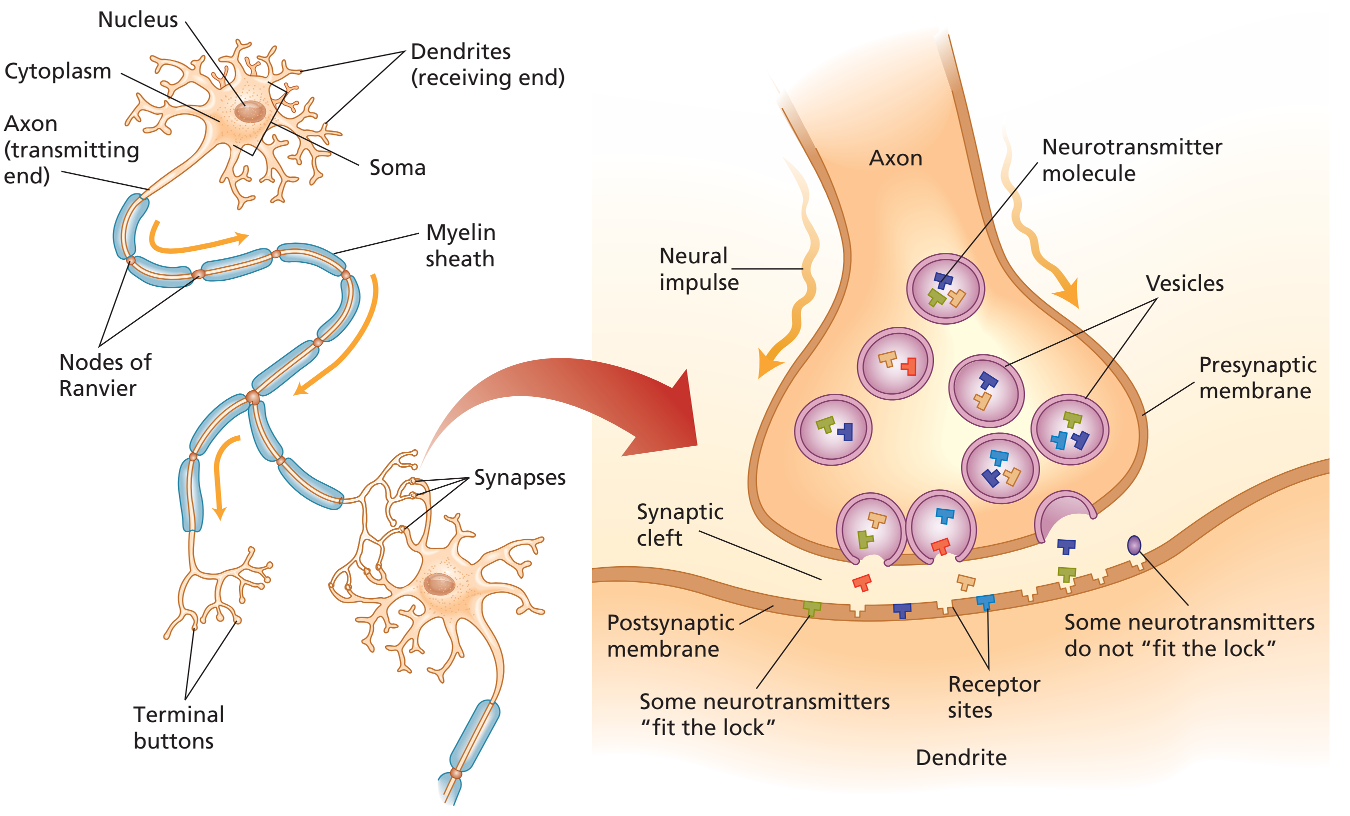
Sensory and motor neurons rarely communicate directly with each other, except in the simplest of reflexive circuits. Instead, they usually rely on the go-between **interneurons** (also shown in Figure 3.3), which make up most of the billions of cells in the brain and spinal cord. Interneurons relay messages from sensory neurons to other interneurons or to motor neurons, sometimes in complex pathways. In fact, the brain itself is mostly a network of billions of intricately connected interneurons.

How Neurons Work A look at Figure 3.4 will help you visualize the parts of a neuron. The "receiver" parts, which accept most of the incoming messages, consist of finely branched fibers called **dendrites.** These dendritic fibers extend outward from the cell body, where they act like a net, collecting messages received by direct stimulation (such as pressure, light, and sound) or from the activity of neighboring neurons.

■ **Motor neuron** Nerve cell that carries messages away from the central nervous system toward the muscles and glands. Also called an *efferent neuron.*

■ **Interneuron** A nerve cell that relays messages between nerve cells, especially in the brain and spinal cord.

■ **Dendrite** A branched fiber that extends outward from the main cell body and carries information into the neuron.



● **FIGURE 3.4** Structure and Function of the Neuron

A typical neuron receives thousands of messages at a time through its *dendrites* and *soma* (cell body). When the soma becomes sufficiently aroused, its own message is then passed to the *axon,* which transmits it by means of an *action potential* to the cell's *terminal buttons.* There tiny *vesicles* containing *neurotransmitters* rupture and release their contents into the *synapse* (synaptic cleft). Appropriately shaped transmitter molecules arriving at the postsynaptic membrane can dock at *receptors,* where they stimulate the receiving cell. Excessive transmitter is taken back into the "sending" neuron by means of *reuptake.*

Significantly, neuroscientists have discovered that dendrites can undergo subtle modifications when we learn (Barinaga, 2000; Kennedy, 2000; Matus, 2000). This discovery has launched a search for drugs that might encourage the changes in dendrites associated with learning. While students will probably never be able to take a pill instead of a psychology class, they may one day be able to ingest harmless chemicals that will help them remember what they have read or heard in class. For the moment, the best we have to offer is coffee—which actually acts as a mild, but temporary, stimulus to the dendrites (Julien, 2001). (The evidence that caffeine promotes learning is controversial.)

Dendrites complete their job by passing incoming messages to the central part of the neuron, the *cell body* or **soma.** Not only does the soma contain the cell's nucleus and life-support machinery, it also has the executive job of assessing all the messages the cell receives from the dendrites (and also directly from other neurons). In this process, the input from a single synapse carries little weight, because a typical neuron may receive messages from hundreds or even thousands of other neurons. And, to make the situation more complex, some of these messages can be *excitatory* (saying, in effect, "Fire!") or *inhibitory* ("Don't fire!"). Just how aroused the cell body becomes depends on the sum total of all the incoming messages.

When excitation triumphs over inhibition, the aroused neuron may generate a message of its own, sent through a single "transmitter" fiber, the **axon,** which can extend over considerable distances. In a college basketball player, the axons connecting the spinal cord with the toes can be more than a meter in length. At the other end of the scale, the axons of interneurons in the brain may span only a tiny fraction of an inch.

The Action Potential Nerve cells employ both electrical and chemical signals to process and transmit information. As we have seen, an impulse in a single neuron begins when a stimulus, such as a sound, a pinprick, or messages from other nerve cells, make the soma excited. When the arousal reaches a critical level, an electrical impulse occurs in the axon, like the electronic flash of a camera. When this happens, the cell is said to "fire."

Much like the battery in that camera, the axon gets its electrical energy from charged chemicals, called *ions.* In its normal, resting state, the ions within the cell give the axon a small negative charge, appropriately called the **resting potential.** But this positive/negative imbalance is easily upset. When the cell body becomes excited, it triggers a cascade of events, known as the **action potential,** that temporarily reverses the charge and causes an electrical signal to race along the axon. This happens when tiny pores open in a small area of the axon's membrane adjacent to the soma, allowing a rapid influx of positive ions. This rapidly changes (we're talking 1/1000 of a second here) the internal charge in that part of the axon from negative to positive. Then, like a row of falling dominoes, these changes progress down the axon, causing an electrical signal to race from the soma toward the axon ending. There's no halfway about this action potential: Either the axon "fires" or it doesn't. Neuroscientists call this the **all-or-none principle.**

Almost immediately, the cell's "ion pump" flushes out the positively charged ions and restores the neuron to its resting potential, ready to fire again. Incredibly, the whole complex cycle may take place in less than a hundredth of a second. It is a mind-boggling performance—but this is not the end of the matter. The information carried by the action potential still must traverse a tiny gap before reaching another cell.

Synaptic Transmission The gap between nerve cells, called the **synapse,** acts as an electrical insulator, preventing the charge speeding down the axon from jumping to the next cell (see Figure 3.4). To pass the message across the *synap-*

■ **Soma** The part of a cell (such as a neuron) containing the nucleus, which includes the chromosomes. Also called the *cell body.*

■ **Axon** In a nerve cell, an extended fiber that conducts information from the *soma* to the *terminal buttons.* Information travels along the axon in the form of an electric charge called the *action potential.*

■ **Resting potential** The electrical charge of the axon in its inactive state, when the neuron is ready to "fire."

■ **Action potential** The nerve impulse caused by a change in the electrical charge across the cell membrane of the axon. When the neuron "fires," this charge travels down the axon and causes neurotransmitters to be released by the terminal buttons.

■ **All-or-none principle** Refers to the fact that the action potential in the axon occurs either full-blown or not at all.

■ **Synapse** The microscopic gap that serves as a communications link between neurons. Synapses also occur between neurons and the muscles or glands they serve.

■ **Terminal buttons** Tiny bulblike structures at the end of the axon, which contain neurotransmitters that carry the neuron's message into the synapse.

■ **Synaptic transmission** The relaying of information across the synapse by means of chemical neurotransmitters.

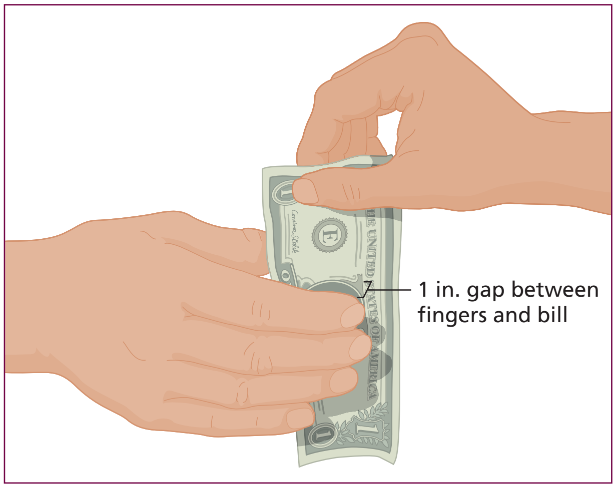
DO IT YOURSELF! Neural Messages and Reaction

For only a dollar you can find out how long it takes for the brain to process information and initiate a response.

Hold a crisp dollar bill by the middle of the short side, so that it dangles downward. Have a friend put his or her thumb and index fingers on opposite sides and about an inch away from the center of the bill, as shown in the illustration. Instruct your friend to pinch the thumb and fingers together and attempt to catch the bill when you drop it.

If you drop the bill without warning (being careful not to signal your intentions), your friend's brain will not be able to process the information rapidly enough to get a response to the hand before the dollar bill has dropped safely away.

What does this demonstrate? The time it takes to respond reflects the time it takes for the sensory nervous system to take in the information, for the brain to process it, and for the motor system to produce a response. All this involves millions of neurons; and, even though they respond quickly, their responses do take time.



tic gap (or *synaptic cleft*), a neuron must initiate a process in tiny bulblike structures called **terminal buttons,** found at the ends of the axon. There, in a remarkable sequence of events known as **synaptic transmission,** the electrical message morphs into a chemical message that easily flows across the synaptic cleft between neurons. This occurs in the following way.

Neurotransmitters At the terminal buttons, the electrical impulse causes a rupture in the small bubble-shaped **synaptic vesicles** (sacs) containing **neurotransmitters,** which are chemicals used in neural communication. (Again, see Figure 3.4.) The vesicles quickly spill their contents—about 5000 transmitter molecules each—into the synaptic cleft (Kandel & Squire, 2000). There, the transmitter molecules diffuse across the gap. If they have the right shape (that is, a shape that complements that of special *receptors* in the membrane of the target cell), the neurotransmitters fit into the receptors, like a key fitting into a lock. This lock-and-key process stimulates the receiving neuron and carries the message forward.

After the transmitter molecules have done their work, they are broken down by other chemicals and recycled back to the terminal buttons, where they are reassembled and reused. In addition, many of the transmitter molecules get recycled before docking at a receptor site. Through a process called *reuptake,* these transmitters are intercepted as they are floating within the synapse and drawn back intact into vesicles. Reuptake, then, has the effect of "turning the volume down" on the message being transmitted between neurons. When we later discuss drug therapy for mental disorders (in Chapter 13), reuptake will be an important term because some important drugs—such as the well-known Prozac—interfere with the reuptake process.

Neuroscientists have identified dozens of different neurotransmitters. Table 3.1 distinguishes several that have proved especially important in psychological functioning. Imbalances in these neurotransmitters are also thought to underlie certain disorders, such as schizophrenia and Alzheimer's disease,

Michael J. Fox suffers from Parkinson disease, caused by a deficiency of dopamine in his brain.

Synaptic vesicle A small "container" holding neurotransmitter molecules that then connects to the presynaptic membrane, releasing the neurotransmitter into the synapse.

Neurotransmitters Chemical messengers that relay neural messages across the synapse. Many neurotransmitters are also hormones.

TABLE 3.1 Seven Important Neurotransmitters

Neurotransmitter	Normal function	Problems associated with imbalance	Substances that affect the action of this neurotransmitter
Dopamine	Produces sensations of pleasure and reward Used by CNS neurons involved in voluntary movement	Schizophrenia Parkinson's disease	Cocaine Amphetamine Methylphenidate (Ritalin) Alcohol
Serotonin	Regulates sleep and dreaming, mood, pain, aggression, appetite, and sexual behavior	Depression Certain anxiety disorders Obsessive–compulsive disorder	Fluoxetine (Prozac) Hallucinogenics (e.g., LSD)
Norepinephrine	Used by neurons in autonomic nervous system and by neurons in almost every region of the brain Controls heart rate, sleep, stress, sexual responsiveness, vigilance, and appetite	High blood pressure Depression	Tricyclic antidepressants Beta-blockers
Acetylcholine	The primary neurotransmitter used by efferent neurons carrying messages from the CNS Also involved in some kinds of learning and memory	Certain muscular disorders Alzheimer's disease	Nicotine Black widow spider venom Botulism toxin Curare Atropine
GABA	The most prevalent inhibitory neurotransmitter in neurons of the CNS	Anxiety Epilepsy	Barbiturates "Minor" tranquilizers (e.g., Valium, Librium) Alcohol
Glutamate	The primary excitatory neurotransmitter in the CNS Involved in learning and memory	Release of excessive glutamate apparently causes brain damage after stroke	PCP ("angel dust")
Endorphins	Pleasurable sensations and control of pain	Lowered levels resulting from opiate addiction	Opiates: opium, heroin, morphine, methadone

as well as poisoning by black widow spider venom and botulism toxin. It shouldn't surprise us, then, that many drugs used to treat mental disorders employ chemicals that act like neurotransmitters or otherwise affect the action of neurotransmitters on nerve cells. Likewise, drugs of abuse (heroin, cocaine, methamphetamine, for example) either mimic, enhance, or inhibit our brains' natural neurotransmitters. We will talk more about neurotransmitters and their relation to drug action in the upcoming "Psychology in Your Life" section.

Plasticity Neurons have the ability to send messages that produce simple reflexes, as when you automatically withdraw your hand from a painfully hot plate. But neurons also have the ability to *change*—to make new connections or to strengthen old ones. This is a hugely important process known as **plasticity.** It means that the nervous system, and especially the brain, has the ability to adapt or modify itself as the result of experience (M. Holloway, 2003; Kandel & Squire, 2000). Earlier we discussed one form of plasticity that involves the changes within dendrites that are associated with learning. Another form involves making new connections among neurons—as when neurons sprout new dendrites, for example. This process is also believed to be associated with learning. Plasticity may also account for the brain's ability to compensate for injury, as in a stroke or head trauma—a controversial concept (Pinel, 2003). In all these ways, then, plasticity is a property that allows the brain to be restructured and "reprogrammed" by experience.

■ **Plasticity** The nervous system's ability to adapt or change as the result of experience. Plasticity may also help the nervous system adapt to physical damage.

Here is a more subtle point: Because of its neural plasticity, the physical structure of the brain can be changed by its interactions with the outside world (Barinaga, 1996; LeDoux, 2002; Singer, 1995). For example, as a violin player gains expertise, the motor area linked to the fingers of the left hand becomes larger (Juliano, 1998). Increased brain area also develops for the index finger used by a blind reader who learns to use Braille (Elbert et al., 1995; LeDoux, 1996). Usually these changes are beneficial. Occasionally, however, intensely traumatic experiences can alter the brain's emotional responsiveness in detrimental ways (Arnsten, 1998; Caldwell, 1995; Mukerjee, 1995). Thus the brain cells of soldiers who experience combat or people who have been sexually assaulted may undergo physical changes that can produce a permanent hair-trigger responsiveness. This can cause them overreact to mild stressors and even to merely unexpected surprises. Taken together, such findings indicate that neural plasticity can produce changes both in the brain's function and in its physical structure in response to experience (Sapolsky, 1990).

CONNECTION: CHAPTER 8

Extremely threatening experiences can cause posttraumatic stress disorder, which can produce physical changes in the brain.

Glial Cells: A Support Group for Neurons Interwoven among the brain's vast network of neurons is an even greater number of *glial cells* that were once thought to "glue" the neurons together. (The name comes from the Greek word for "glue.") In fact, glial cells do provide structural support for neurons, as well as help in forming new synapses (Gallo & Chittajallu, 2001). New evidence suggests that they may also be a crucial part of the process we call *learning* (Fields, 2004). In addition, the multitalented **glial cells** form a *myelin sheath,* a fatty insulation around many axons in the brain and spinal cord. Like the covering on an electrical cable, the myelin sheath insulates and protects the cell and helps speed the conduction of impulses along the axon (see Figure 3.4). Unfortunately, certain diseases, such as multiple sclerosis (MS), attack the myelin sheath, especially in the motor pathways. The result is poor conduction of nerve impulses, which accounts for the increasing difficulty MS patients have in controlling movement.

So there you have the two main building blocks of the nervous system: neurons, with their amazing plasticity, and their supportive glial cells, which protect the neurons and help to propagate neural messages. But, wondrous as these individual components are, we should point out that in the big picture of behavior and mental processes, a single cell doesn't do very much. It takes thousands upon millions of neurons flashing their electrochemical signals in synchronized waves back and forth through the incredibly complex neural networks in your brain to produce thoughts, sensations, and feelings. Similarly, all your actions arise from waves of nerve impulses delivered to your muscles, glands, and organs through the nervous system. Yet, as we will see in the next "Psychology in Your Life" section, the effects of psychoactive drugs, such as tranquilizers, antidepressants, and painkillers, rely on altering the chemistry underlying these waves at the level of individual cells and their synapses (Deadwyler & Hampson, 1995; Ferster & Spruston, 1995). For the moment, however, let's turn our attention to the neural networks themselves—networks that together make up the *nervous system.*

Divisions of the Nervous System

If you could observe a neural message as it moves from stimulus to response, you would see the signal make a seamless transition from one part of the nervous system to another. It might begin, for example, as a signal in the eyes, then travel to the brain for extensive processing, and finally reemerge from the brain as a message instructing the muscles to respond. In fact, the **nervous system,** made up of all the nerve cells in the body, functions as a single, complex,

■ **Glial cells** Cells that bind the neurons together. Glial cells also provide an insulating covering (the myelin sheath) of the axon for some neurons, which facilitates the electrical impulse.

■ **Nervous system** The entire network of neurons in the body, including the central nervous system, the peripheral nervous system, and their subdivisions.

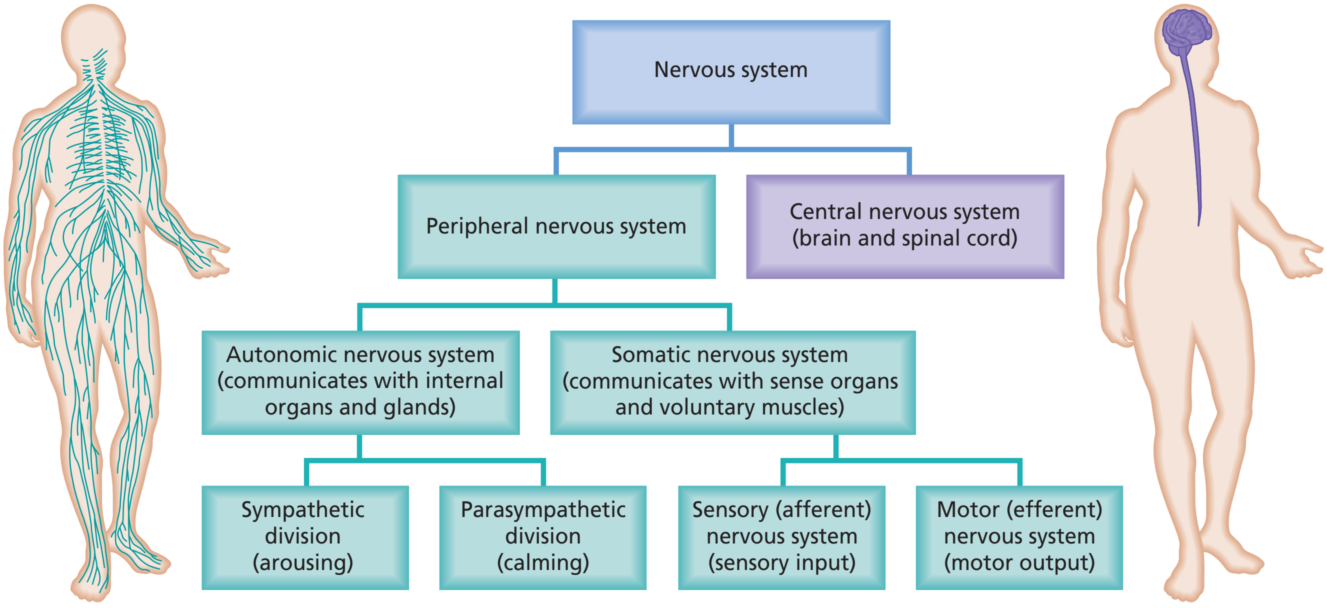


FIGURE 3.5 Organization of the Nervous System
This figure shows the major divisions of the nervous system. (Note: It does *not* show the flow of information in the nervous system!)

and interconnected unit. Nevertheless, we find it convenient to distinguish among divisions of the nervous system, based on their location and on the type of processing they do. The most basic distinction recognizes two major divisions: the *central nervous system* and the *peripheral nervous system.* (See Figure 3.5.)

The Central Nervous System Comprised of the *brain* and *spinal cord*, the **central nervous system** (CNS) serves as the body's "command central." The brain, filling roughly a third of the skull, makes complex decisions, coordinates our body functions, and initiates our behaviors. The spinal cord, playing a supportive role, serves as a sort of neural cable, connecting the brain with parts of the peripheral nervous system extending into the trunk and limbs. (The nerve pathways connecting the brain with the eyes, ears, nose, tongue, skin and muscles of the head, and internal organs do not pass through the spinal cord.)

The spinal cord has another job, too. It takes charge of simple, swift **reflexes** that do not require brain power, such as the knee-jerk reflex your physician elicits with a tap on the knee. We know that the brain does not get involved in these simple reflexes, because a person whose spinal cord has been severed may still be able to withdraw a limb reflexively from a painful stimulus—even though the brain doesn't sense the pain. The brain is required, however, for *voluntary* movements. That's why damage to the nerves of the spinal cord can produce paralysis of the limbs or trunk. As you might expect, the extent of paralysis depends on the location of the damage. In general, the higher the site of damage, the greater the extent of the paralysis. This fact helps explain why an injury high in the spinal cord paralyzed the late actor Christopher Reeve from his neck down.

The Peripheral Nervous System The **peripheral nervous system** (PNS) also plays a supportive role, connecting the central nervous system with the rest of the body through bundles of sensory and motor axons, called *nerves.* Its many branches carry messages between the brain and the sense organs, the internal organs, and the muscles. In this role, the peripheral nervous system carries the incoming messages that tell your brain about the sights, sounds, tastes, smells,

■ **Central nervous system** The brain and the spinal cord.
■ **Reflex** A simple, unlearned response triggered by stimuli—such as the knee-jerk reflex set off by tapping the tendon just below your kneecap.
■ **Peripheral nervous system** All parts of the nervous system lying outside the central nervous system. The peripheral nervous system includes the autonomic and somatic nervous systems.

and textures of the world. Likewise, it carries the outgoing signals that tell your body's muscles and glands how to respond.

You might think of the PNS, therefore, as operating a pick-up-and-delivery service for the central nervous system. If, for example, an aggressive dog approaches you, your PNS picks up the auditory information (barking, growling, snarling) and visual information (bared teeth, hair standing up on the neck) and delivers it to the brain. Quickly, brain circuits assess the situation (Danger!) and communicate with other circuits that give orders for a hasty retreat. The PNS then delivers those orders to mobilize your heart, lungs, legs, and other body parts needed in response to the emergency. It does this through its two major divisions: the *somatic nervous system* and the *autonomic nervous system.* One deals with our external world, the other with our internal responses. (A few moments spent studying Figure 3.5 will help you understand these divisions and subdivisions.)

The Somatic Division of the PNS Think of the **somatic nervous system** as the brain's communications link with the outside world. Its sensory component connects the sense organs to the brain, and its motor component links the CNS with the body's skeletal muscles, the muscles that control voluntary movements. (We met these two divisions earlier in our discussion of sensory and motor neurons.) So, for example, when you see a slice of pizza, the visual image is carried by the somatic division's *afferent* system. Then, if all goes well, the *efferent* system sends instructions to muscles that propel the slice of pizza in just the right direction, into your open mouth.

The Autonomic Division of the PNS The other major division of the PNS takes charge of the pizza once it heads down your throat. It is now in the province of the **autonomic nervous system** (*autonomic* means self-regulating or independent). This network carries signals that control our internal organs to perform such jobs as regulating digestion, respiration, heart rate, and arousal. Amazingly, it does so without our having to think about it—all unconsciously. The autonomic system also works when you are asleep. Even during anesthesia, it can sustain the most basic vital functions.

And—wouldn't you know?—biopsychologists further divide the autonomic nervous system into two major parts: the *sympathetic* and *parasympathetic divisions* (as shown in Figure 3.6). The **sympathetic division** arouses the heart, lungs, and other organs in stressful or emergency situations, when our responses must be quick and powerfully energized. Often called the "fight-or-flight" system, the sympathetic division carries messages that help us respond quickly to a threat either by attacking or fleeing. The sympathetic system also creates the tension and arousal you feel during an exciting movie, a first date, or an oral presentation. Perhaps you can bring to mind what the sympathetic division of your autonomic nervous system was doing during your last public-speaking effort. Was it hard to breathe? Were your palms sweaty? Did your stomach feel queasy?

In contrast, the **parasympathetic division** applies the neural brakes, returning our internal responses to a calm and collected state. But even though it has an opposing action, the parasympathetic division works cooperatively with the sympathetic system, like two children on a teeter-totter. Figure 3.6 shows the most important connections made by these two autonomic divisions.

Now, having completed our whirlwind tour of the nervous system, we return our attention briefly to its partner in internal communication, the *endocrine system.* Again, we will remind you that this system makes use of many of the same chemicals employed in neural communication. In the nervous system we called them *neurotransmitters,* but in the endocrine system, we call these chemical messengers *hormones.*

■ **Somatic nervous system** A division of the peripheral nervous system that carries sensory information to the central nervous system and also sends voluntary messages to the body's skeletal muscles.

■ **Autonomic nervous system** The portion of the peripheral nervous system that sends communications between the central nervous system and the internal organs and glands.

■ **Sympathetic division** The part of the autonomic nervous system that sends messages to internal organs and glands that help us respond to stressful and emergency situations.

■ **Parasympathetic division** The part of the autonomic nervous system that monitors the routine operations of the internal organs and returns the body to calmer functioning after arousal by the sympathetic division.

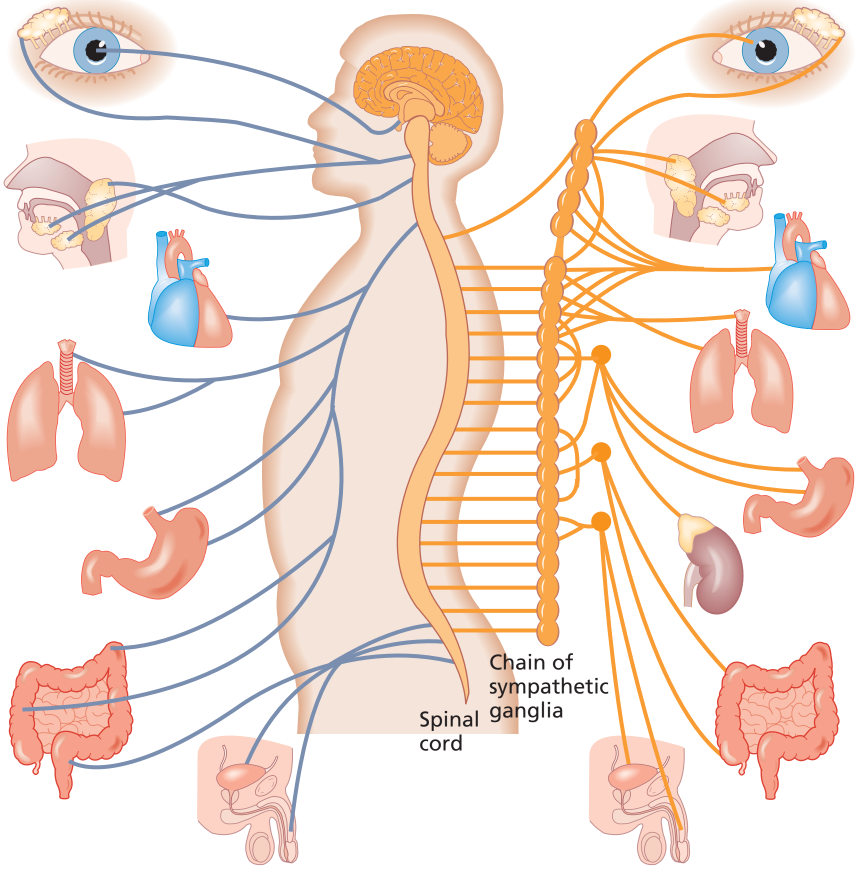


FIGURE 3.6 Divisions of the Autonomic Nervous System

The *parasympathetic nervous system* (at left) regulates day-to-day internal processes and behavior. The *sympathetic nervous system* (at right) regulates internal processes and behavior in stressful situations. On their way to and from the spinal cord, sympathetic nerve fibers make connections with specialized neural clusters called *ganglia.*

The Endocrine System

Consider this little-known fact: Your bloodstream carries *information,* along with oxygen and nutrients. It does so by serving as the communication pathway for the **endocrine system,** shown in Figure 3.7. The glands that make up the endocrine system (which takes its name from the Greek *endo* for "within" and *krinein* for "secrete") transmit information by releasing **hormones** into the bloodstream. Much like neurotransmitters in the nervous system, hormones are chemical messengers that influence not only body functions but behaviors and emotions as well (Damasio, 2003; LeDoux, 2002). For example, hormones from the pituitary stimulate body growth. Hormones from the ovaries and testes influence sexual development and sexual responses. Hormones from the adrenals produce the arousal accompanying fear. And hormones from the thyroid control metabolism (the body's rate of energy use). Once secreted into the blood, hormones circulate throughout the body until delivered to their target muscles, glands, and organs. Table 3.2 outlines the major endocrine glands and the body systems they regulate.

Under normal (unaroused) conditions, the endocrine system works in parallel with the parasympathetic nervous system to sustain our basic body processes. But in a crisis, the endocrine system shifts into a new mode, supporting the actions of the sympathetic nervous system. So, when you encounter a stressor or an emergency (such as the speeding car headed at you), the

■ **Endocrine system** The hormone system–the body's chemical messenger system, including the endocrine glands: pituitary, thyroid, parathyroid, adrenals, pancreas, ovaries, and testes.

■ **Hormone** A chemical messenger used by the endocrine system. Many hormones also serve as neurotransmitters.

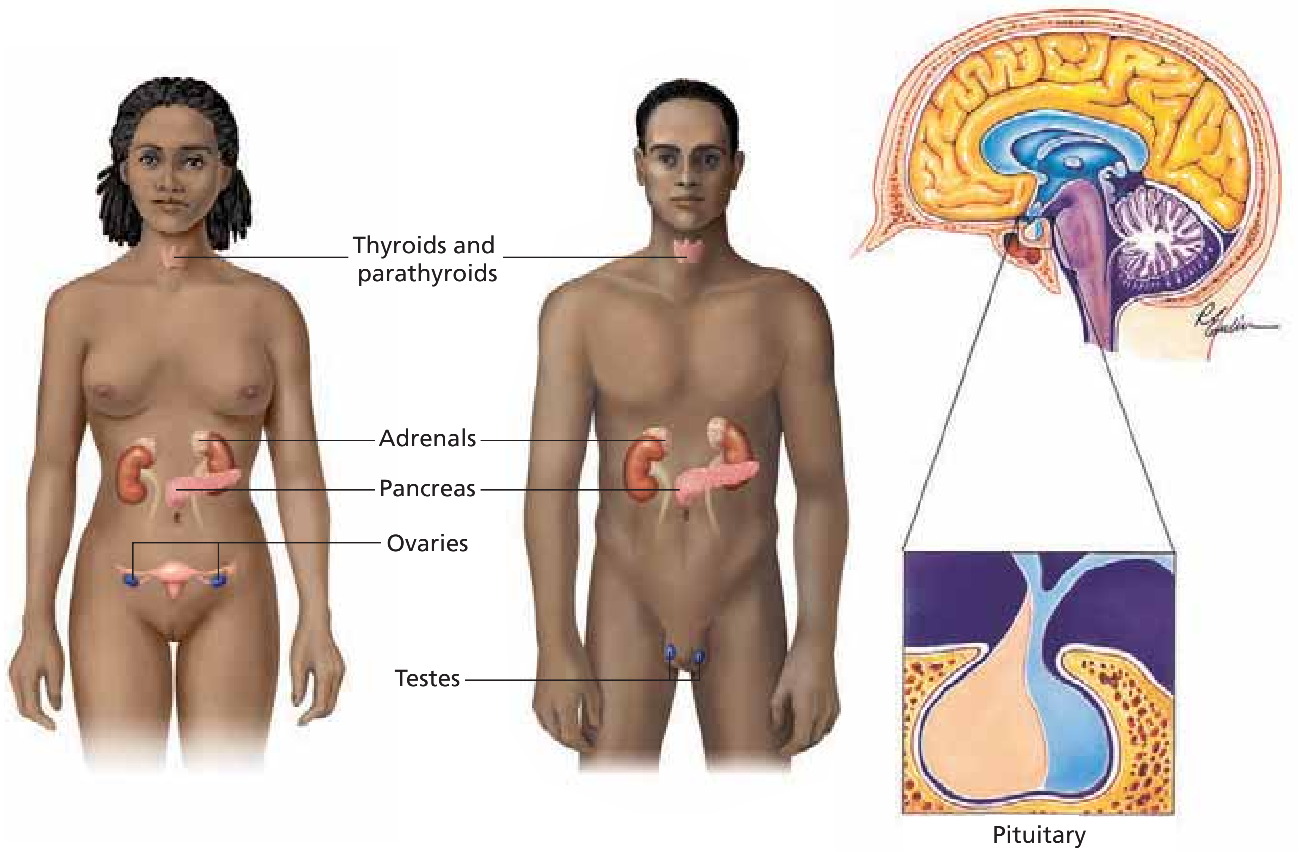


FIGURE 3.7 Endocrine Glands in Females and Males

The pituitary gland (shown at right) is the "master gland" regulating the endocrine glands, whose locations are illustrated at left. The pituitary gland is under the control of the hypothalamus, an important structure in the limbic system.

TABLE 3.2 Hormonal Functions of Major Endocrine Glands

These Endocrine Glands . . .	Produce Hormones That Regulate . . .
Anterior pituitary	Ovaries and testes Breast milk production Metabolism Reactions to stress
Posterior pituitary	Conservation of water in the body Breast milk secretion Uterus contractions
Thyroid	Metabolism Physical growth and development
Parathyroid	Calcium levels in the body
Pancreas	Glucose (sugar) metabolism
Adrenal glands	Fight-or-flight response Metabolism Sexual desire (especially in women)
Ovaries	Development of female sexual characteristics Production of ova (eggs)
Testes	Development of male sexual characteristics Sperm production Sexual desire (in men)

hormone *epinephrine* (sometimes called *adrenalin*) is released into the bloodstream, sustaining the body's defensive reaction that we called "fight or flight." In this way, the endocrine system finishes what your sympathetic nervous system started, by keeping your heart pounding and your muscles tense, ready for action.

CONNECTION: CHAPTER 8

Prolonged stress messages can produce physical and mental disorders by means of the *general adaptation syndrome*.

Later in the book we will see what happens when this stress state persists too long. For example, people who have stressful jobs or unhappy relationships may develop a chronically elevated level of stress hormones in their blood, keeping them in a state of perpetual arousal. But the price of continued arousal is high. The body may not withstand such long-term stress without suffering some physical consequences.

At the base of your brain, a "master gland," called the **pituitary gland,** attempts to keep all these endocrine responses under tight control. (See Figure 3.7.) It does so by sending out hormone signals of its own through the blood. But the pituitary itself is really only a midlevel manager. It takes orders, in turn, from the brain—in particular from a small neural nucleus to which it is physically appended: the *hypothalamus.* We will have more to say about this important brain structure in a moment.

For now, we want to emphasize the idea that the peripheral nervous system and the endocrine system provide parallel means of communication, coordinated by their link in the brain. Ultimately, the brain decides which messages will be sent through both networks. We will turn our attention to this master "nerve center"—the brain—right after exploring, in "Psychology in Your Life," how the concepts you have just learned about can explain the effects of psychoactive drugs.

PSYCHOLOGY IN YOUR LIFE: HOW PSYCHOACTIVE DRUGS AFFECT THE NERVOUS SYSTEM

The mind-altering effects of marijuana, LSD, cocaine, narcotics, tranquilizers, and sedatives entice millions of users. Millions more jolt their brains awake with the caffeine of their morning coffee, tea, or cola and the nicotine in an accompanying cigarette. Then at night they may reverse the cycle with alcohol and sleeping pills. But how do these substances achieve their effects? The answer to that question involves the ability of *psychoactive drugs* to enhance or inhibit natural chemical processes in our neural circuits.

The ecstasy and the agony of these drugs come mainly from their effects on brain synapses. Some drugs impersonate neurotransmitters by mimicking their effects in the brain. Others act less directly by enhancing or dampening the effects of neurotransmitters. We call those that enhance or mimic neurotransmitters **agonists.** Nicotine, for example, is an agonist because it acts like the neurotransmitter acetylcholine. This has the effect of "turning up the volume" in the acetylcholine pathways (the acetylcholine-using bundles innervating the muscles and connecting certain parts of the brain). By contrast, we call chemicals that dampen or inhibit the effects of neurotransmitters **antagonists.** Curare and botulism toxin are antagonists because they interfere with the neurotransmitter acetylcholine—effectively "turning the volume down." In general, agonists facilitate and antagonists inhibit messages in parts of the nervous system using that transmitter.

The well-known antidepressant Prozac (fluoxetine) does its work as an agonist in the brain's serotonin pathways, where it makes more serotonin available (see Figure 3.8). But, because serotonin's effects are complex, fluoxetine can cause not only changes in mood but, occasionally, undesirable changes in sleep patterns, appetite, and thinking (*Physician's Desk Reference,* 2004).

■ **Pituitary gland** The "master gland" that produces hormones influencing the secretions of all other endocrine glands, as well as a hormone that influences growth. The pituitary is attached to the brain's hypothalamus, from which it takes its orders.

■ **Agonist** Drug or other chemical that enhances or mimics the effects of neurotransmitters.

■ **Antagonist** Drug or other chemical that inhibits the effects of neurotransmitters.

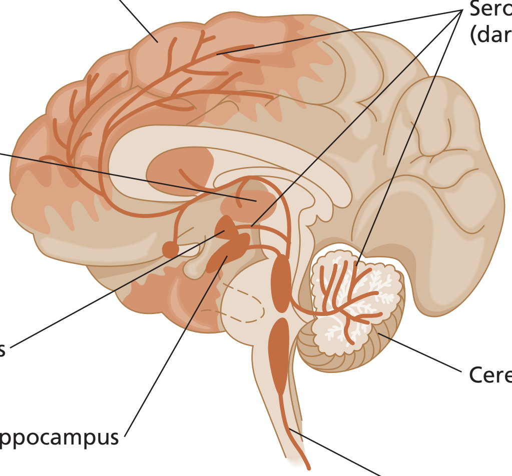


FIGURE 3.8 Serotonin Pathways in the Brain

Each neurotransmitter is associated with certain neural pathways in the brain. In this cross section of the brain, you see the main pathways for serotonin. Drugs that stimulate or inhibit serotonin will selectively affect the brain regions shown in this diagram.

Why the unwanted side effects? The answer to that question involves an important principle about the brain's design. Within the brain are many bundles of neurons—**neural pathways**—that connect different components of the brain. Moreover, each pathway employs only certain neurotransmitters. This fact allows a drug affecting a particular transmitter to target specific parts of the brain. Unfortunately for the drug-takers, different pathways may employ the same neurotransmitter for widely different functions. Thus, serotonin pathways, for example, affect not only mood but sleep, appetite, and cognition. So, taking Prozac (or one of its chemical cousins with other brand names) may treat depression but, at the same time, have side effects on other psychological processes—which explains why the drug ads must list the major possible side effects.

In fact, no psychoactive drug exists that acts like a "magic bullet" that can strike only one precise target in the brain, to work its wonders without causing collateral effects.

Neural pathway Bundle of nerve cells that follow generally the same route and employ the same neurotransmitter.

CHECK YOUR UNDERSTANDING

1. **RECALL:** Of the body's two main communication systems, the _______ is faster, while the _______ sends longer-lasting messages.
2. **RECALL:** The _______ division of the autonomic nervous system increases the heart rate during an emergency, while the _______ division slows the heart rate after an emergency is over.
3. **RECALL:** Which of the following might carry a neural impulse across the synapse?
   - **a.** an axon
   - **b.** the blood
   - **c.** the cerebrospinal fluid
   - **d.** dopamine
   - **e.** an electrical charge
4. **RECALL:** Which part of the brain communicates directly with the "master gland" of the endocrine system?
   - **a.** the brain stem
   - **b.** the cerebellum
   - **c.** the cortex
   - **d.** the hypothalamus
   - **e.** the pituitary
5. **RECALL:** Make a sketch of two connecting neurons. Describe the location and function of the dendrites, soma, axon, myelin sheath, terminal buttons, synapse.

(*continues*)

6. **APPLICATION:** Some people seem to have high blood pressure because they have an anxiety response while having their blood pressure taken at the doctor's office. Which part of the nervous system produces this anxiety response?
   - **a.** the cortex
   - **b.** the parasympathetic nervous system
   - **c.** the somatic nervous system
   - **d.** the spinal cord
   - **e.** the sympathetic nervous system

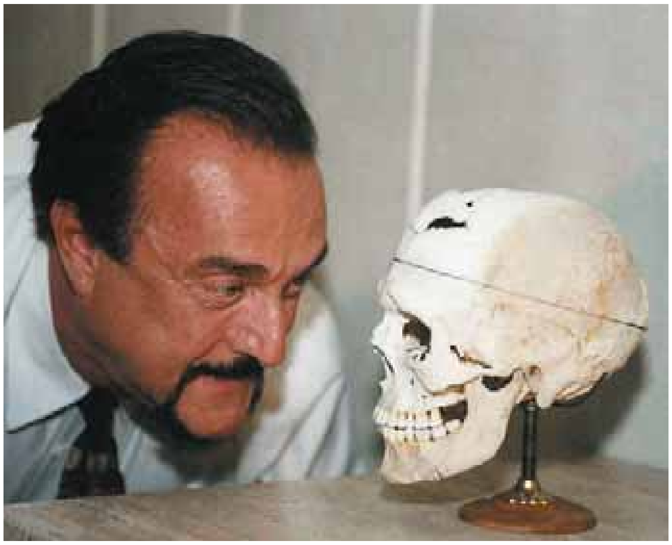
7. **UNDERSTANDING THE CORE CONCEPT:** The chemical messengers in the brain are called _______, while in the endocrine system they are called _______.

ANSWERS: 1. nervous system/endocrine system 2. sympathetic/parasympathetic 3. **d** 4. **d** 5. See Figure 3.4 6. **e** 7. neurotransmitters/hormones

KEY QUESTION

HOW DOES THE BRAIN PRODUCE BEHAVIOR AND MENTAL PROCESSES?

In September 1848, a 25-year-old American railroad worker named Phineas Gage sustained a horrible head injury when a charge of blasting powder drove an iron rod into his face, up through the front of his brain, and out through the top of his head. (See the accompanying photo.) Amazingly, he recovered from this injury and lived another 12 years—but as a psychologically changed man (Fleischman, 2002; Macmillan, 2000). Those who knew him remarked that Gage, once a dependable and likeable crew boss, had become an irresponsible and rowdy ruffian. In essence, he was no longer himself. "Gage was no longer Gage" (Damasio, 1994, p. 8). We cannot help but wonder: Had the site of Gage's injury—the front of his brain—been the home of his "old self"?



Author Phil Zimbardo (left) with the skull of Phineas Gage.

Phineas Gage's accident also raises another question: What is the connection between mind and body? Humans have, of course, long recognized the existence of such a link—although they didn't always know the brain to be the organ of the mind. Even today we might speak, as they did in Shakespeare's time, of "giving one's heart" to another or of "not having the stomach" for something when describing disgust. Today we know that love doesn't flow from the heart, nor courage from the digestive system. We now know that emotions, desires, and thoughts originate in the brain. (The news hasn't reached songwriters, who have yet to pen a lyric proclaiming, "I love you with all my brain.") At last, neuroscientists are unraveling the mysteries of this complex organ, revealing it—perhaps a little less romantically than the songwriters do—as a collection of distinct modules that work together like the components of a computer. This new understanding of the brain becomes the Core Concept for this final section of the chapter:

CORE CONCEPT

The brain is composed of many specialized modules that work together to create mind and behavior.

As you study the brain in the following pages, you will find that the brain's modular components have specialized functions (Cohen & Tong, 2001). Some take responsibility for sensations, such as vision and hearing. Some have a part in regulating our emotional lives. Some contribute to memory. Some generate speech and other behaviors. This is the point: The specialized parts of the brain, like an efficient committee, usually manage to work together. Fortunately, from the perspective of a brain owner, many of these brain modules do so automatically and without conscious direction, as when an infant "knows" to look at a person's eyes. But, when something goes wrong with one or more of the brain's components, as in a stroke or Alzheimer's disease—or as happened to Phineas Gage—the biological basis of thought or behavior captures our attention.

Let's begin the story of the brain by seeing how neuroscientists go about opening their windows on its inner workings. As you will see, much of what we know about the brain's inner workings comes from observations of people with brain disease and head injuries—people like Gage.

Windows on the Brain

The brain can never actually touch velvet, taste chocolate, have sex, or see the blue of the sky. It only knows the outside world secondhand, through changing patterns of electrochemical activity in the peripheral nervous system, the neural network that shuttles messages in and out. The brain, the undisputed master of the body and seat of our personality, has no power to act on its own. To do its bidding, the brain must rely on the neural and endocrine communications networks that carry its messages to the muscles, organs, and glands throughout the body.

And what would you see if you could peer beneath the bony skull and behold the brain? The wrinkled appearance of its surface, rather like a giant walnut, offers no hint of the brain's internal structure or function. For that, we need the *EEG, CT scans, MRIs*, and *f*MRIs.

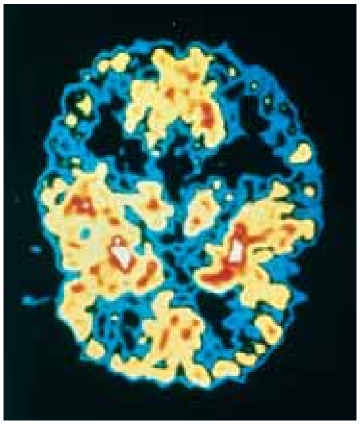
Sensing Brain Waves with the EEG Neuroscientists have learned a great deal about the brain by studying its electrical activity. Using a sensitive device called the **electroencephalograph** (or **EEG**), they can—without opening the skull—record the extremely weak voltage patterns called *brain waves,* sensed by electrodes pasted on the scalp. Much as the lights can tell you which parts of a city are most "alive" at night, the EEG senses which parts of the brain are most active. It can identify, for example, electrical patterns involved in moving the hand or processing a visual image. The EEG can also reveal abnormal waves caused by brain malfunctions, such as occurs in *epilepsy* (a seizure disorder that arises from an electrical "storm" in the brain).

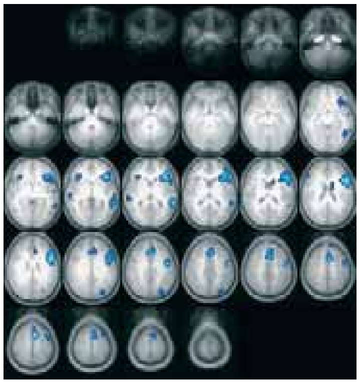
That said, however, the EEG is not a very precise instrument. Within the limits of its sensitivity, it indiscriminately records the brain's electrical activity in the region of the electrode. And because there may be fewer than a dozen electrodes used, the electrical picture of the brain is not detailed. Moreover, the EEG electrodes sample not only the "flash" discharges of the action potential, they also sense other, more subtle electrical charges, such as those in the soma. The result is a coarse, moment-to-moment summary of the electrical activity in millions and millions of neurons lying near the surface of the brain—making it all the more amazing that we can sometimes read the traces of mental processes in the EEG signature, as we will see in more detail in the next chapter.

Mapping the Brain with Electric Probes Half a century ago, the great Canadian neurologist Wilder Penfield opened another window on the brain by "mapping" its pinkish-gray surface with a pen-shaped electric probe. During brain surgery, Penfield stimulated patients' exposed brains with an electrode (a thin wire that conducts a mild electric current, on the order of a flashlight battery) and recorded their responses. (His patients were kept awake, but under local anesthesia, so they felt no pain.)

■ **Electroencephalograph** or **EEG** A device for recording brain waves, typically by electrodes placed on the scalp. The record produced is known as an electroencephalogram (also called an EEG).

This was not just an experiment. As a surgeon, Penfield needed to identify the exact boundaries of the diseased brain areas, to avoid removing healthy tissue. But, as he did so, Penfield was able to demonstrate that the brain's surface is divided into distinct regions, each with different functions. Stimulating a certain spot might cause the left hand to move; another site might produce a sensation, such as a flash of light. Stimulating still other sites might provoke a memory from childhood (Penfield, 1959; Penfield & Baldwin, 1952). Later, other scientists followed Penfield's lead and probed structures deeper in the brain. There they found that electrical stimulation could set off elaborate sequences of behavior and emotions. The overall conclusion from such work is unmistakable: Each region of the brain has its own specific functions.





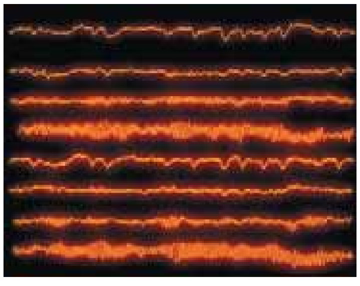


FIGURE 3.9 Windows on the Mind

Images from brain-scanning devices. From top: PET, *f*MRI, EEG. Each scanning and recording device has strengths and weaknesses.

Computerized Brain Scans Advances in brain science during the last couple of decades have opened new windows on the brain by employing sophisticated procedures collectively known as *brain scans.* Some make images with X rays, others use radioactive tracers, and still others use magnetic fields (Pinel, 2003). Thanks to such scanning methods, scientists can now make vivid pictures of brain tissue without opening the skull and physically invading the brain. Medically, these methods also help neurosurgeons locate brain abnormalities such as tumors or stroke-related damage. Psychologically, the images they obtain from brain scans can show where our thoughts and feelings are processed because specific regions of the brain seem to "light up" when a person reads, speaks, solves problems, or feels certain emotions (Raichle, 1994).

The most common brain-scanning methods currently used are CT scanning, PET scanning, MRI, and *f*MRI. (Barinaga, 1997a; Mogilner et al., 1993):

- **CT scanning,** or **computerized tomography,** creates a computerized image of the brain from X rays passed through the brain at various angles. Tomography (from the Greek *tomos,* "section") detects the soft-tissue structures of the brain that X rays normally do not reveal (see Figure 3.9). CT scanning creates a static image of brain structure.
- **PET scanning,** or **positron emission tomography,** produces an image showing brain activity (rather than brain structure). One common PET technique does so by sensing the concentration of low-level radioactive glucose (sugar), which concentrates in the most active brain circuits. Areas of high concentration show up as brightly colored on the image.
- **MRI,** or **magnetic resonance imaging,** makes highly detailed pictures from tissue responses to powerful pulses of magnetic energy. (Another example of an MRI image can be seen in Figure 3.1, at the beginning of the chapter.) While standard MRI images show brain structure, a newer technique called **functional magnetic resonance imaging (*f*MRI)** can distinguish more active brain cells from less active ones (Alper, 1993; Collins, 2001). Thus, *f*MRI allows neuroscientists to determine which parts of the brain are most active during various mental activities. The *f*MRI technique also produces more detailed images than does PET, as you can see in Figure 3.9. *f*MRI enables us to see the brain actually working, or in vivo (Parry & Matthews, 2002).

Each scanning method has its particular strengths and weaknesses. For example, PET is good at tracking the brain's activity, but not as good as MRI for distinguishing the fine details of brain structure. And neither PET nor MRI work well in studying processes that occur at rates faster than a few seconds, such as a startle response. To capture such short-lived "conversations" among brain cells requires the EEG—which, unfortunately, is limited in its detail (Raichle, 1994). Currently, no single scanning technique gives biopsychologists a perfectly clear "window" on the brain.

CT scanning or **computerized tomography** A computerized imaging technique that uses X rays passed through the brain at various angles and then combined into an image.

PET scanning or **positron emission tomography** An imaging technique that relies on the detection of radioactive sugar consumed by active brain cells.

MRI or **magnetic resonance imaging** An imaging technique that relies on cells' responses in a high-intensity magnetic field.

***f*MRI** or **functional magnetic resonance imaging** A type of MRI that reveals which parts of the brain are most active during various mental activities.

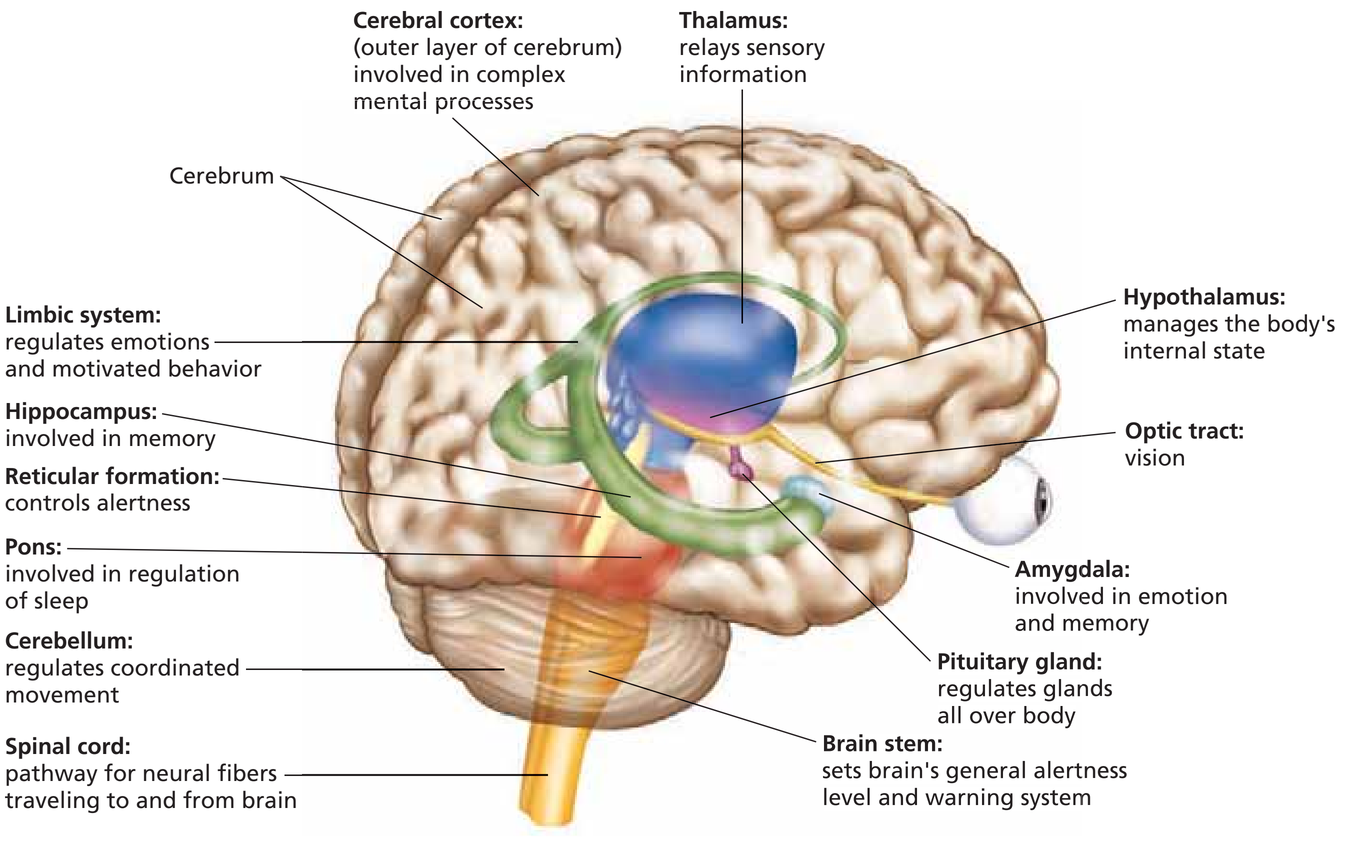
Three Layers of the Brain

What is seen through these windows on the brain depends, of course, on what brain one is examining. Birds and reptiles manage to make a living with a brain that consists of little more than a stalk that regulates the most basic life processes. Creatures with more complex brains—we humans, for example—have essentially the same stalk, the **brain stem.** From an evolutionary perspective, then, this is the part of the brain with the longest ancestry. On top of that stalk, we and our mammalian cousins have evolved two more layers, known as the *limbic system* and the *cerebrum.* (See Figure 3.10.)

Where in the brain do we really live? Is there a module that houses the "self," the real *you*? That question has no easy answer. There are certain parts of the brain stem that you couldn't do without—modules that govern your most vital functions, such as heart rate, breathing, and blood pressure. If something goes radically wrong here, the *you* could vanish. Yet, these are brain-stem functions that are essentially the same as those of any other person, or even a rat or a lizard. For the most part, they operate outside consciousness. Surely, the *you* resides somewhere else.

Perhaps we can find *you* in the brain's middle layer, especially in the limbic system's circuits that generate emotions, memories, and desires. And, although these certainly sound more like the characteristics that make us human, we also should think back to the lesson of Phineas Gage. The iron rod that blasted through his skull and made him a different person didn't touch his brain stem or limbic region. Rather, it tore through the parts of the brain's

■ **Brain stem** The most primitive of the brain's three major layers. It includes the medulla, pons, and reticular formation.



● **FIGURE 3.10** Major Structures of the Brain

From an evolutionary perspective, the brain stem and cerebellum represent the oldest part of the brain; the limbic system evolved next; and the cerebral cortex is the most recent achievement in brain evolution.

topmost layer, destroying circuits that help us "put it all together"—circuits that combine and integrate our emotions, memories, and desires with thoughts, sensations, and perceptions. Is that where you really live? Again, the answer is not simple, but we will pursue it by examining each of these three layers in more detail.

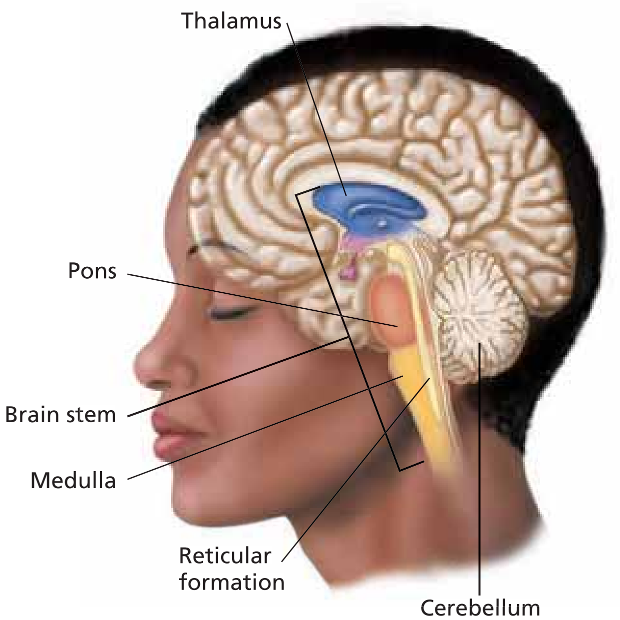
The Brain Stem and Its Neighbors If you have ever fought to stay awake in class, you have struggled with your brain stem. Most of the time, however, it does its many jobs less obtrusively and less obnoxiously. We can infer one of its jobs from the brain stem's location, linking the spinal cord with the rest of the brain. In this position, the brain stem serves as a conduit for nerve pathways that carry messages traveling up and down the spinal pathway between body and brain. Significantly, these pathways cross as they traverse this region. Therefore, *the crossover of the sensory and motor pathways means that each side of the brain connects to the opposite side of the body.* The left side of the brain controls the right side of the body, and the left side of the body sends sensory signals to the right side of the brain. This is an important idea to remember later, when we try to understand the symptoms seen in brain-injured patients.

Components of the Brain Stem More than just a go-between, the brain stem also connects several important information-processing regions, four of which we will mention here: the *medulla,* the *pons,* the *reticular formation,* and the *thalamus.* (See Figure 3.11.) From an evolutionary standpoint, they are all ancient structures, which can be found in the brains of creatures as diverse as penguins, pigs, pandas, pythons, porcupines, and people.

The **medulla,** appearing as a bulge low in the brain stem, regulates basic body functions, including breathing, blood pressure, and heart rate. It operates on "automatic pilot"—without our conscious awareness—to keep our internal organs operating without our having to think about them. An even bigger bulge called the **pons** (the Latin word for *bridge*) appears just above the medulla, where it houses nerve circuits that regulate the sleep and dreaming cycle. True to its name, the pons also acts as a "bridge" that connects the brain stem to the *cerebellum.*

■ **Medulla** A brain-stem structure that controls breathing and heart rate. The sensory and motor pathways connecting the brain to the body cross in the medulla.

■ **Pons** A brain-stem structure that regulates brain activity during sleep and dreaming. The name *pons* derives from the Latin word for "bridge."



● **FIGURE 3.11** The Brain Stem and Cerebellum

These structures in the central core of the brain are primarily involved with basic life processes: breathing, pulse, arousal, movement, balance, and early processing of sensory information.

Running through the center of everything, the **reticular formation** consists of a pencil-shaped bundle of nerve cells that forms the brain stem's core. One of the reticular formation's jobs is keeping the brain awake and alert. Others include monitoring the incoming stream of sensory information and directing attention to novel or important messages. It was the reticular formation against which you were struggling when you became drowsy in class.

From the reticular formation, nerve fibers run, like phone lines, in many directions, but especially down to the spinal cord and up to a small pair of football-shaped structures called the **thalamus.** Perched atop the brain stem, the thalamus lies near the geographic center of the brain. It is also central to the brain in another way: Like the central processing chip in a computer, the thalamus directs nearly all the brain's incoming and outgoing sensory and motor traffic. Accordingly, it receives information from all the senses (except smell) and distributes it to appropriate processing circuits throughout the brain. Incoming visual information, for example, enters the thalamus by way of the optic nerve and is then relayed on to the "gray matter" areas at the back of the brain that specialize in visual perception. Likewise, motor functions use routes between the brain's movement-control areas and the thalamus, which distributes instructions to the neural pathways serving muscles in all parts of the body. And, if that were not enough, the thalamus also seems to have a role in focusing attention—which seems appropriate enough for a structure with its connections to almost everything.

The Cerebellum Lying at the back of the brain stem, the **cerebellum** looks very much like a miniature add-on brain (its name literally means "little brain"), as you can see in Figure 3.11. Although seemingly separate—not actually a part of the brain stem—it works cooperatively with the brain stem and higher brain centers to control those complex movements that we perform without consciously thinking about the details—such as walking, dancing, or drinking from a cup (Spencer et al., 2003; Wickelgren, 1998b). Research also implicates the cerebellum in helping us keep a series of events in order—as we do when listening to the sequence of notes in a melody (Bower & Parsons, 2003). It also gets involved in producing habitual responses on cue—as when you learn to salivate at the sound of the lunch bell (Hazeltine & Ivry, 2002; Raymond et al., 1996; Seidler et al., 2002).

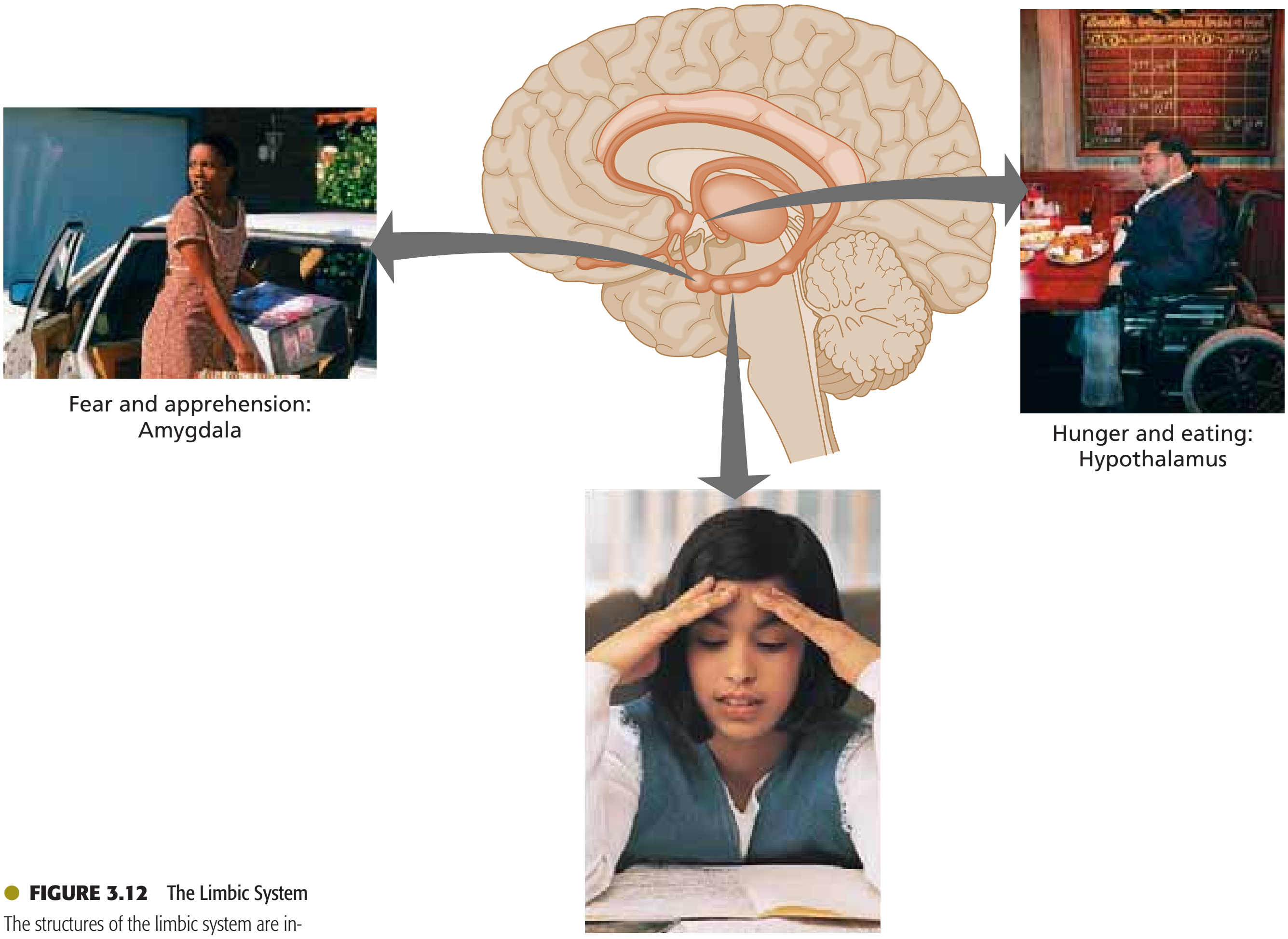
Taken together, the brain stem and cerebellum control the most basic functions of movement and of life itself. Note, again, that much of their work is automatic, functioning largely outside our awareness. The next two layers, however, assert themselves more obviously in consciousness.

The Limbic System: Emotions, Memories, and More We're sorry about your pet canary or goldfish. Only mammals come equipped with a fully developed **limbic system,** a diverse collection of structures that wrap around the thalamus, vaguely in the shape of a pair of ram's horns. (See Figures 3.10 and 3.12.) Together, these structures give mammals greatly enhanced capacity for emotions and memory. These characteristics, it turns out, offer the huge advantage of mental flexibility—so the organism doesn't have to rely solely on the instincts and reflexes that dominate the behavior of simpler creatures.

This layer houses not only modules that process memories, regulate complex motives and emotions, but it is involved in feelings of pleasure and pain. It is also the limbic system that produces fear, rage, and ecstasy. In general, the limbic system elaborates on the simpler urges arising lower in the brain to make mammalian behavior more complex than the behavior of organisms, such as fish or birds, with less complex brains.

Two important limbic structures take their names from their shapes. One, the **hippocampus,** is shaped (vaguely) like a sea horse. Hence, its name—again

- **Reticular formation** A pencil-shaped structure forming the core of the brain stem. The reticular formation arouses the cortex to keep the brain alert and attentive to new stimulation.
- **Thalamus** The brain's central "relay station," situated just atop the brain stem. Nearly all the messages going into or out of the brain go through the thalamus.
- **Cerebellum** The "little brain" attached to the brain stem. The cerebellum is responsible for coordinated movements.
- **Limbic system** The middle layer of the brain, involved in emotion and memory. The limbic system includes the hippocampus, amygdala, hypothalamus, and other structures.
- **Hippocampus** A component of the limbic system, involved in establishing long-term memories.



● **FIGURE 3.12** The Limbic System

The structures of the limbic system are involved with motivation, emotion, and certain memory processes.

from Greek. (Actually, there is one hippocampus on each side of the brain, making two *hippocampi.* See Figure 3.12.) The hippocampus's job is to connect your present with your past and to help you remember locations of things in space (Bilkey, 2004; Fyhn et al., 2004; Leutgeb et al., 2004). We can best see how this pair of brain structures works by pondering the regrettable case of H. M., a man who lost his hippocampi.

In 1953, when H. M. was in his early 20s, he underwent a radical and experimental brain operation, intended to reduce the frequency of the seizures that threatened his life (Hilts, 1995). The surgery, which removed most of the hippocampus on both sides of H. M.'s brain, was successful in reducing the frequency of his seizures and may have saved his life. But in another sense, it was a total failure: Ever since the operation, new experiences disappear from his memory almost as soon as they happen. Like the legendary Rip Van Winkle, H. M. draws a blank for the intervening years. He continues to believe he is living in 1953. Later in the book, we will see that H. M. has much to teach us about the structure of memory. Suffice it for now to note that his case illustrates that the hippocampus is a vital part of the brain's memory system. (We hope you will remember H. M. when we revisit him a few chapters hence.)

■ **Amygdala** A limbic system structure involved in memory and emotion, particularly fear and aggression. Pronounced *a-MIG-da-la.*

Another limbic structure, the **amygdala,** also takes its name from its shape: *amygdala* (again in Greek) means "almond." (See Figure 3.12.) Its function was first revealed by Heinrich Klüver and Paul Bucy (1939), who suspected that the amygdala had a role in emotion. To test this idea, they surgically snipped the connections to the amygdala on both sides of the brain in rhesus monkeys. After surgery, these normally foul-tempered beasts became docile and easy to handle, a change so dramatic that it surprised even Klüver and Bucy. Many studies since then have shown conclusively that the amygdala is involved not only in aggression but also in fear—and probably in other emotional responses (Damasio, 2003; LeDoux, 1996; Whalen, 1998). With this in mind, you shouldn't be surprised to hear that the amygdala also seems to have a role in helping us remember emotionally charged events, such as the September 11 attacks or the explosions of the space shuttles *Columbia* and *Challenger.*

The limbic system also contains several "pleasure centers" that give us the good feelings that accompany eating, sex, and other rewarding activities (Olds & Fobes, 1981; Pinel, 2003). On the street, drugs like cocaine, methamphetamine, and heroin generate wild rushes of pleasure and stimulate limbic "pleasure centers," which all seem to involve the neurotransmitter dopamine. But you don't have to take drugs or undergo brain surgery to stimulate the limbic system. The stimulation of food, drink, or sex will indirectly activate limbic pathways, too (Carlson, 2004), as will exciting activities, such as riding a rollercoaster. Studies also show that the rewarding effects from a dose of rich chocolate stimulate the same brain circuits (Small, 2001).

In the laboratory, studies have shown that rats seem to like mild stimulation in these regions. They like it very much, indeed. In fact, if left on their own to press a lever that delivers a mild electric current to one of these sites, they may stimulate themselves up to 10,000 time an hour! Rats will also pay a high price to get this pleasurable stimulation, including crossing a grid that gives painful shocks to their feet, to reach a lever that can send the obviously pleasurable stimulation to their brains. In a few cases, humans too have been given stimulation in the "pleasure centers" (for medical reasons during brain surgery). And what do they say it feels like? The feeling depends on which "pleasure center" is being stimulated, but the sensation at some locations has been likened to an orgasm. Happily, people who have had this experience do not become so obsessed by it as do rats (Valenstein, 1973).

We have already met another limbic structure, the **hypothalamus,** that has many tasks to perform. Rich with blood vessels, as well as with neurons, it primarily serves as your brain's blood-analysis laboratory. By constantly monitoring the blood, it detects small changes in body temperature, fluid levels, and nutrients. When it detects an imbalance (too much or too little water, for example), the hypothalamus immediately responds with orders that regulate appetite, thirst, and body temperature control, among other responses. Because of these functions, the hypothalamus has a major role in motivation.

CONNECTION: CHAPTER 8

The hypothalamus contains important control circuits for the basic *motives* and *drives.*

The hypothalamus makes its influence felt in other ways, as well. It sends neural messages to "higher" processing areas in the brain—making us aware of the needs it senses (hunger, for example). It also exerts its control through the pituitary gland, the body's master gland, which lies attached to the underside of the hypothalamus. As we saw earlier, the hypothalamus links the nervous system with the endocrine system. Thus, messages from the hypothalamus may tell the pituitary gland (the C.E.O. of the endocrine system) to release certain hormones, which then flow through the bloodstream to regulate such responses as heart rate, blushing, sweating, and goose pimples.

Does the hypothalamus have any role in our emotions? It hosts some of the brain's reward circuits, or "pleasure centers," which generate the feeling-good emotions associated with gratifying the hunger, thirst, and sex drives. A second link with emotion involves the hypothalamus's job of regulating the body's responses during emotional arousal. It does so by sending messages to

■ **Hypothalamus** A limbic structure that serves as the brain's blood-testing laboratory, constantly monitoring the blood to determine the condition of the body.

Cerebral cortex The thin gray-matter covering of the cerebral hemispheres, consisting of a ¼-inch layer dense with cell bodies of neurons. The cerebral cortex carries on the major portion of our "higher" mental processing, including thinking and perceiving.

the internal organs via the autonomic nervous system and, as we have noted, to the pituitary gland. In turn, the pituitary regulates the endocrine (hormone) response to emotional arousal and stress.

The Cerebral Cortex: The Brain's Thinking Cap When you look at a whole human brain, you mostly see the bulging *cerebral hemispheres*—a little bigger than your two fists held together. The nearly symmetrical hemispheres form a thick cap that hides most of the limbic system and the brain's central core. Its thin outer layer forms the **cerebral cortex** (cortex comes from Latin for "bark" or "shell"), with its distinctive wrinkled appearance. The seat of our most awesome mental powers, the cortex and its supporting structures account for two-thirds of the brain's total mass. Flattened out, the cortical surface would cover an area roughly the size of a newspaper page, but the wrinkling and folding enable its billions of cells to squeeze into the tight quarters inside your skull. As a result, only about a third of the cortex is visible on the brain's surface.

The cerebral hemispheres of the human brain.

Although we humans take pride in our large brains, it turns out that ours are not the largest. All large animals have large brains—a fact more closely related to body size than to intelligence (Pinel, 2003). Nor is the wrinkled cortex a distinctively human trait. Again, all large animals have highly convoluted cortexes. We do have more massive cortexes for our body weight than do other big-brained creatures (Carlson, 2004). Yet, human uniqueness lies more in the function of our brains than in their size. Although no one is sure exactly how or why our species evolved such a large cortex (Buss, 2004), we know that it hosts an amazing array of abilities.

Lobes of the Cerebral Cortex

In the late 1700s, the famous Austrian physician Franz Joseph Gall threw his considerable scientific weight behind the idea that specific regions of the brain control specific mental faculties, such as hearing, speech, movement, vision, and memory. Unfortunately, he carried this otherwise sensible idea to muddle-headed extremes. In his theory of *phrenology,* Gall claimed that the brain had specific regions devoted to such traits as spirituality, hope, benevolence, friendship, destructiveness, and cautiousness. Moreover, he asserted that these traits could be detected as bumps on the skull.

A phrenology bust showing the supposed locations of mental faculties, such as intuition, morality, friendship, and dignity. Although phrenologists correctly proposed that the brain is organized in modules, the specifics of their theory turned out to be completely wrong.

These ideas captured the public's attention and became enormously popular, even though Gall was mostly wrong about the details of his theory. But he was absolutely right on one small but important point—which is the reason we mention phrenology in this book: his doctrine of *localization of function,* which stated that *different regions of the brain perform different tasks.* Gall merely got the tasks and the locations wrong. We can forgive him, perhaps, because no one in those days had discovered a scientific method for determining exactly which functions were performed by which parts of the brain.

The technology Gall needed was invented about a century later by two German surgeons. In 1870, on a battlefield of the Franco-Prussian War, Gustav Fritsch and Eduard Hitzig seized an unusual opportunity to study living human brains. Their technique (which seems extreme by modern standards) involved a jolt of electricity to the exposed cortex of unfortunate soldiers who had had parts of their skulls blown away in battle. Not surprisingly, most of the cortical regions they tested gave no response: These were the so-called silent areas. But sometimes the stimulation would cause an arm or leg or some other body part to move, notably when a certain strip of tissue in the *frontal lobes* received the electric current (see Figure 3.13). Thus, Fritsch and Hitzig discovered a region, now called the *motor cortex,* that controls a specific function: voluntary movement of body parts. Later research, of course, has expanded on

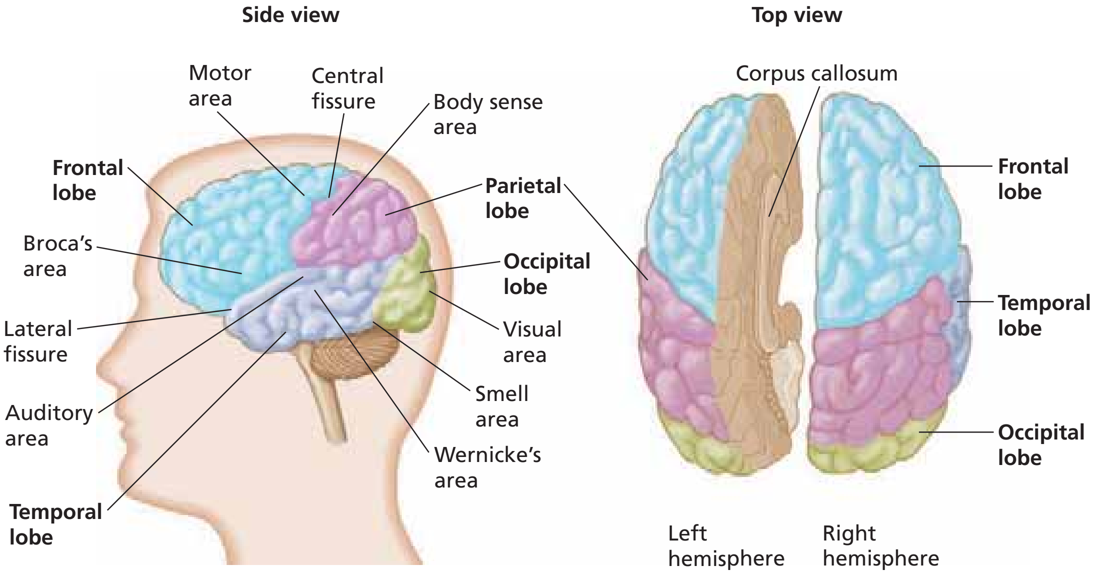


FIGURE 3.13 The Cerebral Cortex

Each of the two hemispheres of the cerebral cortex has four lobes. Different sensory and motor functions have been associated with specific parts of each lobe. The two hemispheres are connected by a thick bundle of fibers called the corpus callosum.

this work by finding functions for the silent areas all over the cortex. In fact, investigations have extended Gall's doctrine of localization of function to deeper regions beneath the cortex. As a result, the entire brain has now been mapped. Let's see what this map looks like.

The Frontal Lobes Your choice of major, your plans for the summer, and your ability to answer test questions all depend on the cortical regions at the front of your brain, aptly named the **frontal lobes.** Here we find modules working together to perform our higher mental functions, such as planning, deciding, and perceiving (Helmuth, 2003a; Koechlin et al., 2003; Shimamura, 1996). The biological substrates of personality and temperament have important components here, too. We know this from accidents that damage the frontal lobes and produce devastating effects, such as we saw earlier in the case of Phineas Gage.

At the back of the frontal lobe lies a special strip of cortex capable of taking action on our thoughts. Known as the **motor cortex,** this area takes its name from its function: controlling the body's motor movement by sending messages via the motor nerves to the voluntary muscles. As you can see in Figure 3.14, the motor cortex contains an upside-down map of the body. We have represented its functions by the *homunculus* (the cartoonish "little man" in the figure). A look at the motor homunculus reveals that certain parts of the body are disproportionately represented, with the lips, tongue, and hands being particularly exaggerated. One of its largest areas is devoted to the fingers (especially the thumb), reflecting the importance of manipulating objects. (Could this also reflect our human fondness for using "rules of thumb"? Perhaps not.) Another major area sends messages exclusively to the muscles of the face, used in expressions of emotion. Please remember, however, that commands from the motor cortex on one side of the brain control muscles on the opposite side of the body, as we saw in our opening vignette.

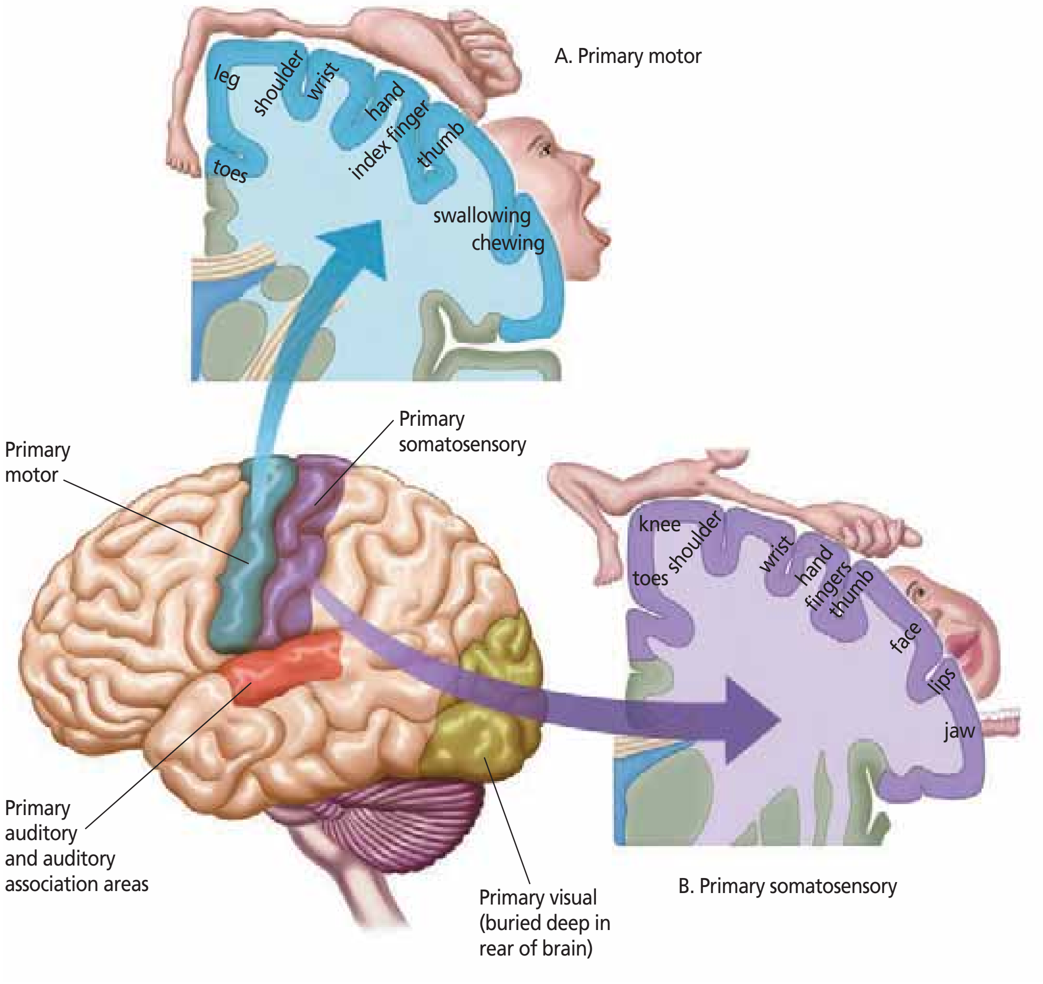
The Parietal Lobes Behind each frontal lobe and running along the top of the brain lie two large patches of cortex that specialize in sensation (see Figure

■ **Frontal lobes** Cortical regions at the front of the brain that are especially involved in movement and in thinking.

■ **Motor cortex** A narrow vertical strip of cortex in the frontal lobes, lying just in front of the central fissure; controls voluntary movement.

● **FIGURE 3.14** The Motor Cortex and the Somatosensory Cortex

Actions of the body's voluntary muscles are controlled by the motor cortex in the frontal lobe. The somatosensory cortex in the parietal lobe processes information about temperature, touch, body position, and pain. The diagram shows the proportion of tissue devoted to various activities or sensitivities in each cortex.



3.13). These **parietal lobes** allow us to sense the warmth of a hot bath, the smoothness of silk, the pressure and movement of a rude elbow, and the gentleness of a caress. A special parietal strip, known as the **somatosensory cortex,** mirrors the adjacent strip of motor cortex that we found in the frontal lobe. This somatosensory cortex has two main functions. First, it serves as the primary processing area for the sensations of touch, temperature, pain and pressure from all over your body (Graziano et al., 2000; Helmuth, 2000). Second, it relates this information to a mental map of the body to help you locate the source of these sensations.

Other maps in the parietal lobes keep track of the position of body parts, so they prevent you from biting your tongue or stepping on your own toes. And, when your leg "goes to sleep" and you can't feel anything but a tingling sensation, your body position has temporarily disabled the nerve cells that carry sensory information to body maps in the parietal lobe. (It was such a parietal body map that was affected by the tumor described in our opening vignette.)

Besides processing sensation and keeping track of body parts, the parietal lobes—especially the one in the right hemisphere—allow us to locate, in three-dimensional space, the positions of external objects detected by our senses. Meanwhile, the left hemisphere's parietal lobe has its own special talents. It specializes in locating the source of speech sounds, as when someone calls your name. It also works with the temporal lobe to extract meaning from speech and writing.

■ **Parietal lobes** Cortical areas lying toward the back and top of the brain; involved in touch sensation and in perceiving spatial relationships (the relationships of objects in space).

■ **Somatosensory cortex** A strip of the parietal lobe lying just behind the central fissure. The somatosensory cortex is involved with sensations of touch.

The Occipital Lobes During the Apollo 11 mission to the moon, lunar module pilot Edwin Aldrin reported back to Earth that he was experiencing mysterious flashes of light. This celestial display apparently resulted from cosmic rays stimulating his **occipital lobes,** at the back of the brain (see Figure 3.13). Similarly—if less pleasantly—you, too, will "see stars" when a sharp blow to your head bounces your brain around and stimulates its occipital lobes. Under more normal circumstances, the occipital lobes receive stimulation relayed from the eyes to the **visual cortex,** which constructs our moving picture of the outside world.

To create this picture, the brain divides up the incoming visual input and sends it to separate cortical areas for the processing of color, movement, shape, and shading—as we will see in more detail in Chapter 4. There is even a distinct patch of cortex dedicated to the recognition of human faces and another for perception of the human body (Downing et al., 2001; Holden, 1997; Turk et al., 2002). But the occipital lobes do not do all this work alone. As we have noted, they rely on adjacent association areas in the parietal lobes to locate objects in space. They also work with temporal regions to produce visual memories (Ishai & Sagi, 1995; Miyashita, 1995).

The Temporal Lobes When the phone rings or a horn honks, the sound registers in your **temporal lobes,** on the lower side of each cerebral hemisphere (see Figure 3.13). There lies the *auditory cortex,* which helps you make sense of the sounds. In most people, a specialized section of auditory cortex on the brain's left side is dedicated to processing speech sounds. Other parts of the temporal lobes assume the task of storing long-term memories. This is not surprising, because the hippocampus lies directly beneath the temporal lobe—and, if you remember H. M., you will remember that the hippocampus is involved in forming memories.

The first detailed description of temporal lobe function was written at neurosurgeon Wilder Penfield's operating table over 50 years ago.* As his electrical probe touched the temporal lobe's auditory cortex of patients under local anesthesia, they often reported hearing sounds, such as buzzing noises. More surprising, when the probe strayed into nearby temporal regions, it occasionally touched a memory. One patient abruptly exclaimed, "I can see Seven-Up Bottling Company—Harrison Bakery," two of Montreal's large illuminated advertisements. Another patient reported, "There was a piano over there and someone playing. I could hear the song, you know." Still another cried out, "Now I hear people laughing—my friends in South Africa." He was surprised because he seemed to be laughing with his cousins on a South African farm, although he knew he was in surgery in Montreal (Penfield, 1975; Penfield & Jasper, 1954; Penfield & Rasmussen, 1950; Penfield & Roberts, 1959). Such reports leave little doubt that the temporal lobes are involved in both hearing and memory.

■ **Occipital lobes** The cortical regions at the back of the brain, housing the visual cortex.

■ **Visual cortex** The visual processing areas of cortex in the occipital and temporal lobes.

■ **Temporal lobes** Cortical lobes that process sounds, including speech. The temporal lobes are probably involved in storing long-term memories.

TABLE 3.3 Major Functions of the Cortical Lobes

Lobe	Functions
Frontal	Movement, speech, abstract thought
Parietal	Sensations of touch, body position, hearing
Temporal	Hearing, smell, vision
Occipital	Vision

*An overview of the functions of the cortical lobes is shown in Table 3.3.

The Cooperative Brain

Like a championship team, no individual part of the brain takes sole responsibility for emotion, memory, personality, or any other complex psychological characteristic—contrary to the beliefs of Gall and his phrenologists. There are no single "brain centers" for any of the major functions of the mind—attention, consciousness, learning, memory, thinking, language, emotion, or motivation. Rather, every mental and behavioral process involves the coordination and cooperation of many brain networks (Damasio, 2003; LeDoux, 2002). For example, when you do something as simple as answering a ringing telephone, you hear it in your temporal lobes, interpret its meaning with the help of the frontal lobes, visually locate it with your occipital lobes, initiate grasping the phone on the orders of your frontal and parietal lobes, and engage in thoughtful conversation, again using frontal-lobe circuitry. Nor are we talking just about the cortex. Even the cortex cannot do its work without communicating with circuits lying deep beneath the surface: the limbic system, thalamus, brain stem, cerebellum, and other structures.

With the brain's democratic division of labor in mind, it shouldn't surprise you to learn that the largest proportion of the human cortex is devoted to integrating and interpreting information gathered from the sensory parts of the brain. Collectively, these regions are known as the **association cortex.** Diverse parts of the association cortex, then, interpret sensations, lay plans, make decisions, and prepare us for action—precisely the mental powers in which we humans excel and which distinguish us from other animals. We have these capabilities because we have more cortical area committed to making associations than does any nonhuman species.

And now that we have seen how the four lobes in each hemisphere have specialized functions and that we depend on the cooperation of each of the parts, let's turn to some evidence that the two cerebral hemispheres are also specialists at different tasks. These differences fall under the heading of *cerebral dominance*—a commonly misunderstood concept.

Cerebral Dominance

In the mid-1800s, at about the same time that Phineas Gage was recovering from his accident, a French neurologist named Paul Broca was studying patients who had speech impairments that resulted from brain injuries. An especially important case involved a man known in the medical books as "Tan"—a name derived from the only word he was able to speak. After Tan's death, an autopsy revealed severe damage in the left front portion of his brain. This clue prompted Broca to study other patients who had developed *aphasia*—the loss of speech caused by brain damage. Again and again, Broca found damage to the same spot, later named *Broca's area,* that had been damaged in Tan's brain. (See Figure 3.13.) This pattern was one of the early suggestions that the two sides of the brain specialize in different tasks. Subsequent work has confirmed and extended Broca's findings:

- Brain-damaged patients suffering paralysis on the right side of their bodies often develop speech disturbances, suggesting that speech production involves the frontal lobe, usually in the left hemisphere. (Again, please recall that the left hemisphere controls the right side of the body.)
- Damage to other areas in the left parietal and left temporal lobes commonly produces problems in understanding language.

People with right-sided brain injuries less often have speech problems, but they are more likely to have difficulties with *spatial orientation* (locating them-

Association cortex Cortical regions throughout the brain that combine information from various other parts of the brain.

selves or external objects in three-dimensional space). They may, for example, feel lost in a previously familiar place or be unable to assemble a simple jigsaw puzzle. Musical ability is also associated with the right hemisphere, particularly with Broca's area (Holden, 2001a; Janata et al., 2002; Zatorre & Krumhansl, 2002).

While the two hemispheres appear to be near mirror images of each other, they assume different functions. This tendency for the hemispheres to take charge of different tasks is called **cerebral dominance.** But what many people don't understand about cerebral dominance is this: While some processes are more under the control of the left hemisphere, and others are predominantly right-hemisphere tasks, *both hemispheres work together to produce our thoughts, feelings, and behaviors.*

That's the broad-brush picture of cerebral dominance. Now, let's look at some details, beginning with some new research showing that the dominance pattern is not always the same from one person to another. This work uses a technique called *transcranial magnetic stimulation* (TMS), involving powerful magnetic pulses that can disable parts of the brain temporarily and without causing damage. When TMS is applied to the language areas of the brain, the results show that some people—about 1 in 10 individuals, and mostly left-handers—process language primarily on the *right* side of the brain. Another 1 in 10—again, mostly left-handers—have language functions distributed equally on both sides of the brain (Knecht et al., 2002).

Other studies have shown that, while one hemisphere usually dominates language functions, both sides of the brain get involved. The left side is usually more dominant in processing the "what," or *content,* of speech. The right hemisphere, by contrast, assumes the role of processing the *emotional tone* of speech (Vingerhoets et al., 2003). In fact, the right hemisphere is usually more involved than the left in interpreting the emotional responses of others. The control of one's own negative emotions, such as fear and anger, stems from the right frontal lobe, while the left frontal lobe regulates the positive emotions, such as joy. (For more information, see Beeman & Chiarello, 1998; Davidson, 1992a, b; Heller et al., 1998; McIntosh & Lobaugh, 2003; Posner & Raichle, 1994; Springer & Deutsch, 1993).

Different though they may be, the two hemispheres don't compete with each other (except under the most unusual conditions, which we will describe in a moment). Rather, they make different contributions to the same task. In the lingo of neuroscience, they have different *processing styles.* For example, on matching tasks performed in the psychology lab, the left hemisphere matches objects analytically and verbally—by similarity in function, as in matching eating utensils (*knife* with *spoon*). By contrast, the right hemisphere matches things that look alike or fit together to form a visual pattern—such as matching *coin* to *clock,* which are both round objects (Gazzaniga, 1970; Sperry, 1968, 1982). In general, we can describe the left hemisphere's processing style as more *analytic* and *sequential,* while the right hemisphere interprets experience more *holistically* and *spatially* (Reuter-Lorenz & Miller, 1998).

The differences between the two sides of the brain have captured the public's interest in recent years. Knowing a fad when they see it, smarmy pseudoscientists have proclaimed that people can be typed as "right-brained" or "left-brained." But we want to emphasize that this distinction is simplistic and misleading. The evidence by no means warrants categorizing people in this way. In reality, the differences between the two hemispheres do not outweigh their similarities (Banich, 1998; Trope et al., 1992). Further, as we have seen, the two hemispheres normally don't work either in isolation from each other or at cross-purposes. Rather, they cooperate, each by making its own complementary contribution to our mental lives (see Figure 3.15).

■ **Cerebral dominance** The tendency of each brain hemisphere to exert control over different functions, such as language or perception of spatial relationships.

● **FIGURE 3.15** Specialization Commonly Found in the Cerebral Hemispheres

There are, however, some exceptions that have actually proved the rule. In a few rare cases, the cerebral hemispheres cannot work together—because they have been disconnected. We are referring to individuals whose brains have been surgically "split." Their story has much to teach us about cerebral dominance in the normal human brain.

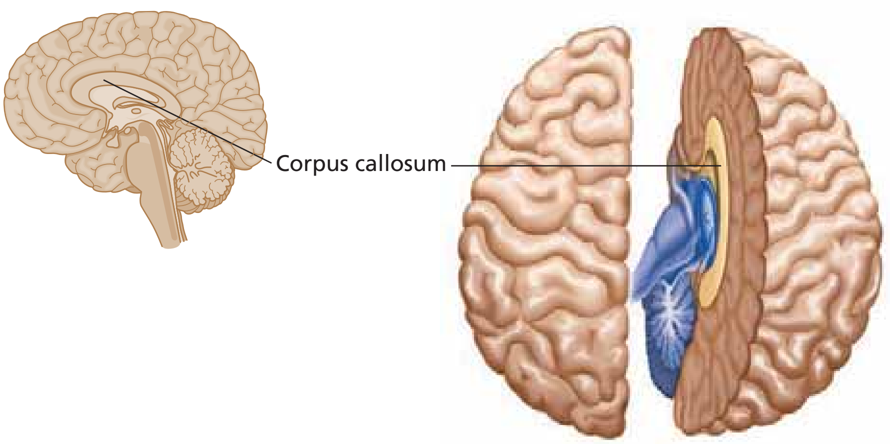
The Split Brain: "I've Half a Mind to . . ."

Imagine what your world might be like if the halves of your brain could not communicate. Would you be, literally, "of two minds"? (Or feel "beside yourself"?) A rare surgical procedure, used to treat severe epilepsy, has given us some answers to such questions. The procedure requires that surgeons cut the **corpus callosum,** the bundle of nerve fibers responsible for transferring information between the two hemispheres (Figure 3.16).

The purpose of the surgery is to prevent abnormal electrical rhythms from "echoing" back and forth between the hemispheres and developing into a full-blown seizure (Trope et al., 1992; Wilson et al., 1977). Indeed, after the operation, most patients' seizures diminish in severity. More remarkably (to psychologists), these *split-brain patients* appear mentally and behaviorally unaffected under all but the most unusual conditions. But what really grabbed psychologists' attention were certain odd responses that these individuals made on cleverly contrived tests conducted by Nobel Prize winner Roger Sperry (1968) and his colleague Michael Gazzaniga (1970).

■ **Corpus callosum** The band of nerve cells that connects the two cerebral hemispheres.

● **FIGURE 3.16** The Corpus Callosum
Only the corpus callosum is severed when the brain is "split." This medical procedure prevents communication between the cerebral hemispheres. Strangely, split-brain patients act like people with normal brains under most conditions. Special laboratory tests, however, reveal a duality of consciousness in the split brain.



Roger Sperry won the Nobel Prize in 1981 for his discoveries concerning "the functional specialization of the cerebral hemispheres" (Nobel, 1981). As the Nobel Committee wrote,

> The cerebrum is made up of two halves, the hemispheres, which are structurally identical. These hemispheres are united to one another through a system consisting of millions of nerve fibers. Therefore, each hemisphere is continually informed about what is happening in the other. For more than a century we have known that, despite their similarities and close linking, the two hemispheres generally perform different functions. The left hemisphere is the center for speech and, accordingly, has been described as the dominant one and has been considered to be superior to the right hemisphere. Outside of this, little was known about where in the brain the higher functions were centered until the beginning of the 1960s when Sperry began his investigations. *Sperry has brilliantly succeeded in extracting the secrets from both hemispheres and in demonstrating that they are highly specialized and also that many higher functions are centered in the right hemisphere.*

Sperry truly "opened up" the brain for study and understanding.

Roger Sperry

Research found that split-brain patients could not identify an unseen object, such as a ball, when it was placed in the left hand—although they had no trouble naming the object when it was shifted to the right hand. Or, in another test, most split-brain patients said they saw nothing when an image of a spoon was flashed briefly on the left side of the visual field. Yet, at the same time, the patient's right hand could reach under a visual barrier and pick the spoon out of an array of other objects.

To understand these strange results, you will need some insider information about the pathways used to get visual information from the eyes to the occipital cortex. This is the tricky part: Visual information coming *from each eye* divides into two streams that flow to the opposite sides of the brain. (Figure 3.17 can help you visualize the sensory pathways involved.) For people with intact brains, this fork in the visual road poses no problem. Thanks to the connecting pathways through the corpus callosum, information from both sides of the visual field is accessible to both hemispheres.

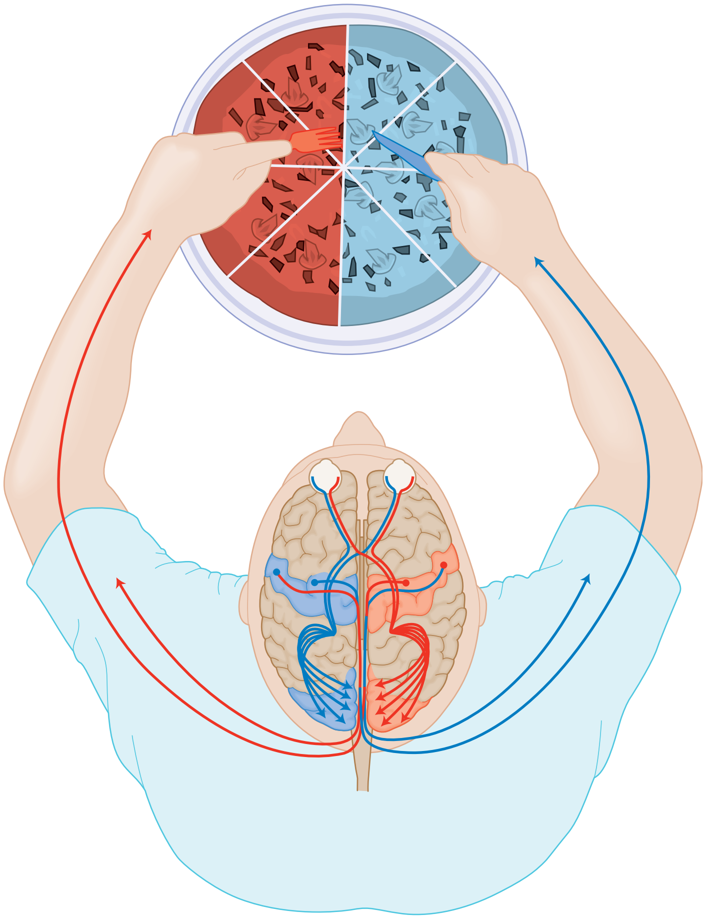
In split-brain patients, however, information sharing across the corpus callosum can't happen. Yet, under everyday conditions outside the laboratory, they get along surprisingly well. They simply scan a scene with their eyes, which sends essentially the same visual information to both sides of the brain. Only when the two hemispheres of split-brain patients get entirely different messages does the bizarre psychological reality of the split brain show itself—as it did in the Sperry and Gazzaniga experiments.

Now, put yourself in an experimenter's shoes, and see if you can explain why the split-brain patient responds as shown in Figure 3.18, on page 101. Why is he able to match, using the left hand, the image seen on the left side of the screen? And, why does he fail the same test when he uses the right hand? (Remember, from our discussion of the brain stem, that each hemisphere communicates with the *opposite* side of the body.)

The patient in the figure has been asked to identify an object that had been visualized only by the brain's right hemisphere (because the image had been flashed only on the left side of the screen). The identification task was easily performed by the left hand, which is connected to the right hemisphere, but impossible for the right hand, which communicates with the left hemisphere. So, before reading the caption for Figure 3.18, would you predict that the patient could, or could not, name the object seen on the screen?

FIGURE 3.17 The Neural Pathways from the Eyes to the Visual Cortex

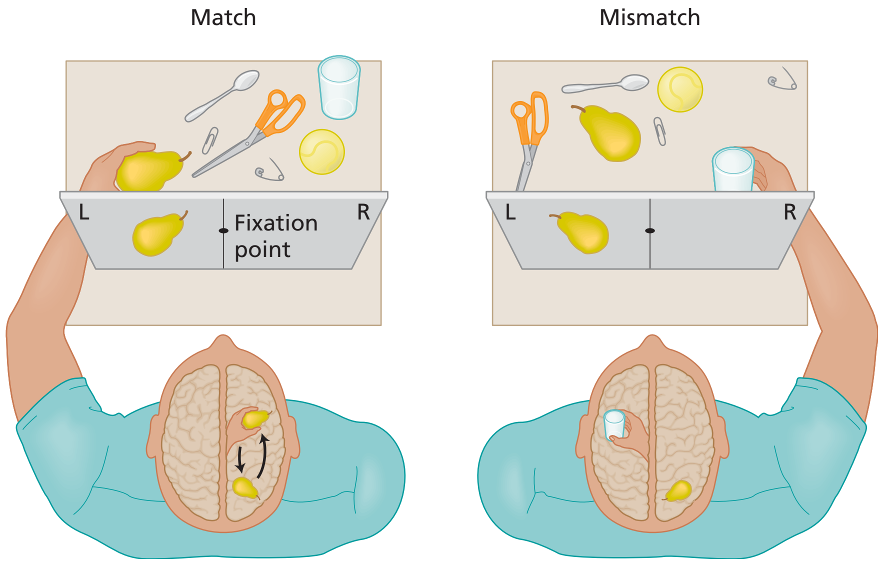
There are two things to notice in this illustration, in which the person is looking at the center of the pizza. First, the information from the left side of the retina in each eye corresponds to the right side of the pizza. Conversely, the right visual field senses the left side of the pizza. (This happens because the lens of the eye reverses the image.) Second, please notice that the left sides of both retinas in the eyes send images to the brain's left visual cortex, while the right sides of the retinas send images to the right visual cortex. As a result, when the eyes are fixated in the center, each side of the brain "sees" the opposite side of the pizza.



Some altogether unexpected effects of having a split brain also showed up in patient reports of their everyday experiences. For example, one patient told how his left hand would unzip his pants or unbutton his shirt at inappropriate times, especially when he was under stress. In fact, it was usually the left hand that would play such tricks. But why? The researchers theorize that the right hemisphere—which has little language ability but controls the left hand—was merely trying to find a way to communicate (Sperry, 1964). It's almost as if the right hemisphere were saying, "Look at me!"

Such cerebral antics point up the most interesting finding in Sperry and Gazzaniga's work: the *duality of consciousness* observed in split-brain patients. It was as if each patient were two separate individuals. When different stimuli were presented to opposite sides of the brain (as in Figure 3.18), the two hemispheres could respond independently. For example, the right hemisphere might direct the left hand to select a pear, and the left hemisphere might tell the right hand to select a glass. In other tests, they found that right-hemisphere responses tended to respond more emotionally, while the left hemisphere was more analytic. As expected, the left hemisphere typically had much more language fluency than did the right.

We must be cautious about generalizing such findings from split-brain patients to individuals with normal brains, says Gazzaniga (1998a, b). He suggests that we think of the human mind as neither a single nor a dual entity but rather as a *confederation of minds*, each specialized to process a specific kind of information. If so, the input from these many separate "miniminds" must be synthesized and coordinated for action by still other (poorly understood)



● **FIGURE 3.18** Testing a Split-Brain Patient

When a split-brain patient uses the left hand to find a match to a hidden object flashed briefly in the left visual field, eye–hand coordination is normal, because both are registered in the right hemisphere. (The patient, however, cannot name the object because speech is mainly a left-hemisphere function.) Alternatively, when asked to use the right hand to match an object seen in the left visual field, the patient cannot perform the task and mismatches a pear with some other object, such as a glass–although the patient can now name the object in his hand!

executive processors in the brain. The corpus callosum, then, is a connecting pathway that helps our confederation of minds share information. And so, we come full circle to a Core Concept that we encountered at the beginning of this section: The brain is composed of many specialized modules that work together to create mind and behavior (Baynes et al., 1998; Strauss, 1998).

PSYCHOLOGY IN YOUR LIFE: BRAIN DAMAGE AND BEHAVIOR

Nearly everybody knows someone who has suffered brain damage from an accident, a stroke, or a tumor—such as we described in the chapter-opening vignette. Your new knowledge of the brain and behavior will help you understand the problems such people must face. And if you know what abilities have been lost or altered, you can usually make a good guess as to which part of the brain sustained the damage—especially if you bear in mind two simple principles:

1. Each side of the brain communicates with the opposite side of the body. Thus, if symptoms appear on one side of the body, it is likely that the other side of the brain was damaged. (See Figure 3.19.)
2. For most people, speech is mainly a left-hemisphere function.

Now we invite you to use your knowledge of the brain to guess where the damage probably occurred in the brains of the following individuals:

- Edna had a *stroke* (an interruption of blood supply to a part of the brain) and lost her ability to speak, although she could still understand speech. Where did the stroke most likely affect her brain?
- Theo was in an auto accident, which left him with jerky, uncoordinated movements. Brain scans revealed no damage to his cerebral cortex. Where did the accident have its effect in the brain?
- Just prior to her seizures, Lydia has a strange sensation (an "aura") that feels like pinpricks on her left leg. What part of her brain generates this sensation?

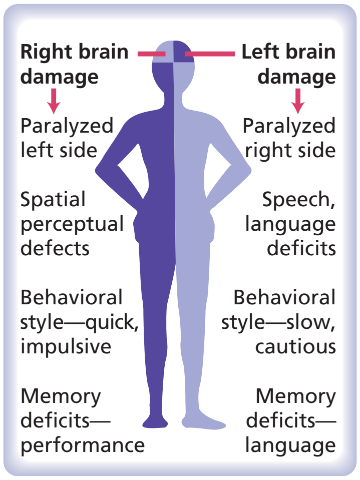


FIGURE 3.19 Effects of Damage to the Cerebral Hemispheres

Edna's case could have a happy ending. Depending on her age, physical condition, the extent of the stroke, and how quickly she received medical attention, she may get some or all of her speech back. Even if Broca's area in her left frontal lobe has been permanently damaged, other parts of Edna's brain may be able to take over some of the lost function. As we have noted, neuroscientists call this the *plasticity* of the brain. Long-term therapy for Edna will emphasize speech therapy.

Theo may also regain some or all his abilities, especially if the affected neural cells in his cerebellum were merely bruised but not destroyed in the accident. Long-term treatment for him will involve physical therapy. Both Edna and Theo may also need psychological therapy to help them cope with any permanent loss of function.

Lydia has epilepsy, originating in her right somatosensory cortex. Like most people with epilepsy, she will probably receive significant help from antiseizure medications. The chances are good that she will be completely symptom-free when the drugs are properly adjusted.

A lesson from all these cases is that people who suffer from brain damage can often receive significant help. Note, too, that help may come in many forms, both physical and mental. Perhaps the most important long-term therapy, however, is social support—a good thing to remember if you know someone who has suffered brain damage. (For more information on social support under stress, see Chapter 8, "Stress, Health, and Well-Being.")

CHECK YOUR UNDERSTANDING

1. **RECALL:** Which technique for studying the brain relies on the brain's electrical activity?
   - **a.** CT
   - **b.** EEG
   - **c.** *f*MRI
   - **d.** MRI
   - **e.** PET

2. **RECALL:** Name the three main layers of the human brain discussed in the text: _______, _______, and _______.

3. **APPLICATION:** A brain tumor in the limbic system is most likely to produce changes in a person's
   - **a.** coordination.
   - **b.** emotions.
   - **c.** hearing.
   - **d.** sleep patterns.
   - **e.** vision.

4. **RECALL:** Make a sketch showing the four lobes of the cerebral cortex. Indicate the main functions of each lobe. Which hemisphere of the brain controls language in most people? Which hemisphere of your brain controls your left hand?

5. **RECALL:** In the split-brain operation, what part of the brain is severed?
   - **a.** the cerebrum
   - **b.** the corpus callosum
   - **c.** the left hemisphere
   - **d.** the occipital lobe
   - **e.** the right hemisphere

6. **ANALYSIS:** The split-brain patient in Figure 3.18 has trouble using the _______ hand to select the object flashed on the left side of the screen.
   - **a.** right
   - **b.** left

   (*Hints:* Which hemisphere controls each hand? Which hemisphere processes information from the left side of the visual field?)

7. **UNDERSTANDING THE CORE CONCEPT:** The brain is composed of many specialized and interconnected modules that work together to create mind and behavior. Can you name at least two specialized parts of the brain that are known to work together? What is the result of the collaboration of the structures you have named?

ANSWERS: 1. **b** 2. the brain stem and cerebellum, the limbic system, the cerebrum 3. **b** 4. See the location of the four lobes in Figure 3.13. The left hemisphere controls language, and the right hemisphere controls your left hand. 5. **b** 6. **a** 7. Examples include the interaction of regions in the four lobes of the cerebral cortex when a person is answering the phone. There are many other examples mentioned in this section.

BIOPSYCHOLOGY: THE STATE OF THE ART

Now that we have had a look at the biology behind psychology, you must be wondering how to put together all the details we have covered. For example, how do all the separate modules in the brain cooperate in processing information, making decisions, and initiating action? The frank answer: No one knows precisely how the components of the brain manage to work together (Horgan, 1993). Do we need a more detailed map of the brain's interconnections? Perhaps. But even if we knew every connection for every nerve cell in the brain, we still wouldn't understand how it senses, thinks, and feels. We would be long on detail and short on insight. What we really need is a good *model*, or theory, of the brain that tells us how the parts work in synchrony. The lack of such a theory represents one of the two biggest mysteries in biopsychology.

The other mystery involves genes and psychological processes. During the last decade, scientists have made great strides in deciphering the human genome, but we still have only the sketchiest understanding of how genes regulate our thoughts, feelings, desires, and actions. How, for example, does a genetic tendency for depression become activated? Does it require some sort of "trigger" from the environment? And, how do the genes communicate with the brain?

So, at the beginning of the 21st century, these are the two burning issues that lie at the cutting edge of theory and research in biopsychology. Students just now entering the field will have an opportunity to find the answers.

USING PSYCHOLOGY TO LEARN PSYCHOLOGY

Putting Your Knowledge of the Brain to Work

The old idea that we use only 10% of our brains is bunk. We hope this chapter has shown you that every part of the brain has a known function, and it gets used every day—but not necessarily for intellectual purposes. We now know that much of the brain merely controls basic biological functions. This tells us that simply engaging more of our brains is not the royal road to increased brain power.

So, have neuroscientists found anything that you can use to improve your memory, especially for the concepts you are learning in your classes? Among their most important discoveries is the revelation that many different regions of the cerebral cortex are involved in learning and memory (Kandel & Squire, 2000). Accordingly, if you can bring more of this cerebral circuitry to bear on your studies (about biopsychology, for example), your brain will lay down a wider web of memories.

To be more specific, reading the material in this book will help you form verbal (language) memories, parts of which involve circuits in the temporal cortex. Taking notes brings the motor cortex of the frontal lobes into play, adding a "motor memory" component to your study. Scanning the accompanying photos, charts, and drawings adds visual and spatial memory components in the occipital and parietal lobes. Listening actively to your professor's lectures and discussing the material with a study partner will engage the auditory regions of the temporal cortex and lay down still other memory traces. Finally, study time spent anticipating what questions will appear on the exam will involve regions of the frontal lobes in your learning process.

In general, the more ways that you can deal with the material—the more sensory and motor channels you can employ—the more memory components you will build in your brain's circuitry. As a result, when you need to remember the material, you will have more possible ways of accessing what you have learned. So, put your knowledge of your brain to work in your studying!

CHAPTER SUMMARY

KEY QUESTION CORE CONCEPT

HOW ARE GENES AND BEHAVIOR LINKED?

Charles Darwin's theory of evolution explains behavior as the result of natural selection. Variation among individuals and competition for resources lead to survival of the most adaptive behavior and features. This principle underlies human behavior, as well as that of other animals. Research in genetics has clarified the biological basis for natural selection and inheritance. Our chromosomes contain thousands of genes, carrying traits inherited from our parents. Each gene consists of a DNA segment that encodes for a protein. Proteins, in turn, serve as the building blocks for the organism's structure and function, including the functioning of the brain. While a draft of the human genome was recently completed, we do not yet know precisely how specific genes influence behavior and mental processes.

Evolution has fundamentally shaped psychological processes because it favors genetic variations that produce adaptive behavior.

HOW DOES THE BODY COMMUNICATE INTERNALLY?

The body's two communication systems are the nervous system and the endocrine system. The neuron, the basic unit of the nervous system, is specialized for processing information. It receives messages by means of stimulation on the dendrites and soma and, when sufficiently aroused, generates an action potential along the axon. Neurotransmitter chemicals relay the message to receptors on cells across the synapse.

The nervous system, composed of billions of interconnected neurons, has two main divisions: the central nervous system (the brain and the spinal cord) and the peripheral nervous system. The peripheral nervous system, in turn, can be divided into the somatic nervous system (further divided into sensory and motor pathways) and the autonomic nervous system, which communicates with internal organs and glands. The somatic division of the autonomic NS is most active under stress, while the parasympathetic division attempts to maintain the body in a more calm state.

The glands of the slower endocrine system also communicate with cells around the body by secreting hormones into the bloodstream. Its activity is controlled by the pituitary gland attached to the base of the brain, where it receives orders from the hypothalamus.

Psychoactive drugs affect the nervous system by influencing the effects of neurotransmitters. Moreover, they may act as agonists or antagonists. Unfortunately for drug users, many neural pathways in the brain may employ the same neurotransmitter, causing unwanted side effects.

The brain coordinates the body's two communications systems, the nervous system and the endocrine system, which use similar chemical messengers to communicate with targets throughout the body.

HOW DOES THE BRAIN PRODUCE BEHAVIOR AND MENTAL PROCESSES?

Early medicine learned about the brain from the study of brain-injured persons, such as Phineas Gage. In modern times, researchers have opened windows on the brain, using the EEG to sense the brain's electrical activity, along with electric probes sometimes used to stimulate the brain during surgery. In recent years, computer technology has led to brain-scanning techniques, such as CT, PET, MRI, and *f*MRI—each having its advantages and disadvantages.

We can conceive of the brain as being organized in three integrated layers. The brain stem and associated structures (including the medulla, reticular formation, pons, thalamus, and cerebellum) control many vital body functions, along with influencing alertness and motor movement. The limbic system (including the hippocampus, amygdala, and hypothalamus) plays vital roles in motivation, emotion, and memory. The cerebral cortex contains highly specialized modules—each with distinct functions. Its frontal lobes involve both motor functions and higher mental functions. The parietal lobes specialize in sensation, especially the senses of touch and body position. The occipital lobes deal exclusively with vision, while the temporal lobes have multiple roles involved in vision, hearing, and smell. Even though the functions of the brain are highly localized within specific modules, they normally work seamlessly together.

The two cerebral hemispheres are also differently specialized. Language, analytical thinking, and positive emotions are regulated by specific parts of the left hemisphere, while circuits in the right hemisphere control spatial interpretation, visual and musical memory, and negative emotions. If the hemispheres are surgically severed, as when the corpus callosum is cut in split-brain patients, a duality of consciousness emerges. In such cases, each hemisphere functions independently and has no direct awareness of stimulation or cognitive activities affecting the other. In people with intact brains, however, the two hemispheres communicate and cooperate with each other.

The brain is composed of many specialized modules that work together to create mind and behavior.

REVIEW TEST

For each of the following items, choose the single best answer. The correct answers appear at the end.

1. According to Darwin's theory of natural selection,
   a. the environment "selects" organisms that are more complex and more advanced.
   b. the members of a species that are best adapted to their environment are more likely to survive and produce more offspring.
   c. giraffes evolved longer necks because they were constantly reaching for the tender, higher leaves in the tall trees in their environment.
   d. evolution is a process whereby experience modifies an organism's genes.
   e. evolution is the sole factor affecting the behavior of current species.

2. Although Darwin never knew it, evolution takes advantage of genetic ______ that enhance survival and reproduction of the individual.
   a. variations
   b. environments
   c. thoughts
   d. diseases
   e. theories

3. During a neural impulse, a neuron "fires" when
   a. it is physically contacted by another cell that is transmitting the signal.
   b. an electric charge travels down the axon.
   c. it contracts and releases powerful chemicals directly into the bloodstream.
   d. signals entering at the axon travel the length of the cell and exit through the dendrites.
   e. neurotransmitters attach to the dendritic receptors.

4. Neurotransmitters are released by the terminal buttons into the ______, and hormones are released by the endocrine system into the ______.
   a. sympathetic nervous system/parasympathetic nervous system
   b. cortex/brain stem
   c. left hemisphere/right hemisphere
   d. receptor sites/glands
   e. synaptic cleft/bloodstream

5. Which one of the following is an example of behavior controlled primarily by the autonomic nervous system?
   a. typing a sentence accurately on a keyboard
   b. solving a mathematical problem
   c. reading this textbook
   d. feeling hungry
   e. breathing and swallowing while asleep

6. Which form of brain scanning employs radioactive tracers to reveal the most active regions of the brain?
   a. EEG
   b. CT
   c. PET
   d. MRI
   e. *f*MRI

7. Which of the following statements identifying the locations of important brain structures is true?
   a. The hypothalamus is part of the brain stem.
   b. The medulla is part of the limbic system.
   c. The occipital lobe is part of the cerebral cortex.
   d. The limbic system regulates breathing.
   e. The pons is responsible for processing of memory.

8. Which of the three brain layers is often thought of as the "emotional brain"?
   a. the brain stem
   b. the cerebellum
   c. the limbic system
   d. the medulla
   e. the cerebrum

9. What part of the cerebral cortex is most involved with initiating and controlling body movements?
   a. the frontal lobes
   b. the hippocampus
   c. the temporal lobes
   d. the occipital lobes
   e. the parietal lobes

10. The left hemisphere of the cerebral cortex is usually more involved than the right hemisphere in activities such as
    a. recognizing and appreciating visual stimuli.
    b. enjoying and appreciating music.
    c. using spoken and written language.
    d. understanding spatial relationships.
    e. processing emotions.

ANSWERS: 1.b 2.a 3.b 4.e 5.e 6.c 7.c 8.b 9.a 10.c

KEY TERMS

Biopsychology (p. 63)
Neuroscience (p. 63)
Evolution (p. 64)
Natural selection (p. 65)
Genotype (p. 66)
Phenotype (p. 66)
DNA (p. 66)
Gene (p. 66)
Chromosome (p. 67)
Sex chromosomes (p. 68)
Neuron (p. 72)
Sensory neuron (p. 72)
Motor neuron (p. 73)
Interneuron (p. 73)
Dendrite (p. 73)
Soma (p. 74)
Axon (p. 74)
Resting potential (p. 74)
Action potential (p. 74)
All-or-none principle (p. 74)
Synapse (p. 74)
Terminal buttons (p. 74)
Synaptic transmission (p. 74)
Synaptic vesicle (p. 75)
Neurotransmitters (p. 75)
Plasticity (p. 76)
Glial cells (p. 77)
Nervous system (p. 77)
Central nervous system (p. 78)
Reflex (p. 78)
Peripheral nervous system (p. 78)
Somatic nervous system (p. 79)
Autonomic nervous system (p. 79)
Sympathetic division (p. 79)
Parasympathetic division (p. 79)
Endocrine system (p. 80)
Hormone (p. 80)
Pituitary gland (p. 82)
Agonist (p. 82)
Antagonist (p. 82)
Neural pathway (p. 83)
Electroencephalograph or **EEG** (p. 85)
CT scanning or **computerized tomography** (p. 86)
PET scanning or **positron emission tomography** (p. 86)
MRI or **magnetic resonance imaging** (p. 86)
***f*MRI** or **functional magnetic resonance imaging** (p. 86)
Brain stem (p. 87)
Medulla (p. 88)
Pons (p. 88)
Reticular formation (p. 89)
Thalamus (p. 89)
Cerebellum (p. 89)
Limbic system (p. 89)
Hippocampus (p. 89)
Amygdala (p. 90)
Hypothalamus (p. 91)
Cerebral cortex (p. 92)
Frontal lobes (p. 93)
Motor cortex (p. 93)
Parietal lobes (p. 94)
Somatosensory cortex (p. 94)
Occipital lobes (p. 95)
Visual cortex (p. 95)
Temporal lobes (p. 95)
Association cortex (p. 96)
Cerebral dominance (p. 97)
Corpus callosum (p. 98)

AP* REVIEW: VOCABULARY

Match each of the following vocabulary terms to its definition.

1. Genotype
2. Phenotype
3. Gene
4. Chromosome
5. Plasticity
6. Agonist
7. Antagonist
8. Thalamus
9. Motor cortex
10. Association cortex

_____ **a.** Encodes directions for inherited characteristics of an organism.

_____ **b.** The nervous system's ability to adapt or change as a result of experience.

_____ **c.** Cortical regions that combine information from various other parts of the brain.

_____ **d.** An organism's genetic makeup.

_____ **e.** Drug or other chemical that inhibits the effects of neurotransmitters.

_____ **f.** Narrow vertical strip of cortex in the frontal lobes.

_____ **g.** The brain's central "relay station."

_____ **h.** Drug or other chemical that enhances or minics the effects of neurotransmitters.

_____ **i.** Consist primarily of DNA.

_____ **f.** An organism's observable physical characteristics.

AP* REVIEW: ESSAY

Use your knowledge of the chapter concepts to answer the following essay question.

One of the most basic functions of the brain relies on neurons. Describe the function of a neuron/neuron chain, being sure to address each of the following in context and in an appropriate manner.

a. Depolarization

b. Excitation

c. Inhibition

d. Neurotransmitter release/binding to next neuron

e. Reuptake

OUR RECOMMENDED BOOKS AND VIDEOS

ARTICLE

Nash, M. R. (2001, July). The truth and the hype of hypnosis. *Scientific American, 285,* 46–49, 52–55. Everyone has ideas and images of hypnosis: glittering watches, drowsy subjects commanded to feel "verrry sleepy . . ." Modern cognitive science now illuminates how and why hypnosis works in pain relief, memory retrieval, and other applications.

BOOKS

Ackerman, D. (2004). *An alchemy of mind: The marvel and mystery of the brain.* New York: Scribner. Poet and naturalist Diane Ackerman investigates the "crowded chemistry lab" of the human nervous system, discovering how identity emerges within the "three-pound blob" that is the brain.

Finger, S. (1999). *Minds behind the brain.* New York: Oxford University Press. Historian Stanley Finger uses biographical sketches to study the development of brain science from ancient times to the present.

Johnson, S. (2004). *Mind wide open: Your brain and the neuroscience of everyday life.* Writer Steven Johnson describes his own experience undergoing brain scans, empathy tests, and neurofeedback, presenting the results and discussing the processes revealed. If you want to know what such tests feel like and mean, here are clear explanations and inviting glimpses into brain science.

LeDoux, J. (2003). *The synaptic self: How our brains become who we are.* New York: Penguin Books. Descartes asserted that "I think, therefore I am." Neuroscientist Joseph LeDoux once spotted a T-shirt that countered, "I don't know—so maybe I'm not." For LeDoux, getting the joke shows that the brain's hardwired pathways interact with one's unique experiences, producing not only conscious experience, but the unique self. His book is as absorbing as a mystery, with instructive humor.

MacMillan, M. (2002). *An odd kind of fame: Stories of Phineas Gage.* Cambridge, MA: MIT Press. In the mid-19th century, a railway worker in Vermont suffered and survived a horrendous brain injury after an accidental explosion. One hundred and fifty years later, Phineas Gage remains famous in neuropsychology because the injury, mainly to his frontal lobe, altered his personality more than any bodily function—thus pinpointing the brain site of individuality. This is a well-researched, poignant history.

VIDEOS

Awakenings. (1990, color, 121 min.). Directed by Penny Marshall; starring Robin Williams, Robert DeNiro, Julie Kavner. Based on Oliver Sacks's collection of the same title, this is the true story of "sleeping sickness" patients who, after decades in a vegetative state, were briefly "awakened" by one doctor's synthetic dopamine therapy. Does medicine have the right to treat patients if the experimental "cure" might offer only temporary hope? (*Rating PG-13*)

Inherit the Wind. (1960, B&W, 127 min.). Directed by Stanley Kramer; starring Spencer Tracy, Fredric March, Gene Kelly, Dick York. This wonderful adaptation of the stage play is based on the 1925 "monkey trial" of John Scopes, a Tennessee man prosecuted for teaching evolution in his public school class. Watch the movie—then research the facts about the real people behind the characters. (*Rating PG*)