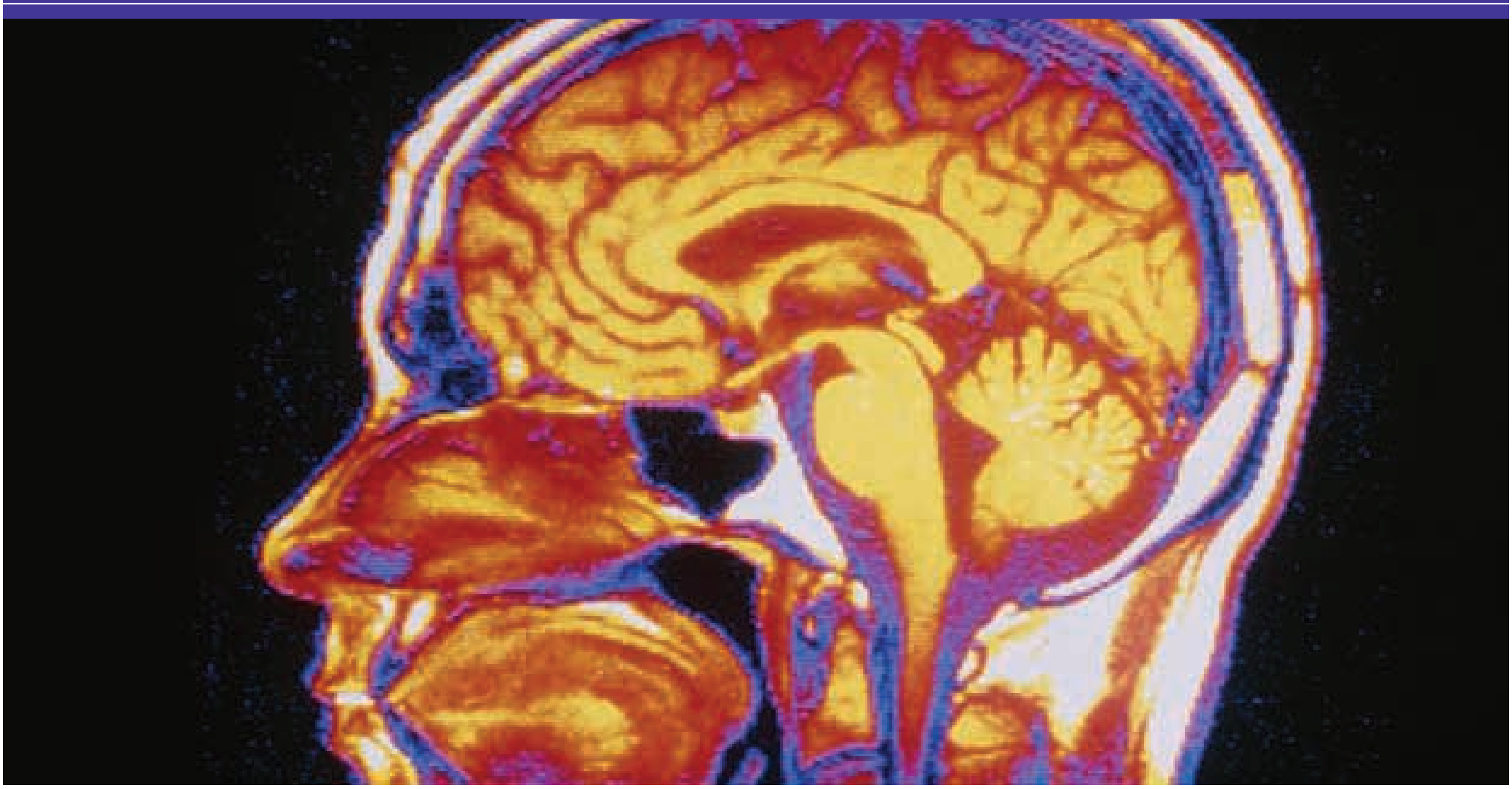
Key Questions/ Chapter Outline	Core Concepts	Psychology Matters
2.1 How Are Genes and Behavior Linked? Evolution and Natural Selection Genetics and Inheritance	• Evolution has fundamentally shaped psychological processes because it favors genetic variations that produce adaptive behavior.	**Choosing 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?
2.2 How Does the Body Communicate Internally? The Neuron: Building Block of the Nervous System The Nervous System The Endocrine System	• 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.	**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.
2.3 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 Revisited: "I've Half a Mind to … "	• The brain is composed of many specialized modules that work together to create mind and behavior.	**Using Psychology to Learn Psychology** The fact that we employ many different regions of the cerebral cortex in learning and memory may be among neuroscience's most practical discoveries.

Critical Thinking Applied: **Left Brain vs. Right Brain**

chapter 2

biopsychology, neuroscience, and human *nature*



To visualize the human brain, make two fists and put them together. Your fists represent the two **cerebral hemispheres,** which make up the bulk of the brain and house the neural circuits that give us our powers of learning, memory, thinking, and feeling. The two hemispheres communicate with each other over a connecting band of fibers, known as the **corpus callosum,** shown in Figure 2.1.

Now imagine what your world might be like if the two hemispheres could *not* communicate—if your brain were, somehow, "split" in two. Would you be, literally, "of two minds"? This is not an idle question, because there *are* people with "split brains," the result of a last-resort surgical procedure used to treat a rare condition of almost continuous epileptic seizures.

What could be the rationale for such a drastic procedure? In these patients, abnormal electrical bursts of brain waves seem to "echo" back and forth between the hemispheres, quickly building into a seizure—much as feedback through a microphone

Cerebral hemispheres The large symmetrical halves of the brain located atop the brain stem.

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

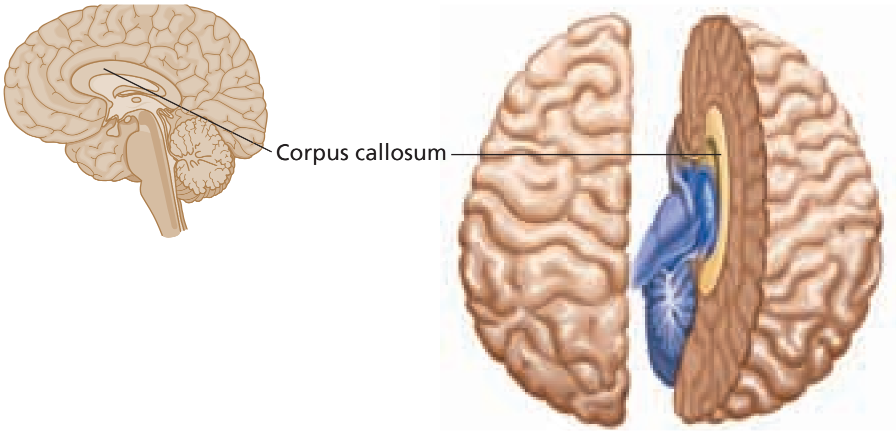


FIGURE 2.1
The Corpus Callosum

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.

generates a loud screeching noise. So the idea is to cut the corpus callosum and thereby prevent the seizure from ranging out of control.

In fact, this neurosurgical trick works quite well. Some patients even become seizure free after the split-brain operation. But what is the psychological price they pay? Curiously, split-brain patients appear mentally and behaviorally unaffected by this extreme procedure under all but the most unusual conditions.

Those unusual conditions involve clever tests contrived by Nobel Prize winner Roger Sperry (1968) and his colleague Michael Gazzaniga (2005). When holding a ball in the left hand, as shown in Figure 2.2, their split-brain patients could not identify it by feel, even though they had no trouble saying what it was when the ball was transferred to the right hand. In another test, split-brain patients said they saw nothing when an image of a spoon flashed briefly on the left side of the visual field. Yet, they could reach around a visual barrier with the right hand and easily pick the spoon out of an array of other objects.

PROBLEM: Why does it make a difference which hand a split-brain patient uses to identify an object by touch?

Finding an answer to this problem requires several pieces of information about the brain that we will assemble throughout this chapter. In the process

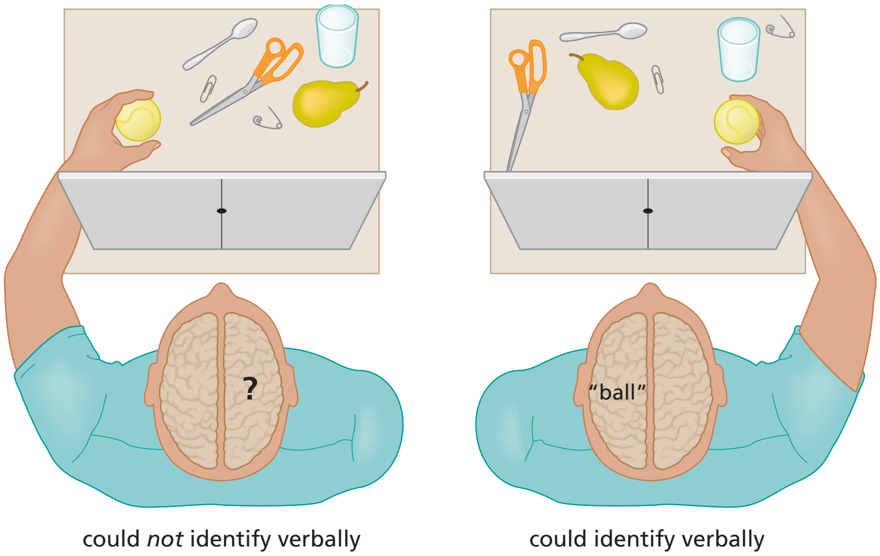


FIGURE 2.2
Testing a Split-Brain Patient

Split-brain patients can name unseen objects placed in the right hand, but when an object is placed in the left hand, they cannot name it. Why?

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of understanding why split-brain patients respond as they do, you will gain a broad knowledge of the brain and how it interacts with the rest of the nervous system.

What do we know about the human 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 bald facts give us no hint of the brain's amazing structure and capabilities. Some 100,000,000,000 nerve cells, each connecting with up to 10,000 other nerve cells, make the human brain the most complex structure known. Our largest computers seem primitive by comparison with its intricate circuitry.

At birth, you had far more nerve cells than you do now. Many of them have been pruned away, probably from disuse in the first few years of your life. (Don't worry: It happens to everyone!) By adolescence the number stabilized. So, while your brain generates some new nerve cells throughout life, and some more cells die along the way, the total remains essentially the same throughout adulthood (Gage, 2003). Even so, it is sobering to realize that some 200,000 brain cells will die every day of your adult life (Dowling, 1992).

As for its capabilities, the human 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. Most of this brain activity operates unconsciously behind the scenes—much like the electronics in your TV. Yet, when disease, drugs, or accidents destroy brain cells, the biological basis of the human mind becomes starkly apparent. Then we realize that biology underlies all human sensation and perception, learning and memory, passion and pain, reason—and even madness.

Most remarkable of all, perhaps, the human brain has the ability to think about itself. This fact fascinates specialists in **biopsychology,** who work in a rapidly growing field that lies at the intersection of biology, behavior, and mental processes. Biopsychologists often collaborate 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).

Looking at mind and behavior from a *biological perspective,* as we will throughout this chapter, has produced many practical applications. For example, we now know that certain parts of the brain control sleep patterns—with the result that we now have effective treatments for a number of formerly untreatable sleep disorders. Likewise, the effects of certain psychoactive drugs, such as cocaine, heroin, and methamphetamine, make sense now that we understand how these drugs interact with chemicals made by the brain. And, as we will see, recent discoveries involving "mirror neurons," the genetic code for human life, brain implants, and the biological basis of memory promise many more benefits for people who suffer from brain disease.

CONNECTION • CHAPTER 8
Neuroscientists have discovered the causes and treatments for many sleep disorders.

We 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. Next, 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 come to understand the odd communication patterns of the split brain. More important, you will learn how biological processes also shape your every thought, feeling, and action.

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

2.1 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 emerges already "programmed" for language, social interaction, self-preservation, and many other functions—as we can readily see in the interaction between babies and their caregivers. Babies "know," for example, how to search for the breast, how to communicate rather effectively through coos and cries, and, surprisingly, how to imitate a person sticking out her tongue. We'll look more closely at the menu of innate human behaviors in our discussion of human development (Chapter 6), 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 fails to work on a strain of bacteria that has evolved a resistance. When it comes to larger and more complex organisms, change occurs over much longer time spans, as they adapt to changing climates, predators, diseases, and food supplies. In our own 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. It also suggests explanations for some otherwise mysterious psychological processes, as you will see. Our explanation of evolution begins in this section with the story of Charles Darwin, who gave the idea of evolutionary change to the world. Following that, we will build on Darwin's insight with a look at *genetics,* which involves the molecular machinery that makes evolution work—and ultimately influences all our thoughts and behaviors.

Evolution and Natural Selection

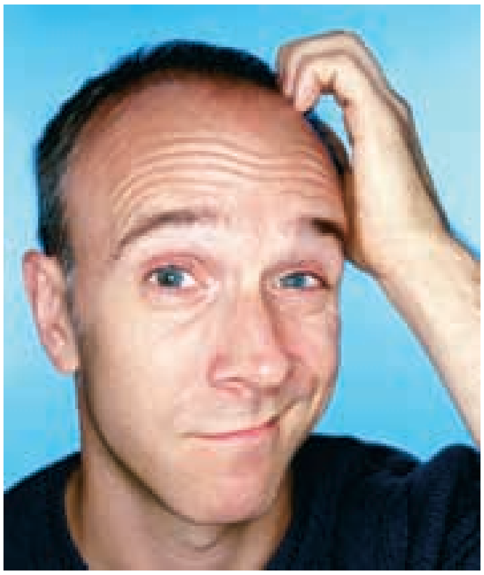
Although he had trained for careers in both medicine and the ministry, Charles Darwin decided that biology was his calling. So, in 1831, he signed on as a naturalist aboard HMS *Beagle,* a British research vessel commissioned to survey the coastline of South America. Returning five years later with numerous specimens and detailed records of the many unusual life-forms 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. So, 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).

The Evidence That Convinced Darwin

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

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



More than 98% of our genetic material is also found in chimpanzees (Pennisi, 2007). This supports Darwin's idea that humans and apes had a common ancestor.

to cracking certain seeds. But he had also observed *variation* among individuals within a species—just as some humans are taller than others or have better eyesight (Weiner, 1994). It occurred to Darwin that such variations could give one individual 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 offspring, and their line may die out. (You may have heard this described as *survival of the fittest,* a term Darwin disliked.) Through natural selection, then, a species gradually changes as it adapts to its environment.

Application to Psychology This process of adaptation and evolution helps us to make sense of many observations we make in psychology. For example, human *phobias* (extreme and incapacitating fears) almost always involve stimuli that signaled danger to our ancestors (snakes, lightning, or blood). In the same way, the fact that we spend about a third of our lives asleep makes sense in evolutionary terms: Sleep kept our ancestors out of trouble in the dark. Evolution also explains our 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, as a result, many people have a distorted understanding of 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 people and monkeys had a common ancestor millions of years ago—a big difference. Evolutionary theory says that, over time, the two species have diverged, with each developing different sets of adaptive traits. For humans, this meant developing a big brain adapted for language (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 also 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. As we saw in Chapter 1, this *nature–nurture issue* has a long history in psychology, and it is an issue that we will meet again and again throughout this book.

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

In later chapters we will discuss specific evolutionary theories 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 genetics and the biological underpinnings of heredity and evolutionary change.

Genetics and Inheritance

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 inherited traits. Consider your own unique combination of physical characteristics. Your height, facial features, and hair color, for example, all stem from the encoded genetic "blueprint" inherited from your parents and inscribed in every cell in your body. Likewise, genetics influences psychological characteristics, including your basic temperament, tendency to fears, and certain behavior patterns (Pinker, 2002).

CONNECTION • CHAPTER 10

Infants differ on their tendency to be shy or outgoing, which is believed to be an aspect of *temperament* that has a strong biological basis.

Yet, even under the influence of heredity, you are a unique individual—different from either of your parents. One source of your uniqueness lies in your experience: the environment in which you grew up—distinct in time and, perhaps, in place from that of your parents. Another source of difference between you and either of your parents arises from the random combination of traits, both physical and psychological, that each parent passed on to you from past generations in their own family lines. This hybrid inheritance produced your unique **genotype,** the genetic pattern that makes you different from anyone else on earth. Still, as different as people may seem, 99.9 percent of our genetic material is the same (Marks, 2004).

If the genotype is the "blueprint," then the resulting structure is the **phenotype.** All your physical characteristics make up your phenotype, including not only your visible traits (for instance, your height or your hair color) but also "hidden" biological traits, such as the chemistry and "wiring" of your brain. In fact, any *observable* characteristic is part of the phenotype—so the phenotype includes *behavior.* We should quickly point out that, while 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, stress, and experiences that leave a lasting mark in the form of learning. We can easily see the influence of environment in, for example, poor medical care that results in a birth defect.

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 were yet to be discovered in Darwin's time.

Chromosomes, Genes, and DNA

The blockbuster film *Jurassic Park* and its sequels relied on a clever twist of plot in which scientists recovered the genetic code for dinosaurs and created an island full of reptilian problems. The stories, of course, are science fiction, yet the films rest on an important scientific fact: Every cell in the body carries a complete set of biological instructions for building the organism. For humans, these instructions are spelled out in 23 pairs of *chromosomes,* which, under a high-powered microscope, look like tiny twisted threads. Zooming in for an even closer look, we find that each chromosome consists of a long and tightly coiled chain of **DNA** (deoxyribonucleic acid), a molecule that happens to be especially well suited for storing biological information.

Genes are the "words" that make up each organism's instruction manual. Encoded in short segments of DNA, each gene contributes to the operation of an organism by specifying a single protein. Thousands of such proteins, in turn, serve as the building blocks for the organism's physical characteristics (part of the phenotype) and the regulation of the body's internal operations. Genes,

Genotype An organism's genetic makeup.

Phenotype An organism's observable physical and behavioral 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.

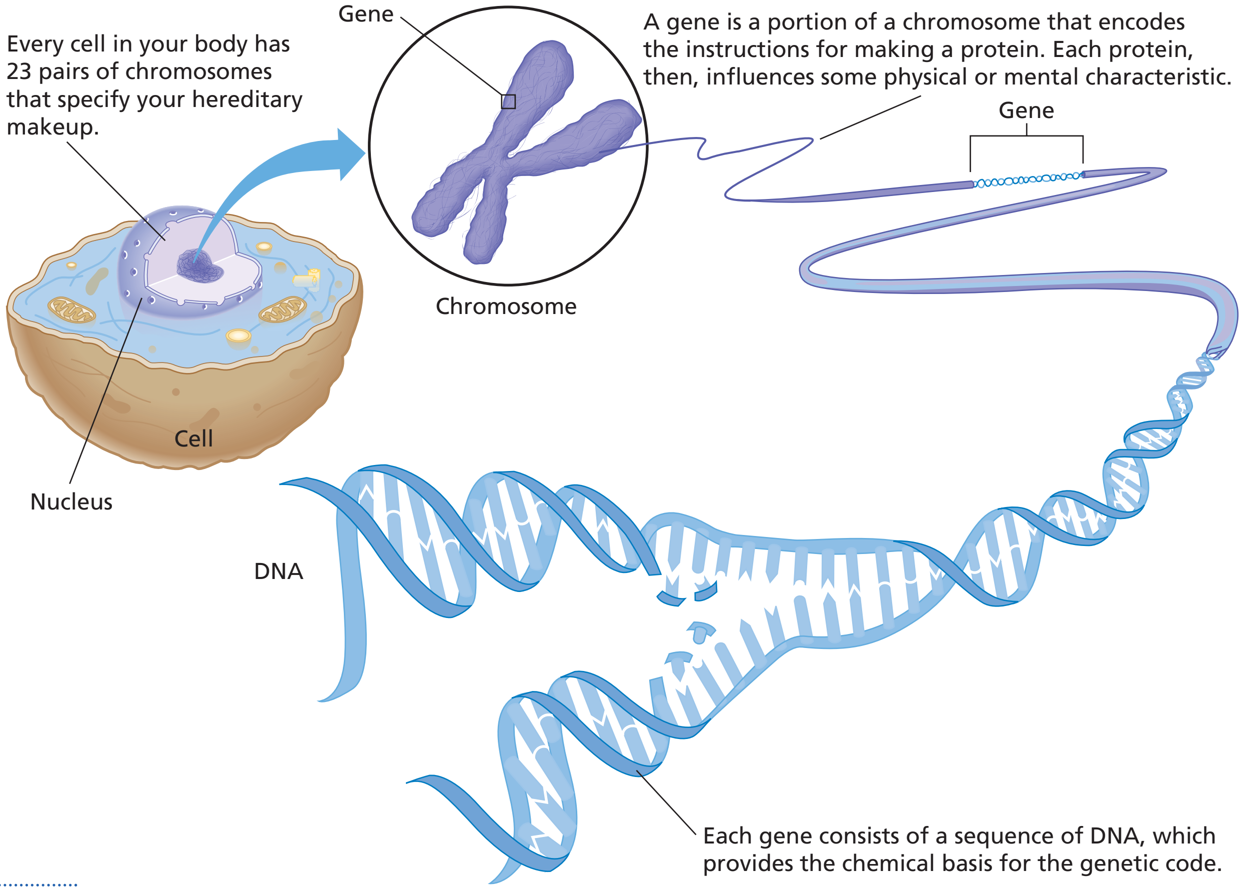


FIGURE 2.3
DNA, Genes, and Chromosomes

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 has identified the sequence of nucleotides in all 23 pairs of our chromosomes.

because they differ slightly from one individual to another, provide the biological source for the variation that caught Darwin's attention.

Like the string of words in this paragraph, genes occur in sequence on the **chromosomes.** But the chromosomes are much more than strings of genes. Like paragraphs, they also contain "punctuation" that indicates where each gene begins and ends, along with commands specifying how and when the genes will be expressed (Gibbs, 2003). Sometimes, however, these commands are wrong, or the genes themselves have defects. The resulting errors in gene expression can cause physical and developmental problems, such as cerebral palsy and mental retardation.

On a still smaller scale (now we're getting beyond the power of microscopes to resolve), genes are composed of even tinier molecular units called *nucleotides* that serve as individual "letters" in the genetic "words." Instead of a 26-letter alphabet, the genetic code uses just four nucleotides. Consequently, 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 2.3.)

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

How many genes does it take to make a human? The complete package of human DNA contains approximately 30,000 genes—surprisingly few, in view of the human organism's complexity (Marcus, 2004). Together with their supplemental instructions, these genes reside on 46 chromosomes, arranged in 23 pairs. One in each pair of your chromosomes came from your mother, with the remaining 23 being your father's genetic contribution. After repeated duplication, copies of all this information are crammed inside the trillions of cells throughout your body, where they direct cellular operations. In this way, your body, with all its cells, is like 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 or a Y 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 chromosome we get from our fathers—either an X or a Y—determines 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"—the genes themselves—"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. 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 exactly how or to what extent genes are involved in most psychological processes (Rutter, 2006).

In only a few cases can we hold a single gene responsible for a specific 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 (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 St. George-Hyslop, 2000).

CONNECTION • CHAPTER 12
Schizophrenia is a psychotic disorder that affects about 1 out of 100 persons.

So, does this mean that heredity determines our psychological destiny? Will you grow up to be like your Uncle Henry? Not to worry. Although you share many of his genes, your heredity never acts alone. Heredity and environment always work together to 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 mes-

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

sage: *Never attribute psychological characteristics 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 has come from biopsychology—can be seen in a condition called *Down's 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's 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's syndrome are capable of considerable learning, despite their genetic impairment. With special programs that teach life skills, those with Down's syndrome now can learn to care for themselves, work, and establish some personal independence.

"Race" and Human Variation Certain features of skin color and other physical characteristics are more (or less) common among people who trace their ancestry to the same part of the world. Tropical ancestry is often associated with darker skin, which affords some protection from the sun, and lighter skin frequently identifies people from high latitudes, which receive less sun. While it is common to speak of "race" in terms of these superficial characteristics, biologists tell us that there are no physical characteristics that divide people cleanly into distinct "racial" groups. We are all one species.

In reality, the physical characteristics of the so-called "races" blend seamlessly one into another. We should think of "race," therefore, as a socially defined term, rather than a biological one. Alternatively, the concept of *culture* serves as a far better explanation for most—perhaps all—the group differences that are important to psychologists (Cohen, 1998).

In this chapter, where we talk about the brain, we should be especially clear that there is no physical characteristic that reliably distinguishes the brain of a person of one geographic region, skin color, or ethnic origin from that of another. Inside the skull are many physical differences—even some gender differences—but no race-based differences.

Just because race is not a precise biological concept, however, doesn't mean that its social meaning is unimportant. On the contrary, race as a socially defined category can exert powerful influences on behavior. We will see, for example, that social conceptions of race influence expectations and prejudices. Please keep this notion in mind when we look at studies in which people who identify with different racial or ethnic groups are compared, for example on intelligence and academic achievement (Eberhardt & Randall, 1997; Hirschfeld, 1996).

PSYCHOLOGYMATTERS

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, cloned from one of her mother's cells. But what about the prospects for genetic manipulation in people? Thanks to the scientists working on the Human Genome Project, the human genetic code has been cracked: We now know the sequence of nucleotides on all the human chromosomes (Pennisi, 2001).

Psychologists expect this information to teach us something about the genetic basis for human differences in abilities, emotions, and resistance to stress (Kosslyn et al., 2002). The rest of the 21st century will see us mining the data for insight into the genetic basis for many physical and mental difficulties. 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 problems, such as Down's syndrome.

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. Most probably 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?

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 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 (Patenaude et al., 2002).

CONNECTION • CHAPTER 5

While intelligence is influenced by heredity, the relative contributions of nature and nurture are hotly debated.

Already, psychologists are called on to provide guidance about how genetic knowledge can best be applied (Bronheim, 2000), 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 partner to require you to be tested before conceiving children? 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 this century. When answering these questions, consider how the critical thinking guidelines from Chapter 1 might affect your responses. For instance, to what degree might your own emotional bias color your reaction to these questions?

Check Your Understanding

1. **RECALL:** Explain how natural selection works to increase certain genetic characteristics with a population of organisms.

2. **APPLICATION:** Name one of your own characteristics that is a part of your phenotype.

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.

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

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. Name a common human behavior that illustrates this concept.

Answers **1.** Natural selection relies on genetic variation among individuals within a population (or group) of organisms. Those who are best adapted to the environment have a survival and reproduction advantage, leaving more offspring than others. Over generations, this increases these adaptive characteristics within the population. **2.** Your observable physical and behavioral characteristics, such as height and weight or the way you speak, make up your phenotype. **3.** d **4.** c **5.** Language, social interaction, self-preservation, basic parenting "instincts," feeding in newborns—all have been influenced by evolution.

2.2 KEY QUESTION
HOW DOES THE BODY COMMUNICATE INTERNALLY?

You are driving on a winding mountain road, and suddenly a car comes 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 is the fast-acting *nervous system,* with its extensive network of nerve cells carrying messages in pulses of electrical and chemical energy throughout the body. This first-responder network comes quickly 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 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.*

The two internal message systems cooperate not only in stressful situations but in happier circumstances of high arousal, as when you receive an unexpected "A" on a test or meet someone especially attractive. The endocrine system and nervous system also work together during states of low arousal, to keep the vital body functions operating smoothly. Managing this cooperation between the endocrine system and the nervous system is the body'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. Another reason for studying the biology behind the body's internal communications is it can help us understand how drugs, such as caffeine, alcohol, heroin, and Prozac, can change the chemistry of the mind. Finally, it will help you understand many common mental and behavioral disorders, such as stroke, Alzheimer's disease, and schizophrenia.

Our overview of the body's dual communication systems first spotlights the building block of the nervous system: the *neuron.* Next, we will see how networks of these neurons work together as modular components of the great network of the *nervous system* that extends all through the body. Then, we will shift our attention to the *endocrine system,* a group of glands that operates together and in parallel with the nervous system—again throughout the body.

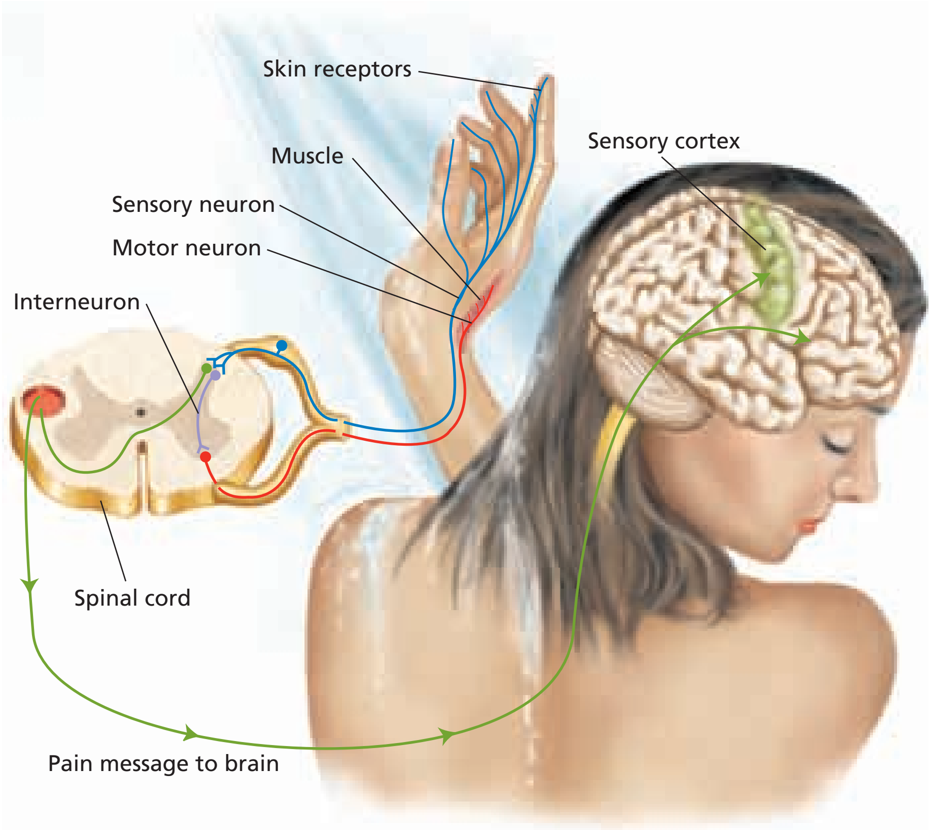
The Neuron: Building Block of the Nervous System

Like transistors in a computer, *neurons* or *nerve cells* are the fundamental processing units in the brain. In simplest terms, a **neuron** is merely a cell special-

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.*

FIGURE 2.4
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*.



ized to receive, process, and transmit information to other cells. And neurons do that very efficiently: A typical nerve cell may receive messages from a thousand others and, within a fraction of a second, decide to "fire," passing the message along at speeds up to 100 meters per second to another thousand neurons—sometimes as many as 10,000 (Pinel, 2005).

Types of Neurons While neurons vary in shape and size, all have essentially the same structure, and all send messages in essentially the same way. Nevertheless, biopsychologists distinguish three major classes of neurons according to their location and function: *sensory neurons, motor neurons,* and *interneurons*. (See Figure 2.4.) **Sensory neurons,** or *afferent neurons,* act like one-way 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.

In contrast, **motor neurons,** or *efferent neurons,* form the one-way routes that transport messages *away* from the brain and spinal cord to the muscles, organs, and glands. Motor neurons, therefore, carry the instructions for all our actions. So, in our shower example, the motor neurons deliver the message 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 2.4), 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. To see how fast these neural circuits work, try the demonstration in the accompanying "Do It Yourself!" box.

Sensory neuron A nerve cell that carries messages *toward* the central nervous system from sense receptors. Also called *afferent neurons.*

Motor neuron A nerve cell that carries messages *away* from the central nervous system toward the muscles and glands. Also called *efferent neurons.*

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

DO IT YOURSELF! Neural Messages and Reaction Time

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. 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.

How Neurons Work A look at Figure 2.5 will help you visualize the neuron's main components. 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 of the sense organs (e.g., the eyes, ears, or skin) or from other neurons.

Significantly, neuroscientists have discovered that learning can cause subtle changes in our dendrites (Barinaga, 2000). As you might imagine, this discovery has launched a search for drugs that may one day improve learning. While students will probably never be able to take a pill instead of a psychology class, a more realistic possibility involves a chemical that will help them remember what they have read or heard in class. For the moment, the best we have to offer is coffee or tea—the caffeine in which actually acts as a mild, but temporary, stimulus to the dendrites (Julien, 2005). (Whether or not caffeine actually promotes learning is controversial.)

Dendrites complete their job by passing messages on to the central part of the neuron, called the *cell body* or **soma.** Not only does the soma contain the cell's chromosomes, it must also assess the messages received by the cell. Input from a single nerve cell carries little weight in this process, because a typical neuron may receive stimulation from hundreds or even thousands of other neurons. Making the assessment even more complex, some of these messages received by the neuron can be *excitatory* (saying, in effect, "Fire!") or *inhibitory* ("Don't fire!"). The "decision" made by the cell body depends on its overall level of arousal—which depends, in turn, on the sum of all the incoming messages.

When sufficient excitation triumphs over inhibition, the neuron initiates a message of its own, sent along a single "transmitter" fiber, known as the **axon.** In some cases, these axons 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 extreme, the axons of interneurons in the brain may span only a tiny fraction of an inch.

The Action Potential When arousal in the cell body reaches a critical level, it triggers an electrical impulse in the axon—like the electronic flash of a camera—and, as we said, the cell "fires." Much like a battery, the axon gets the electrical energy it needs to fire from charged chemicals, called *ions*. In its normal, resting state, the ions within the axon give it a negative electrical charge, appropriately called the **resting potential.** But this negative state 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. (See Figure 2.5.) 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. Almost immediately, the internal charge in that part of the axon changes from negative to

Dendrite Branched fiber that extends outward from the cell body and carries information into the neuron.

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.

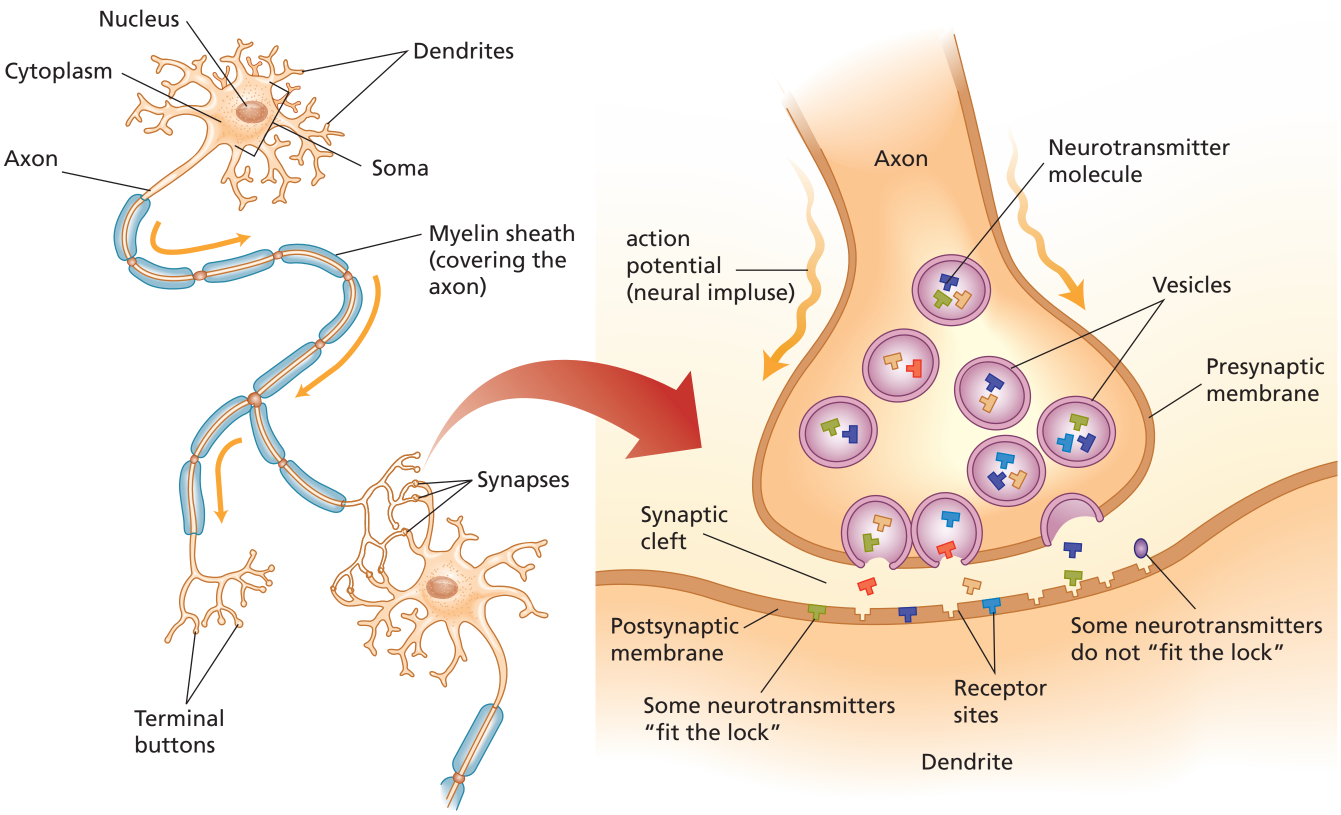


FIGURE 2.5
Structure and Function of the Neuron

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.*

positive. (We're talking 1/1000 of a second here.) Then, like a row of falling dominoes, these changes in the cell membrane progress down the axon. The result is an electrical signal that races 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.** Incidentally, when this process careens out of control, with very large numbers of neurons becoming hypersensitive and firing too easily, the result can be an epileptic seizure.

Almost immediately after firing, 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 an amazing performance—but this is not the end of the matter. Information carried by the action potential still must traverse a tiny gap before reaching another cell.

All-or-none principle Refers to the fact that the action potential in the axon occurs either completely 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 that 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.

Synaptic Transmission The microscopic gap between nerve cells, called the **synapse,** acts as an electrical insulator in most neurons. (See Figure 2.5.) This *synaptic gap* (or *synaptic cleft*) prevents the charge from jumping directly from the axon to the next cell in the circuit (Dermietzel, 2006). To pass a message across the synaptic gap, the neuron must stimulate 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.

Neurotransmitters When the electrical impulse arrives at the terminal buttons, it causes bursting of tiny bubblelike *vesicles* (sacs) located next to the synapse. This causes the vesicles to release their contents, consisting of chemical **neurotransmitters,** into the synapse. These neurotransmitters, expelled from the vesicles, then carry the neural message across the gap to the next neuron in the chain. (Again, see Figure 2.5.)

Each ruptured vesicle releases about 5000 neurotransmitter molecules into the synapse (Kandel & Squire, 2000). There, if they have the right shape, the neurotransmitters can fit into special *receptors* in the receiving neuron—much as a key fits into a lock. This lock-and-key process stimulates the receiving neuron, which passes the message onward.

After the transmitter molecules have done their work, other chemicals break them down and recycle them back to vesicles inside the terminal buttons for reuse. Many of the transmitter molecules, however, don't make it across the synapse. Through a process called *reuptake,* a large fraction of transmitters are intercepted within the synapse and drawn back into vesicles. Reuptake, then, has the effect of "turning the volume down" on the message being transmitted between neurons. Certain drugs—such as the well-known Prozac—interfere with the reuptake process, as we will see in more detail when we later discuss drug therapy for mental disorders (in Chapter 13).

The brain uses dozens of different neurotransmitters, and Table 2.1 describes several that have proved especially important in psychological functioning. Neuroscientists believe that imbalances in these neurotransmitters underlie certain disorders, such as depression. It shouldn't surprise us, then, that most drugs used to treat mental disorders act like neurotransmitters or otherwise affect the action of neurotransmitters on nerve cells. Similarly, 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 "Psychology Matters" section, coming up.

Synchronous Firing Over the last decade, neuroscientists have discovered that some neurons—a small minority—don't play by the customary rules of synaptic transmission. That is, instead of using neurotransmitters to send messages across the synapse, they forego the chemical messages and communicate directly through electrical connections (Bullock et al., 2005; Dermietzel, 2006). Scientists have found these exceptional neurons with electrical synapses concentrated in special parts of the brain that orchestrate synchronized activity in a large number of other neurons, such as those involved in the coordinated beating of the heart. These synchronized bursts may also underlie the greatest mystery of all in the brain: how the brain combines input from many different modules into a single sensation, idea, or action.

Plasticity Regardless of the communication method—electrical or chemical—neurons have the remarkable ability to *change*. That is, neurons can make new connections or strengthen old ones, a hugely important property known as **plasticity.** This 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 changes within dendrites when we learn. Another form involves making new synapses, a process also believed to be involved in learning. In addition, plasticity may account for the brain's ability to compensate for injury, as when one region takes on a new task, pinch-hitting for another site that can has been injured—as in a stroke or head trauma (Pinel, 2005). In all these ways, then, plasticity is a property that allows the brain to be restructured and "reprogrammed" by experience.

Here is a more subtle point: Because of the brain's neural plasticity, interactions with the outside world can change its physical structure (LeDoux, 2002). For example, as a violin player gains expertise, the motor area linked to the fingers of the left hand becomes larger (Juliano, 1998). Likewise, the brain dedicates more neural real estate to the index finger used by a blind Braille reader

Neurotransmitter Chemical messenger that relays neural messages across the synapse. Many neurotransmitters are also hormones.

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.

TABLE 2.1 Seven Important Neurotransmitters

Neurotransmitter	Normal Function	Problems Associated with Imbalance	Substances That Affect the Action of This Neurotransmitter
Dopamine	A transmitter used in brain circuits that produce 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

CONNECTION • CHAPTER 14

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

(Elbert et al., 1995; LeDoux, 1996). While these changes in the brain usually have beneficial effects, plasticity also allows traumatic experiences to alter the brain's emotional responsiveness in detrimental ways (Arnsten, 1998). Thus, the brain cells of soldiers who experience combat or people who have been sexually assaulted may undergo physical changes that can produce a hair-trigger responsiveness that can cause them to 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.

Brain Implants Plasticity, of course, cannot compensate for injuries that are too extensive. Driven by this problem, neuroscientists have been experimenting with computer chips implanted in the brain, where they offer the hope of restoring some motor control in paralyzed patients. In one recent case, a 26-year-old paralyzed male received such a chip as an implant in his motor cortex. By merely thinking about movement, the patient learned to send signals from his brain to a computer, controlling a cursor by thought, much as he might have used a computer's mouse by hand. In this cerebral way, he could play video games, draw circles, operate a TV set, and open e-mails—all of which his paralysis would have made impossible without the implant (Dunn, 2006; Hochberg et al., 2006).

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. (In fact, the name comes from the Greek word for "glue.") Now we know that glial cells provide structural support for neurons, as well as help in forming the new synapses needed for learning (Fields, 2004; Gallo & Chittajallu, 2001). In addition, the **glial cells** form the *myelin sheath,* a fatty insulation that covers many axons in the brain and spinal cord. Like the sheath covering on an electrical cable, the myelin sheath on a neuron insulates and protects the cell. It also helps speed the conduction of impulses along the axon (see Figure 2.5). 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 some 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 the supportive *glial cells,* which protect the neurons and help to propagate neural messages. But, wondrous as these individual components are, 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. It is to this larger picture—the nervous system—that we now turn our attention.

By means of a chip implanted in his motor cortex, this man can use his brain waves to control a computer that helps him operate other electronic devices. In this way, he can play video games, make simple drawings, and select TV programs.

The Nervous System

If you could observe a neural message as it moves from stimulus to response, you would see it flow seamlessly from one part of the nervous system to another. The signal might begin, for example, 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,** consisting of all the nerve cells in the body, functions as a single, complex, 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 2.6.)

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 most of our behaviors. The spinal cord, playing a supportive role, serves as a sort of neural cable, connecting the brain with parts of the peripheral sensory and motor systems.

Reflexes The spinal cord has another job, too. It takes charge of simple, swift **reflexes—** responses that do not require brain power, such as the reflex your physician elicits with a tap on the knee. We know that the brain does not become 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. *Voluntary* movements, however, do require the brain. That's why damage to the nerves of the spinal cord can produce paralysis of the limbs or trunk. The extent of paralysis depends on the location of the damage: The higher the site of damage, the greater the extent of the paralysis.

Contralateral Pathways Significantly, most of the sensory and motor pathways carrying messages between the brain and the rest of the body are *contralateral*—that

Glial cell One of the cells that provide structural support for neurons. 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.

Central nervous system The brain and the spinal cord.

Reflex Simple unlearned response triggered by stimuli—such as the knee-jerk reflex set off by tapping the tendon just below your kneecap.

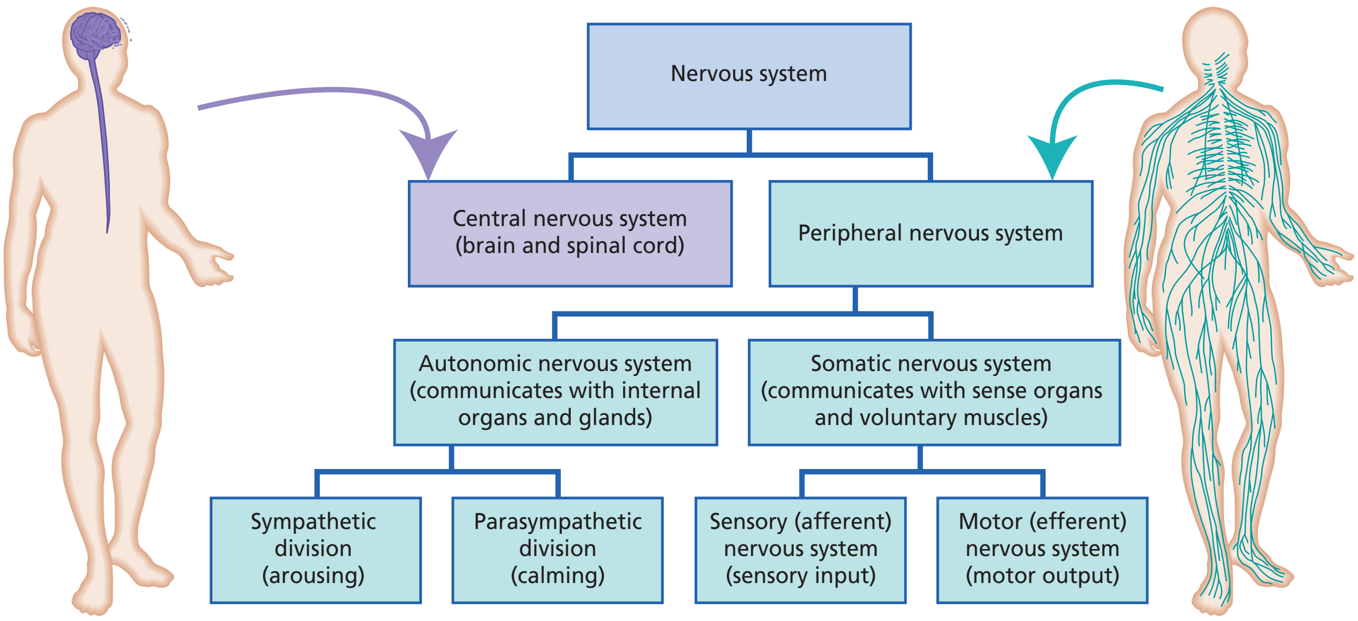


FIGURE 2.6
Organization of the Nervous System

This figure shows the major divisions of the nervous system. The figure on the left shows the *central nervous system,* while the figure on the right shows the *peripheral nervous system.*

is, they cross over to the opposite side in the spinal cord or in the brain stem. The result is that each side of the brain communicates primarily with the opposite side of the body or the opposite side of the environment. This fact is important in understanding how damage to one side of the brain often results in disabilities on the opposite side of the body. (See Figure 2.7.)

The crossover of communication pathways is also an important piece of the puzzle of the split-brain patients' performance on the special laboratory tests devised by Sperry and Gazzaniga. As you will recall, a crucial part of those tests involved presenting visual or tactile (touch) information to only one hemisphere. Because the sensory pathways cross to the opposite side, each hemisphere perceives touch sensation from the hand on the opposite side of the body. The visual pathways are more complicated, as we will see, but the result is simple: Information from one side of the visual field of each eye is processed in the hemisphere on the opposite side of the brain.

The Peripheral Nervous System Also playing a supportive role, the **peripheral nervous system (PNS)** connects the central nervous system with the rest of the body through bundles of sensory and motor axons, called *nerves*. The many branches of the PNS 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, 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 as 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) for delivery to the brain. Quickly, perceptual and emotional circuits in the brain assess the situation (Danger!) and communicate with other circuits that dispatch 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

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.

its two major divisions, the *somatic nervous system* and the *autonomic nervous system*. One deals primarily with our external world, the other with our internal responses. (A few moments spent studying Figure 2.6 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 skeletal 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* (sensory) system. Then, if all goes well, the *efferent* (motor) system sends instructions to muscles that propel the pizza on just the right trajectory, into your open mouth.

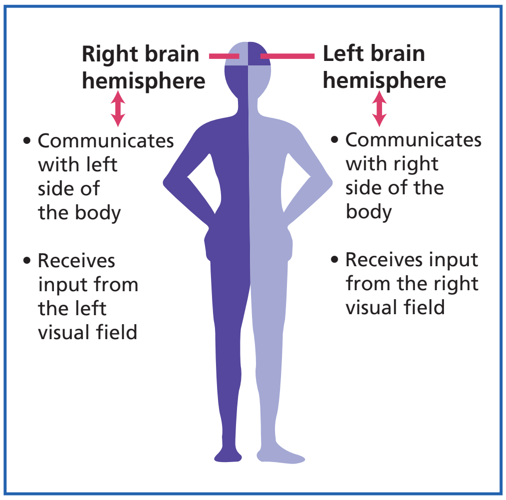


FIGURE 2.7
Contralateral Connections

For most sensory and motor functions, each side of the brain communicates with the opposite side of the body. (This is known as *contralateral* communication.) The case of vision is a bit more complicated: The visual cortex on one side "sees" the opposite side of the external world, as the text will explain.

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

And—wouldn't you know?—biopsychologists further divide the autonomic nervous system into two subparts: the *sympathetic* and *parasympathetic divisions* (as shown in Figure 2.8). 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 or a first date. Perhaps you can recall how the sympathetic division of your autonomic nervous system made you feel during your last oral presentation. Was it hard to breathe? Were your palms sweaty? Did your stomach feel queasy? All these are sympathetic division functions.

The **parasympathetic division** does just the opposite: It applies the neural brakes, returning the body 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 2.8 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*.

The Endocrine System

Perhaps you had never thought of the bloodstream as a carrier of *information,* along with oxygen, nutrients, and wastes. Yet, blood-borne information, in the form of *hormones,* serves as the communication channel among the glands of the **endocrine system,** shown in Figure 2.9. (*Endocrine* comes from the Greek *endo* for "within" and *krinein* for "secrete.")

Playing much the same role as neurotransmitters in the nervous system, **hormones** carry messages that influence not only body functions but behaviors and emotions (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

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.

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

Hormones Chemical messengers used by the endocrine system. Many hormones also serve as neurotransmitters in the nervous system.

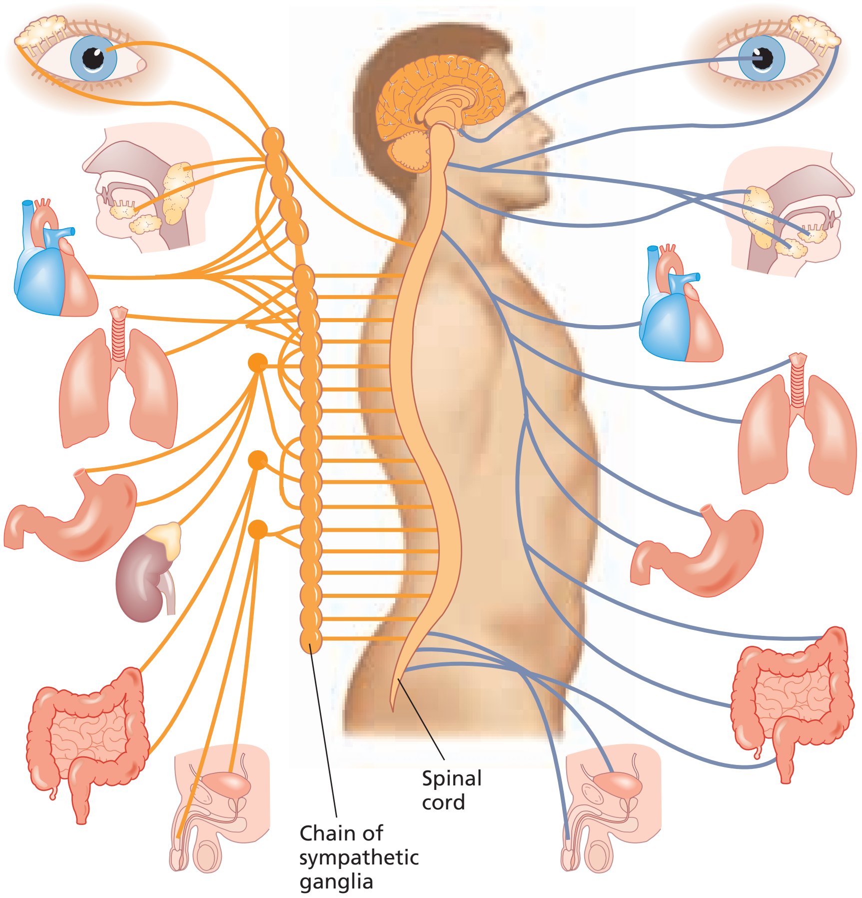


FIGURE 2.8
Divisions of the Autonomic Nervous System

The *sympathetic nervous system* (at left) 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 *parasympathetic nervous system* (at right) regulates day-to-day internal processes and behavior.

produce the arousal accompanying fear. And hormones from the thyroid control metabolism (rate of energy use). Once secreted into the blood by an endocrine gland, hormones circulate throughout the body until delivered to their targets, which may include not only other endocrine glands but muscles and organs. Table 2.2 outlines the major endocrine glands and the body systems they regulate.

How Does the Endocrine System Respond in a Crisis? 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, it shifts into a different mode, in support of the sympathetic nervous system. So, when you encounter a stressor or an emergency (such as the speeding car headed at you), the hormone *epinephrine* (sometimes called *adrenalin*) is released into the bloodstream, sustaining the body's defensive reaction that we call "fight or flight." In this way, the endocrine system finishes what your sympathetic nervous system has started by keeping your heart pounding and your muscles tense, ready for action.

Later in the book we will see what happens when this stressful state gets out of control. 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 prolonged state of arousal. The price your mind and body pays for this extended arousal can be dear.

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

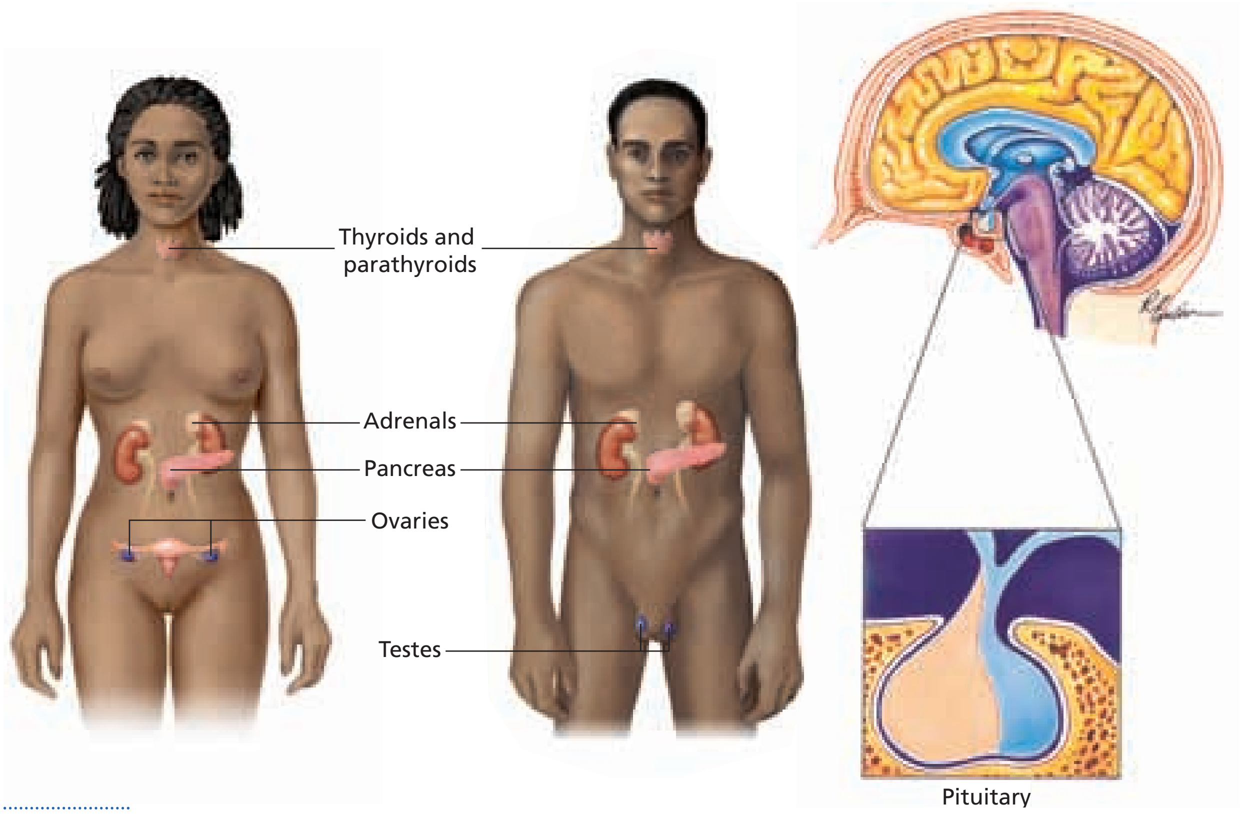

FIGURE 2.9
Endocrine Glands in Females and Males

The pituitary gland (shown at right) is the "master gland," regulating the endocrine glands, whose locations are illustrated at left. The pituitary gland is itself under control of the hypothalamus, an important structure that regulates many basic functions of the body.

TABLE 2.2 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)

What Controls the Endocrine System? At the base of your brain, a "master gland," called the **pituitary gland,** oversees all these endocrine responses. (See Figure 2.9.) It does so by sending out hormone signals of its own through the blood to other endocrine glands throughout the body. 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,* a brain component about which we will have more to say in a moment.

For now, we want to emphasize the notion 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 how the concepts we have just covered can explain the effects of psychoactive drugs.

PSYCHOLOGYMATTERS

How Psychoactive Drugs Affect The Nervous System

The mind-altering effects of marijuana, LSD, cocaine, narcotics, tranquilizers, and sedatives attract 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 attempt to reverse their arousal with the depressant effects of alcohol and sleeping pills. How do these seductive substances achieve their effects? The answer involves the ability of *psychoactive drugs* to enhance or inhibit natural chemical processes in our brains.

Agonists and Antagonists The ecstasy and the agony of psychoactive drugs come mainly from their interactions with neurotransmitters. Some impersonate neurotransmitters by mimicking their effects in the brain. Other drugs act less directly by enhancing or dampening the effects of neurotransmitters. Those that enhance or mimic neurotransmitters we call **agonists.** Nicotine, for example, is an agonist because it acts like the neurotransmitter acetylcholine. (See Table 2.1.) This has the effect of "turning up the volume" in the acetylcholine pathways (the acetylcholine-using bundles of nerve cells controlling the muscles and connecting certain parts of the brain). Similarly, the well-known antidepressant Prozac (fluoxetine) acts as an agonist in the brain's serotonin pathways, where it makes more serotonin available (see Figure 2.10).

In contrast, those chemicals that dampen or inhibit the effects of neurotransmitters we refer to as **antagonists.** So, curare and botulism toxin are antagonists because they interfere with the neurotransmitter acetylcholine—effectively "turning the volume down." So-called beta blockers act as antagonists against both epinephrine and norepinephrine, thereby counteracting the effects of stress. In general, agonists facilitate and antagonists inhibit messages in parts of the nervous system using that transmitter.

Why Side Effects? Why the occasional unwanted side effects of drugs? The answer to that question involves an important principle about the brain's design. The brain contains many bundles of neurons—**neural pathways—**that interconnect its components, much as rail lines connect major cities. Moreover, each pathway employs only certain neurotransmitters—like rail lines allowing only certain companies to use their tracks. 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, just as the same railroad serves many cities. 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 involving serotonin. That is, because serotonin's effects are not limited

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.

Agonists Drugs or other chemicals that enhance or mimic the effects of neurotransmitters.

Antagonists Drugs or other chemicals that inhibit the effects of neurotransmitters.

Neural pathways Bundles of nerve cells that follow generally the same route and employ the same neurotransmitter.

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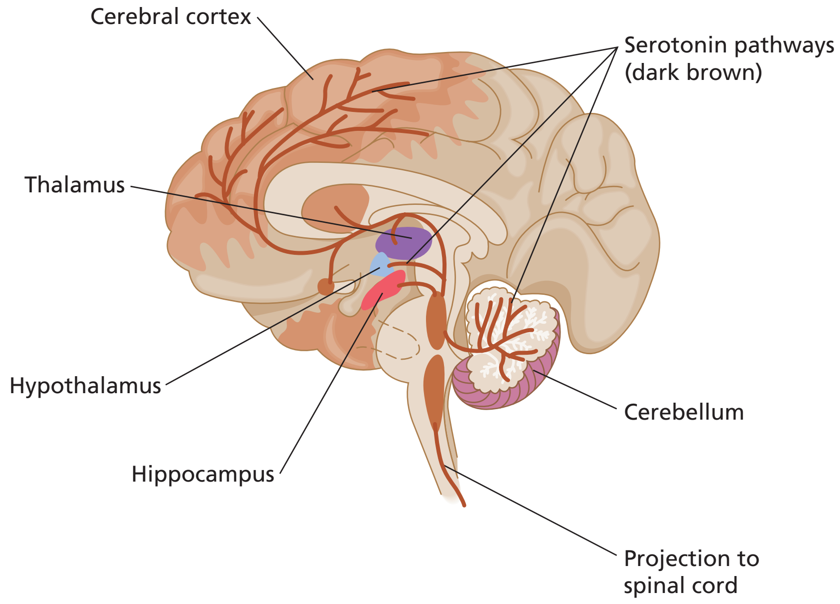


FIGURE 2.10
Serotonin Pathways in the Brain

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.

to the pathways involved in mood, fluoxetine can also cause changes in sleep patterns, appetite, and thinking.

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.

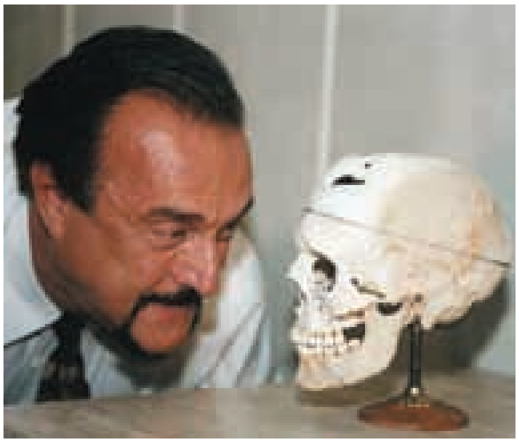
Check Your Understanding

1. **RECALL:** Of the body's two main communication systems, the _____ is faster, while the _____ sends longer-lasting messages.
2. **APPLICATION:** You are touring a "haunted house" at Halloween, when suddenly you hear a blood-curdling scream right behind you. The _____ division of your autonomic nervous system quickly increases your heart rate. As you recover from your fright, the _____ division slows your heart rate to normal.
3. **RECALL:** Explain how a neural message is carried across the synapse.
4. **RECALL:** Which gland takes orders from the brain but exerts control over the rest of the endocrine system?
5. **RECALL:** Make a sketch of two connecting neurons, indicating the locations of the dendrites, soma, axon, myelin sheath, terminal buttons, and synapse. Which part of the neuron sends messages by means of a brief electric charge?
6. **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.** When the electrical impulse arrives at the axon ending, it causes neurotransmitters to be released into the synapse. Some of those neurotransmitters lodge in receptor sites on the opposite side of the synapse, where they stimulate the receiving neuron. **4.** the pituitary gland **5.** Your diagram should be similar to the one on the left side in Figure 2.5. The burst of electric energy (the action potential) occurs in the axon. **6.** neurotransmitters/hormones

2.3 KEY QUESTION
HOW DOES THE BRAIN PRODUCE BEHAVIOR AND MENTAL PROCESSES?

News flash: In September of 1848, a 25-year-old American railroad worker named Phineas Gage sustained a horrible head injury when a charge of blasting



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

powder drove an iron rod into his face, up through the front of his brain, and out through the top of his head. (See accompanying photo.) Amazingly, Gage 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," remarked his former companions (Damasio, 1994, p. 8). We cannot help but wonder: Had the site of his injury—the front of his brain—been the home of Phineas Gage's "old self"?

Gage's accident 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 revulsion. But today we know that love doesn't really flow from the heart, nor disgust 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 have begun unraveling the deep mysteries of this complex organ of the mind. They now see the brain as a collection of distinct modules that work together like the components of a computer. This new understanding of the brain, then, 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, you will find that each of its modular components has its own responsibilities (Cohen & Tong, 2001). Some process sensations, such as vision and hearing. Some regulate our emotional lives. Some contribute to memory. Some generate speech and other behaviors. What's the point? The specialized parts of the brain act like members of a championship team: each doing a particular job, yet working smoothly together. Happily, many of these brain modules perform their tasks automatically and without conscious direction—as when you simultaneously walk, digest your breakfast, breathe, and carry on a conversation. But, when something goes awry with one or more of the brain's components, as it does in a stroke or Alzheimer's disease—or as happened to Phineas Gage—the biological basis of thought or behavior comes to the fore.

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

Windows on the Brain

Isolated within the protective skull, 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 brain's link with the world outside. To communicate within the body, the brain must rely on the neural and endocrine pathways that carry its messages to and from the muscles, organs, and glands throughout the body.

But what would you see if you could peer beneath the bony skull and behold the brain? Its wrinkled surface, rather like a giant walnut, tells us little about the brain's internal structure or function. For that, technology—especially *EEG, electrical stimulation,* and various types of *brain scans*—has opened new windows on the brain.

Sensing Brain Waves with the EEG For nearly one hundred years, neuroscientists have been using the **electroencephalograph (or EEG)** to record the extremely weak voltage patterns called *brain waves,* sensed by electrodes pasted on the scalp. Much as the city lights can tell you which parts of town are most "alive" at night, the EEG senses which parts of the brain are most active. The EEG can identify, for example, regions involved in moving the hand or processing a visual image. It can also reveal abnormal waves caused by brain malfunctions, such as *epilepsy* (a seizure disorder that arises from an electrical "storm" in the brain). You can see the sort of information provided by the EEG in Figure 2.11.

CONNECTION • CHAPTER 8

Sleep researchers use *brain waves,* recorded by the EEG, to distinguish REM sleep, which is characterized by dreaming.

Useful as it is, however, the EEG is not a very precise instrument, indiscriminately recording the brain's electrical activity in a large region near the electrode. Because there may be fewer than a dozen electrodes used, the EEG does not paint a detailed electrical picture of the brain. Rather, it produces a coarse, moment-to-moment summary of the electrical activity in millions of neurons—making it all the more amazing that we can sometimes read the traces of mental processes in an EEG record.

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. During brain surgery, using a pen-shaped electric probe, Penfield stimulated patients' exposed brains with a gentle electric current and recorded the responses. (His patients were kept awake, but under local anesthesia, so they felt no pain.)

This was not just an experiment born of curiosity. As a surgeon, Penfield needed to identify the exact boundaries of the diseased brain areas, to avoid removing healthy tissue. In the process, he found that the brain's surface had distinct regions, with distinct 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 occasionally provoked a memory from childhood (Penfield, 1959; Penfield & Baldwin, 1952). Later, other scientists followed his lead and probed structures deeper in the brain. There they found that electrical stimulation could set off elaborate sequences of behavior or emotions. The overall conclusion from such work is unmistakable: Each region of the brain has its own specific functions.

Electroencephalograph (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).

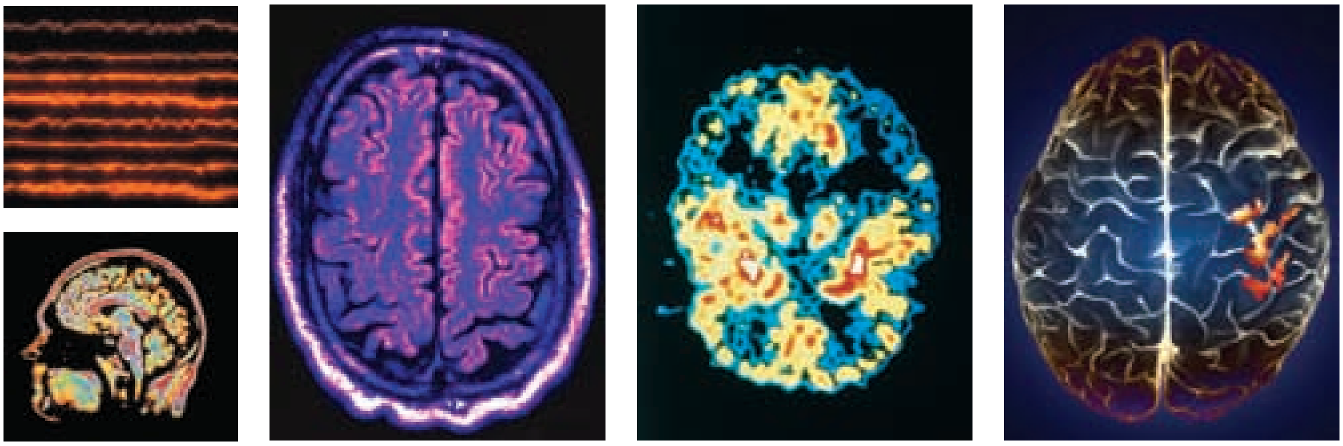


FIGURE 2.11
Windows on the Mind

Images from brain-scanning devices. *Top:* EEG; *Bottom:* MRI; *From left: CT scan,* PET, and fMRI. Each scanning and recording device has strengths and weaknesses.

Computerized Brain Scans Advances in brain science during the last few decades have given us more detailed views of the brain by employing sophisticated procedures collectively known as *brain scans.* Some types of scans make images with X-rays, others use radioactive tracers, and still others use magnetic fields. Thanks to such scanning methods, scientists can now make vivid pictures of brain structures without opening the skull. In medicine, brain scans help neurosurgeons locate brain abnormalities such as tumors or stroke-related damage. And in psychology, the images obtained from brain scans can show where our thoughts and feelings are processed. How? Depending on the scanning method used, specific regions of the brain may "light up" when, for example, a person reads, speaks, solves problems, or feels certain emotions (Raichle, 1994).

The most common brain-scanning methods currently employed are *CT, PET, MRI,* and *fMRI:*

CT scanning, or **computerized tomography,** creates digital images of the brain from X-rays passed through the brain at various angles, as though it were being sliced like a tomato. By means of sophisticated computer analysis, this form of tomography (from the Greek *tomos,* "section") reveals soft-tissue structures of the brain that X-rays alone cannot show. (See Figure 2.11.) CT scanning produces good three-dimensional images, and it is relatively inexpensive; the downside is that it employs X-rays, which can be harmful in high doses. CT scans are often used in hospitals for assessing traumatic brain injuries.

PET scanning, or **positron emission tomography,** produces an image showing brain *activity* (rather than just brain *structure*). One common PET technique does this by sensing low-level radioactive glucose (sugar), which concentrates in the brain's most active circuits. Areas of high metabolic activity show up as brightly colored on the image. (See Figure 2.11.) Thus, researchers can use PET scans to show which parts are more active or less active during a particular task.

MRI, or **magnetic resonance imaging,** uses brief, powerful pulses of magnetic energy to create highly detailed pictures of the structure of the brain. (Again, see Figure 2.11.) The MRI technique makes exceptionally clear, three-dimensional images, without the use of X-rays, which favors its use in research despite its higher cost.

fMRI, or **functional magnetic resonance imaging** is a newer technique that can also distinguish brain *activity* as well as the *structure* shown in standard MRI images (Alper, 1993; Collins, 2001). By monitoring the blood and oxygen flow in the brain, it can also identify more active brain cells from less active ones. Thus, fMRI allows neuroscientists to determine which parts of the brain are at work during various mental activities, much the same as PET, except that the fMRI technique produces more detailed images. (See Figure 2.11.)

Which Scanning Method Is Best? Each type of brain scan has its particular strengths and weaknesses. For example, both PET and fMRI are good at showing which parts of the brain are active during a particular task, such as talking, looking at a picture, or solving a problem. Standard MRI excels at distinguishing the fine details of brain structure. But none of these methods can detect processes that occur only briefly, such as a shift in attention or 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 all the brain's activity.

Three Layers of the Brain

What one sees through these windows on the brain also depends on the 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

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.

fMRI or **functional magnetic resonance imaging** A newer form of magnetic resonance imaging that reveals different activity levels in different parts of the brain.

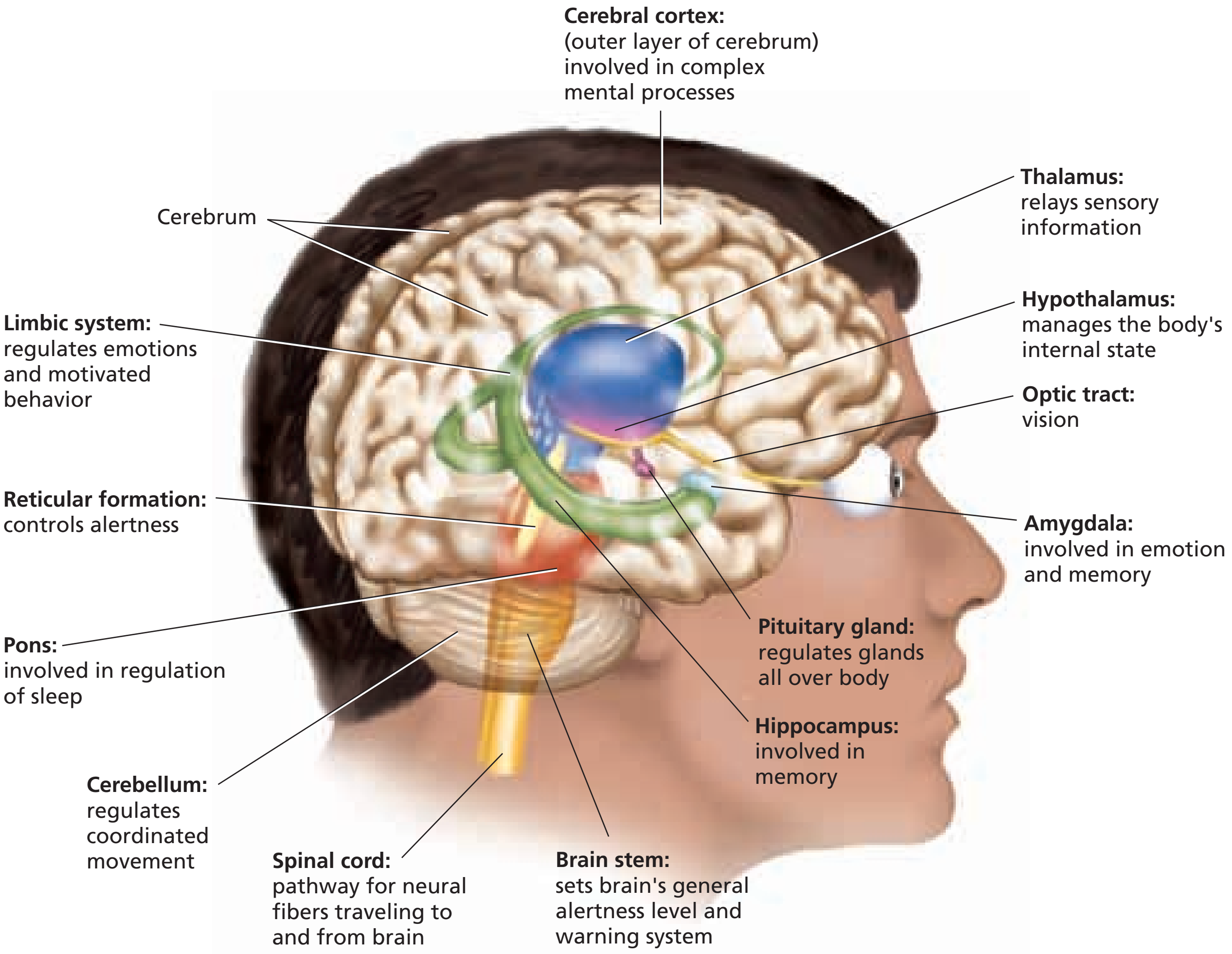


FIGURE 2.12
Major Structures of the Brain

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.

and instinctual responses. Our own more complex brains arise from essentially the same stalk, called the **brain stem.** From an evolutionary perspective, then, this is the part of the brain with the longest ancestry and most basic functions. On top of that stalk, we and our mammalian cousins have evolved two more layers, known as the *limbic system* and the *cerebrum,* that give us greatly expanded brain powers. (See Figure 2.12.)

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 obviously and less obnoxiously. We can infer one of the brain stem's tasks from its location, linking the spinal cord with the rest of the brain. In this position, it serves as a conduit for nerve pathways that carry messages traveling up and down the spinal pathway between the body and the central processing areas of the brain. Significantly, as we have seen, the sensory and motor pathways between the brain and our sense organs and skeletal muscles cross over to the opposite side, with many of them doing so in this region. This fact has the following extremely important consequence that bears reiterating: *Each side of the brain connects to the opposite side of the body.*

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

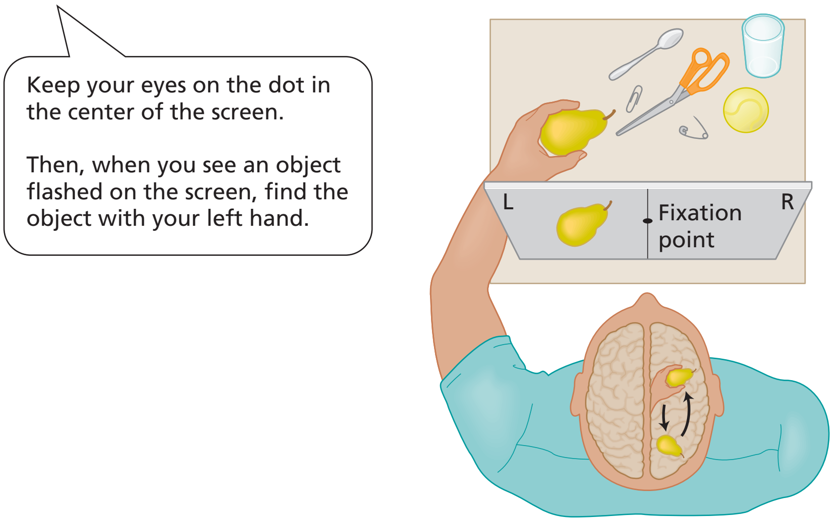


FIGURE 2.13
Communicating with the Opposite Hemisphere

Sensory pathways from the left hand cross over to the right hemisphere of the brain. Likewise, visual information from the left side of the visual field of both eyes is sent to the right hemisphere.

The Brain Stem in Split-Brain Patients: A Piece of the Puzzle The crossover of sensory and motor pathways gives us a clue that can help us explain the puzzling responses of the split-brain patients described at the beginning of the chapter. It is important to realize that the surgeons did *not* cut these cross-over pathways when they severed the corpus callosum in these patients. That is, they left the brain stem and spinal cord intact. Thus, the sensory-motor pathways in the brain stem and spinal cord could still carry information from one side of the body to the hemisphere on the opposite side. In their experiments, Sperry and Gazzaniga cleverly used these intact pathways to send information selectively to one hemisphere or the other in these patients. Figure 2.13 shows what they did. When the experimenters flashed the image of the pear on the left side of the visual field, the patient perceived it in the right hemisphere—which also communicates with the left hand. Similarly, the left hemisphere processes information from the right side of the visual field and communicates with the right hand.

Brain Stem Components and Connections More than just a conduit, the brain stem also connects several important information-processing regions, three of which are contained in the brain stem itself—the *medulla,* the *pons,* and the *reticular formation*—along with two adjacent parts of the brain, the *thalamus* and the *cerebellum* (Pinel, 2005). From an evolutionary standpoint, they are all ancient structures that can be found in the brains of creatures as diverse as penguins, pigs, pandas, pythons, porcupines, and people. You can see their location in Figure 2.14.

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. An even bigger bulge called the **pons** (meaning *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,* a structure involved in making coordinated movements.

The **reticular formation,** running through the center of everything, 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. And—don't blame your professor—it is the reticular formation you struggle with when you become drowsy in class.

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."

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.

The **thalamus,** a pair of football-shaped bodies perched atop the brain stem, receives nerve fibers from the reticular formation. Technically part of the cerebral hemispheres, not the brain stem, the thalamus acts like the central processing chip in a computer, directing the brain's incoming and outgoing sensory and motor traffic. Accordingly, it receives information from all the senses (except smell, oddly enough) and distributes this information to appropriate processing circuits throughout the brain. The thalamus also has a poorly understood role in focusing attention—which seems appropriate for a structure with its connections to almost everything.

CONNECTION • CHAPTER 7
The sense of smell has a unique ability to invoke memories.

The **cerebellum,** tucked beneath the back of the cerebral hemispheres and behind the stalk formed by the brain stem, looks very much like a neural knot stuck on the brain as an evolutionary afterthought. (It will help to locate its position visually in Figure 2.14.) Although not counted as a part of the brain stem by many anatomists, the cerebellum works cooperatively with processing units in the brain stem and the cerebral hemispheres to coordinate the movements that we perform without thinking (Spencer et al., 2003; Wickelgren, 1998b). It is your cerebellum that allows you to run down a flight of stairs without being conscious of the precise movements of your feet. The cerebellum also helps us keep a series of events in order—as we do when listening to the sequence of notes in a melody (Bower & Parsons, 2003). Finally, the cerebellum gets involved in a basic form of learning that involves habitual responses we perform on cue—as when you learn to wince at the sight of the dentist's drill (Hazeltine & Ivry, 2002).

Taken together, these modules associated with the brain stem 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.

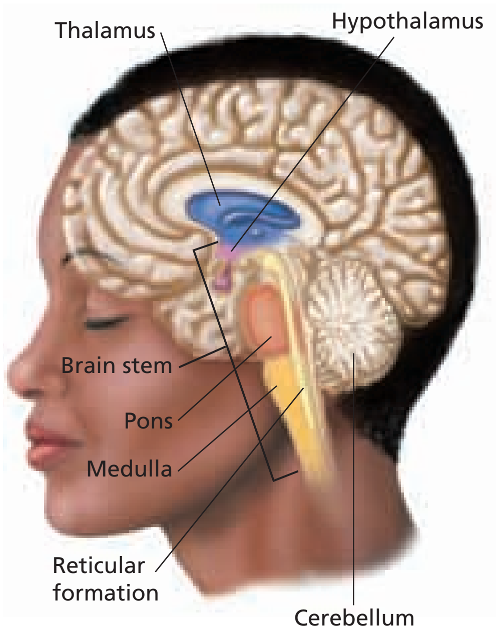


FIGURE 2.14
The Brain Stem and Cerebellum

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.

The Limbic System: Emotions, Memories, and More We're sorry to report that your pet canary or goldfish doesn't have the emotional equipment that we mammals possess. You see, only mammals have a fully developed **limbic system,** a diverse collection of structures that wraps around the thalamus deep inside the cerebral hemispheres. (See Figures 2.12 and 2.15.) Together, these ram's-horn-shaped structures give us greatly enhanced capacity for emotions and memory, facilities that offer the huge advantage of mental flexibility. Because we have limbic systems, we don't have to rely solely on the instincts and reflexes that dominate the behavior of simpler creatures.

The limbic layer houses other modules as well. Certain parts of the limbic system regulate basic motives, such as hunger and thirst. Others regulate body temperature. In general, you can think of the limbic system as a brain's multitasking command central for emotions, motives, memory, and maintenance of a balanced condition within the body.

Two especially important limbic structures take their names from their shapes. One, the **hippocampus,** is shaped (vaguely) like a sea horse—hence its name, again from Greek. (Actually, the brain has one hippocampus on each side, giving us two *hippocampi.* See Figures 2.12 and 2.15.) One of its jobs is to help us remember the location of objects, as when you remember where you left your car in a large parking lot (Squire, 2007). Its other main task is also a memory function, originally revealed by the notorious case of H. M.

H. M.: The Man Who Lost His Hippocampus In 1953, when he was in his early 20s, H. M. underwent a radical and experimental brain operation, intended to treat the frequent seizures that threatened his life (Hilts, 1995). The surgery, which removed most of the hippocampus on both sides of his brain, indeed succeeded in reducing the frequency of his seizures. But in another sense, it proved a total failure: Ever

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.

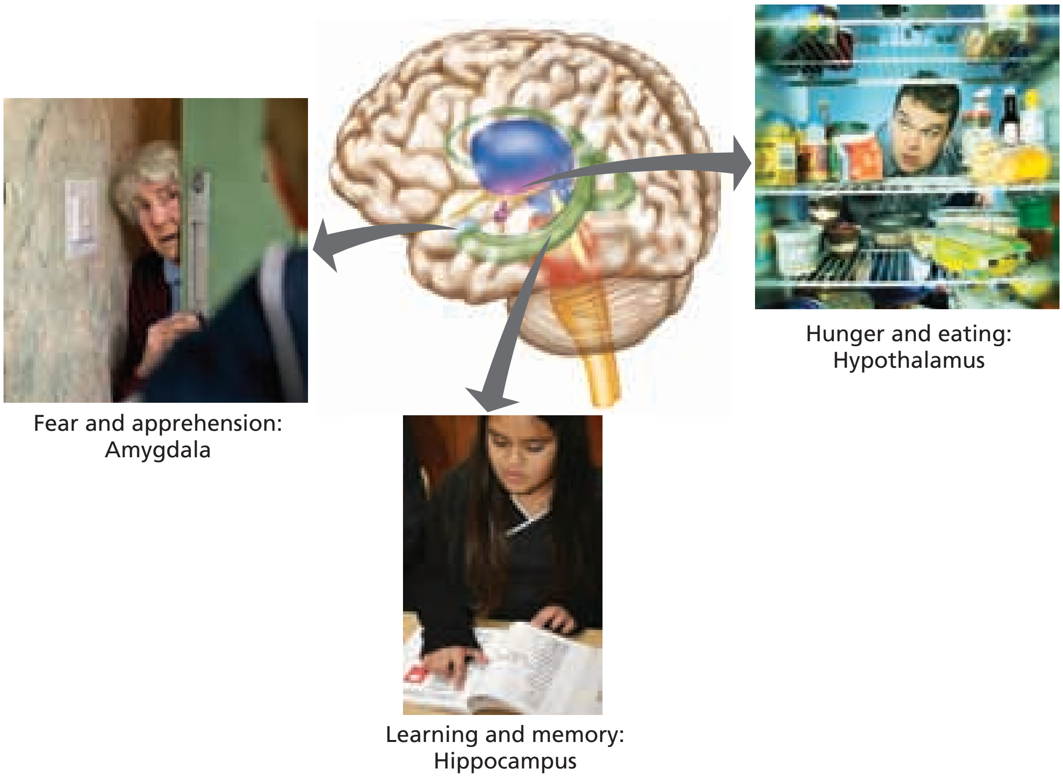


FIGURE 2.15
The Limbic System

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

since the operation, new experiences disappear from H. M.'s memory almost as soon as they happen. Now, when he tries to search his memory for the years since 1953, H. M. draws a blank. He doesn't even recognize those who care for him every day in a nursing home near Boston. In fact, he continues to believe he is living in 1953. Later in the text, we will return to H. M., but suffice it for now to note that his tragic case illustrates the important role played by the hippocampus in storing our experiences in long-term memory.

The Amygdala and Emotion Another limbic structure, the **amygdala,** also takes its name from its shape: *amygdala* (again in Greek) means "almond." Your brain has two amygdalas, one extending in front of the hippocampus on each side. (See Figure 2.15.)

In a classic experiment designed to find out what the amygdala does, Heinrich Klüver and Paul Bucy (1939) surgically snipped the connections to the amygdala on both sides of the brain in normally foul-tempered rhesus monkeys. Postsurgically, the beasts became so docile and easy to handle that even Klüver and Bucy were surprised. Since then, many studies have shown that the amygdala is involved not only in aggression but in fear—and probably in other emotional responses (Damasio, 2003).

Pleasure and the Limbic System In addition to the amygdala and hippocampus, the limbic system contains several so-called "pleasure centers" that create good feelings when aroused by electrical stimulation or by addictive drugs like cocaine, methamphetamine, and heroin (Olds & Fobes, 1981; Pinel, 2005). But you don't have to take drugs to stimulate these limbic pleasure circuits. Sex will do it, too. So will eating and drinking or otherwise exciting activities, such as riding a roller coaster. Even a serving of rich chocolate can arouse the same rewarding brain circuits (Small, 2001).

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

And one more thing: Psychologists Vinod Goel and Raymond Dolan (2001) have found indications that the brain's reward circuits also participate in our response to humor. For most people, having a brain scan is not the most pleasant experience—largely because of the cramped spaces and strange, loud noises made by the machine. But by telling jokes during the fMRI scan, Goel and Dolan got a few laughs from volunteers with their heads in the scanner. (Sample: "Why don't sharks bite lawyers?" Punch line: "Professional courtesy.") And, sure enough, for those who thought it was funny, parts of the brain's reward circuitry "lit up." Other researchers have corroborated these findings and, depending on the type of humor involved, implicated other brain areas, such as those involved in language and emotion (Watson, Matthews, & Allman, 2007).

The Hypothalamus and Control over Motivation In passing, we have already met the **hypothalamus,** another limbic structure that performs multiple tasks related to maintaining the body in a stable, balanced condition. (See Figure 2.14.) Rich with blood vessels, as well as with neurons, the hypothalamus 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 aimed at restoring balance.

CONNECTION • CHAPTER 9

The *hypothalamus* contains important control circuits for several basic motives and drives, such as hunger and thirst.

The hypothalamus makes its influence felt in other ways, as well. Although much of its work occurs outside of consciousness, the hypothalamus can send neural messages to "higher" processing areas in the brain—making us aware of the needs it senses (hunger, for example). It also can control our internal organs through its influence on the pituitary gland, attached to the underside of the hypothalamus at the base of the brain. Thus, the hypothalamus serves as the link between the nervous system and the endocrine system, through which it regulates emotional arousal and stress. Finally, the hypothalamus also plays a role in our emotions by hosting some of the brain's reward circuits, especially those that generate the feel-good emotions associated with gratifying the hunger, thirst, and sex drives.

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 accounts for two-thirds of the brain's total mass and hides most of the limbic system. The hemispheres' thin outer layer, the **cerebral cortex,** with its distinctive folded and wrinkled surface, allows billions of cells to squeeze into the tight quarters inside your skull. Flattened out, the cortical surface would cover an area roughly the size of a newspaper page. But because of its convoluted surface, only about a third of the cortex is visible when the brain is exposed. For what it's worth: Women's brains have more folding and wrinkling than do men's, while, as we have seen, men's brains are slightly larger than women's, on the average (Luders et al., 2004). And what does the cerebral cortex do? The locus of our most awesome mental powers, it processes all our sensations, stores memories, and makes decisions—among many other functions that we will consider in our discussion of its lobes, below.

Although we humans take pride in our big brains, it turns out that ours are not the biggest on the planet. All large animals have large brains—a fact more closely related to body size than to intelligence. Nor is the wrinkled cortex a distinctively human trait. Again, all large animals have highly convoluted cortexes. If this bothers your self-esteem, you can take comfort in the fact that we do have more massive cortexes for our body weight than do other big-brained creatures. Although no one is sure exactly how or why the brain became so large in our species (Buss, 2008; Pennisi, 2006), the comparisons with other animals show that human uniqueness lies more in the way our brains operate, rather than in their size.

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 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 cerebral hemispheres of the human brain.

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 sensible idea to muddle-headed extremes. In his theory of *phrenology,* Gall claimed that the brain also had 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, the "reading" of which became a minor scam industry.

Gall's ideas captured the public's attention and became enormously popular, even though his theory was mostly wrong. But he was absolutely right on one important point: his doctrine of *localization of function.* Stated simply, localization of function means that *different parts of the brain perform different tasks.* The discoveries made by modern neuroscience have helped us to correct Gall's picture of the cerebral cortex. As we discuss the geography of the cortex, please keep in mind that, while the lobes are convenient features, the functions we will ascribe to each (see Table 2.3) do not always respect the precise boundaries of the lobes.

The Frontal Lobes Your choice of major, your plans for the summer, and your ability to answer test questions all depend heavily on the cortical regions at the front of your brain, aptly named the **frontal lobes.** (See Figure 2.16.) Here, especially in the foremost regions, known as the *prefrontal cortex,* we find circuitry that contributes to our most advanced mental functions, such as planning, deciding, and anticipating future events (Miller, 2006; O'Reilly, 2006). The biological underpinnings of personality, temperament, and our sense of "self" seem to have important components here, too, as the case of Phineas Gage suggested (Bower, 2006).

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 patch of brain takes its name from its main function: controlling the body's motor movement by sending messages to the motor nerves and on to the voluntary muscles. As you can see in Figure 2.17, the motor cortex contains an upside-down map of the body, represented by the *homunculus* (the distorted "little man" in the figure). A closer look at the motor homunculus shows that it exaggerates certain parts of the body, indicating that the brain allots a larger amount of cortex to those body parts. Note especially the areas representing the lips, tongue, and hands. Perhaps the most exaggerated areas represents the fingers (especially the thumb), reflecting the importance of manipulating objects. Another large area connects 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. So a wink of your left eye originates in your right motor cortex, while the left motor cortex can wink your right eye.

Mirror Neurons Discovered in the Frontal Lobes Recently, neuroscientists have discovered a new class of neurons, called *mirror neurons,* scattered throughout the brain

TABLE 2.3 Major Functions of the Cortical Lobes

Lobe	Functions
Frontal	Movement, producing speech, abstract thought
Parietal	Sensations of touch, body position, understanding speech
Temporal	Hearing, smell, recognizing faces
Occipital	Vision

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.

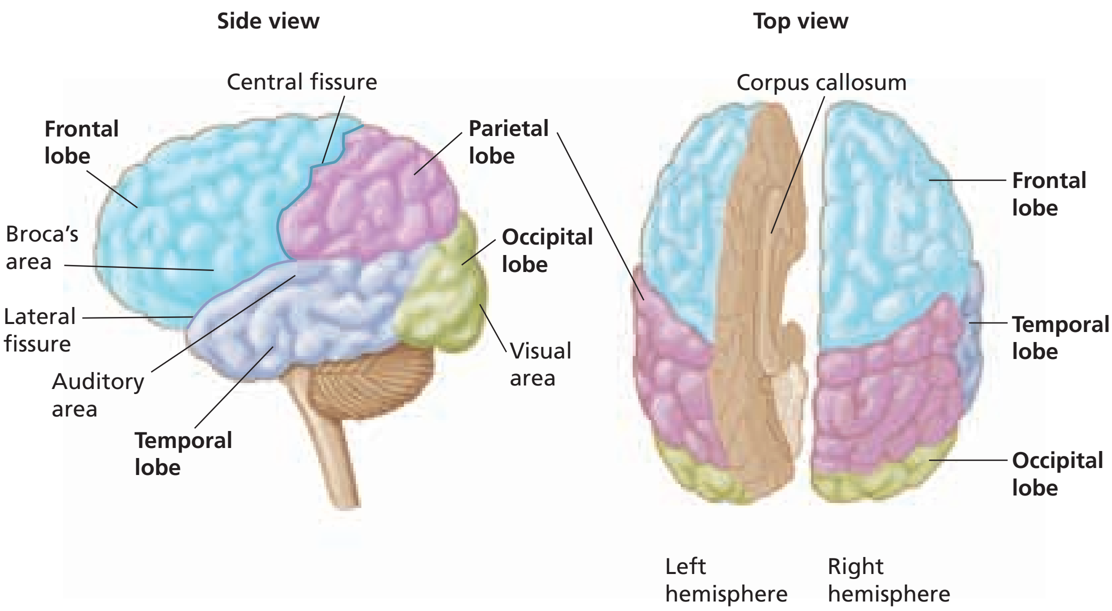


FIGURE 2.16
The Four Lobes of the Cerebral Cortex

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*.

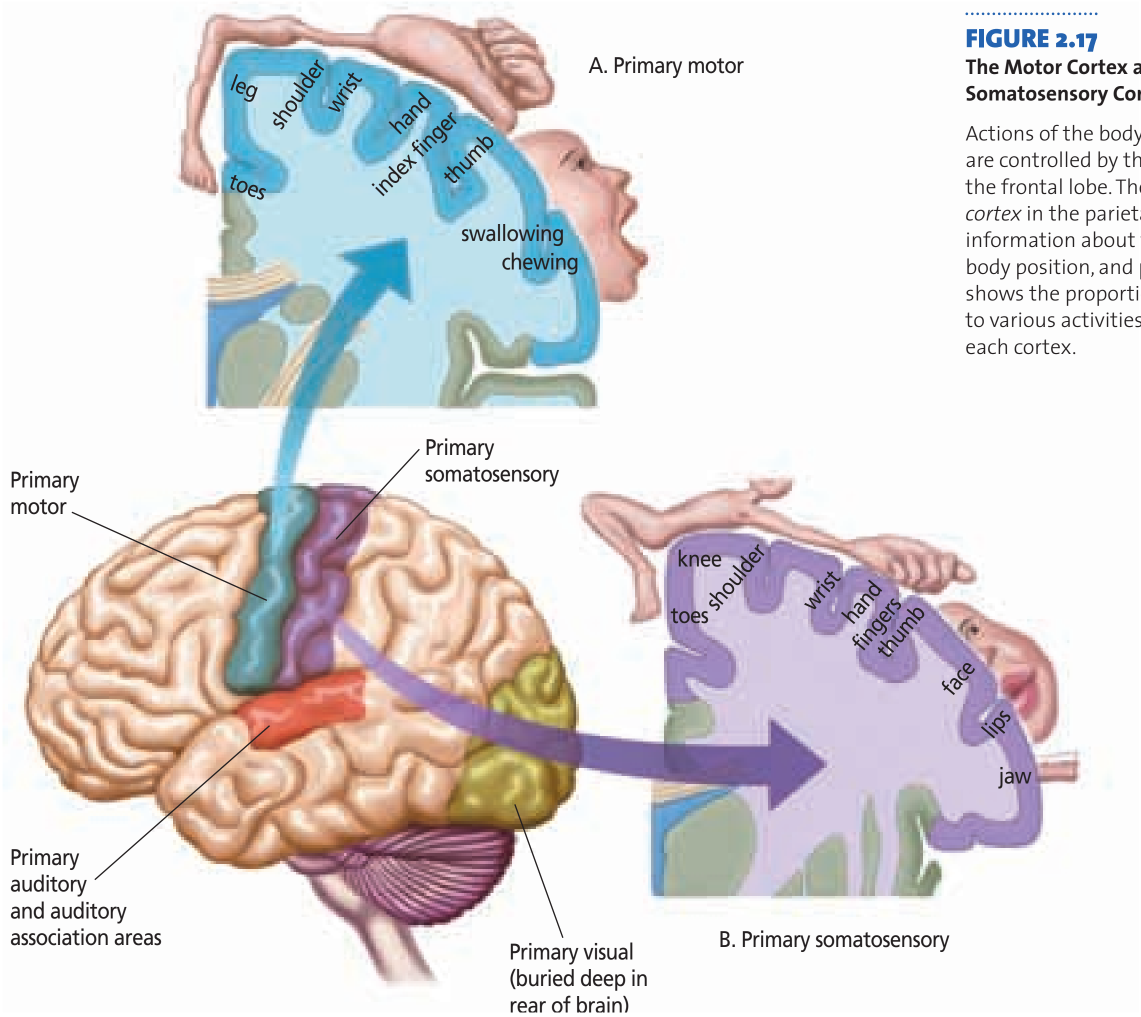


FIGURE 2.17
The Motor Cortex and the Somatosensory Cortex

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. This diagram shows the proportion of tissue devoted to various activities or sensitivities in each cortex.

but especially in motor areas of the frontal lobes. When we observe another person performing some action, such as waving, drinking from a cup, or swinging a golf club, these **mirror neurons** fire, just as if we had performed the same act ourselves. They also fire "empathetically" when we observe another person's emotions. In effect, we do and feel what we see in others—but in the privacy of our own minds (Dobbs, 2006a).

What could be their purpose? For one thing, mirror neurons may help children mimic—and therefore learn—language. But more than that, these specialized cells form part of a brain network that allows us to anticipate other people's intentions, says Italian neuroscientist Giacomo Rizzolatti, one of the discoverers of mirror neurons (Rizzolatti et al., 2006). Because they connect with the brain's emotional circuitry, mirror neurons allow us to "mirror" other people's emotions in our minds. From an evolutionary perspective, observing and imitating others is a fundamental human characteristic, so mirror neurons may even turn out to be the biological basis of culture. Finally, some researchers believe that deficits in the mirror system may underlie disorders, such as autism, that involve difficulties in imitation and in understanding others' feelings and intentions (Ramachandran & Oberman, 2006).

The Frontal Lobes' Role in Speech ... and the Split-Brain, Again In most people, the left frontal lobe has yet another important function: the production of speech. So, damage to this region on the left side of the brain can leave a person without the ability to talk—although, if other areas are spared, the ability to understand speech may be unimpaired. This offers us another clue that can help us understand the split-brain patients' inability to *name* an unseen object held in the left hand, which connects to the right hemisphere: Because the left side of the brain usually has greater language ability, it makes sense that the right hemisphere would have trouble naming objects.

The Parietal Lobes

To the rear of each frontal lobe lie two large patches of cortex that specialize in sensation. (See Figure 2.16.) These **parietal lobes** allow us to sense the warmth of a hot bath, the smoothness of silk, the poke 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 the body (Graziano et al., 2000; Helmuth, 2000). Second, it relates this information to a mental map of the body to help us 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, you have temporarily interrupted messages from the nerve cells that carry sensory information to body maps in the parietal lobe.

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.

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 penetrating the **occipital lobes** at the back of his brain (see Figure 2.16). Similarly—if less pleasantly—you, too, will "see stars" when a sharp blow to your head bounces your brain around and stimulates your occipital lobes. Under more normal circum-

Mirror neuron A recently discovered class of neuron that fires in response to ("mirroring") observation of another person's actions or emotions.

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.

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

stances, the occipital lobes receive stimulation relayed from the eyes. There the **visual cortex** constructs our moving picture of the outside world.

Specialized Visual Processing Regions in the Cortex To create our pictures of the outside world, 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 7. 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). There is even a distinct patch of temporal cortex dedicated to the recognition of faces and another for perception of the human body (Kanwisher, 2006; Tsao, 2006). In one patient, neurosurgeons found a neuron that responded *only* to images of Halle Berry (Quiroga, 2005)! To complete the picture, we should note that congenitally blind people recruit the visual cortex to help them read Braille (Amedi et al., 2005; Barach, 2003).

Visual Pathways in Split-Brain Patients Now let's return again to the split-brain patients described at the beginning of the chapter. As we have said, they were able to name objects seen in the right visual field, but not on the left. A look at the visual pathways, shown in Figure 2.18, will show you why.

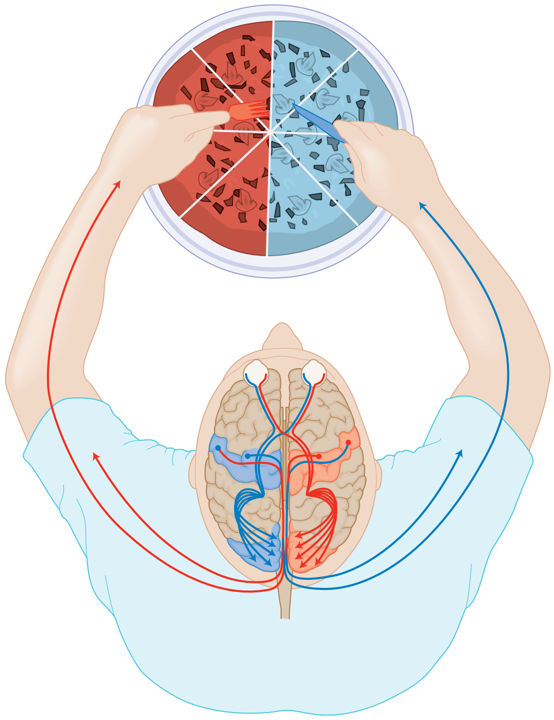


FIGURE 2.18
The Neural Pathways from the Eyes to the Visual Cortex

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 pizza.

Notice in Figure 2.18 that everything to the left of the point of eye fixation goes to the *right* side of the retina *of each eye*. Similarly, everything to the *right* goes to the *left side of each eye*. This happens because the lenses of the eyes flip everything backward (whether or not the individual has a split brain). As the information flows back to the visual cortex from each eye, it splits into two streams because the optic nerve separates into two pathways here (again, whether or not the corpus callosum has been cut). The result is that *everything a person sees on the right gets processed in the left hemisphere's visual cortex*, while *the right visual cortex processes everything to the left* of the point on which the eyes are fixed.

How can we apply this schema to the odd responses of the split-brain patients? Because language is usually a left hemisphere function, it makes sense that these patients could name objects that were "seen" by the left hemisphere—coming from the right visual field. The right hemisphere, on the other hand (so to speak), cannot produce speech and so cannot name objects seen in the left visual field—which are processed by the right hemisphere. Studying how the visual pathways cross over in Figure 2.18 should make this clear.

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 2.16). There lies the *auditory cortex,* which helps you make sense of the sounds, especially speech. In most people, a specialized section of auditory cortex on the brain's left side helps process the meaning of speech sounds.

But the temporal lobes take responsibility for more than just hearing. As we have seen, portions of the temporal lobes "subcontract" from the visual cortex the work of recognizing faces. Other temporal regions work with the hippocampus on the important task of storing long-term memories. (And, when you think of it, this makes a lot of sense, because the hippocampus, which has a central role in forming memories, lies directly beneath the temporal lobes.) Finally, we should note that deaf individuals apparently recruit the speech areas of the temporal lobes for understanding sign language (Neville et al., 1998).

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.

The Cooperative Brain No single 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 faculties 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, each an expert at some highly specialized task (Damasio, 2003; LeDoux, 2002). For example, when you do something as simple as answer 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. 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.

CONNECTION • CHAPTER 7
The puzzle of how the brain "puts it all together" is known as *the binding problem.*

Clearly, the brain usually manages to "put it all together" in a coordinated effort to understand and respond to the world. Exactly *how* it does so is not clear to neuroscientists—and, in fact, this constitutes one of the biggest mysteries of modern psychology. Some clues have appeared in recent work, however. Constantly active, even when we are asleep, our brains produce pulses of coordinated waves that sweep over the cortex that are thought, somehow, to coordinate activity in far-flung brain regions (Buzsáki, 2006). Stay tuned for further developments.

With the brain's democratic division of labor in mind, it shouldn't surprise you to learn that we use the largest proportion of the cortex for integrating and interpreting information gathered from the sensory parts of the brain and from memory. Collectively, we call these regions 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 seen that the four lobes in each hemisphere have specialized functions and that we depend on them working cooperatively with the rest of the brain. Now, let's turn to some additional evidence that the two cerebral hemispheres themselves are not strictly mirror images of each other but specialize in 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 lay recovering from his accident, a French neurologist named Paul Broca occupied himself 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 injury. Again and again, Broca found damage to the same spot, later named *Broca's area,* that had been damaged in Tan's brain, as well. (This is the frontal lobe speech area we mentioned earlier. You can see its location in Figure 2.16.) Broca's discovery was one of the early suggestions that the two sides of the brain specialize in different tasks. Subsequent work has confirmed and extended his findings:

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

- 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 the left parietal and left temporal lobes commonly causes problems in understanding language.

What about damage to the right hemisphere? People with right-sided brain injuries less often have speech problems, but they are more likely to have difficulties with *spatial orientation* (locating themselves 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 the right-side counterpart to Broca's area (Janata et al., 2002; Zatorre & Krumhansl, 2002).

Thus, while the two hemispheres superficially appear to be near mirror images of each other, they assume somewhat different functions. This tendency for the hemispheres to take the lead in different tasks is called **cerebral dominance,** an often-misunderstood concept. What many people don't realize 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.*

Some People Are Different—But That's Normal Just to complicate your picture of cerebral dominance, you should know that the dominance pattern is not always the same from one person to another. Research demonstrating this fact uses a technique called *transcranial magnetic stimulation* (TMS) to deliver powerful magnetic pulses through the skull and into the brain. There the magnetic fields interfere with the brain's electrical activity, temporarily disabling the targeted region but without causing permanent damage. The experiments found that, when the left-side language areas receive TMS, language abilities remain unaffected in some people. Oddly enough, most of these people are left-handers. In general, these studies show that about one in ten individuals process language primarily on the *right* side of the brain. Another one in ten—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 to some extent. Typically, the left side is 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 and relating it to social expectations (Vingerhoets, 2003). In fact, the right hemisphere is generally more involved than the left in interpreting the emotional responses of others. As for our own emotions, the control of *negative* emotions, such as fear and anger, usually stems from the right frontal lobe, while the left frontal lobe typically regulates the *positive* emotions, such as joy (Davidson, 2000b).

Different Processing Styles Different though they may be, the two hemispheres don't compete with each other—as is sometimes supposed—except under the most unusual conditions, which we will describe in a moment. Rather, they make different contributions to the same task, except in split-brain patients, of course. In the lingo of neuroscience, the two hemispheres have different *processing styles.* For example, the left hemisphere groups objects analytically and verbally—as by similarity in function (*knife* with *spoon*)—while the right hemisphere might match things by form or visual pattern—as in 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, emotionally,* and *spatially* (Reuter-Lorenz & Miller, 1998).

Male and Female Brains In a culture where bigger is often seen as better, the undeniable fact that men (on the average) have slightly larger brains than do women has caused heated debate. The real question, of course, is: What is the meaning of the size differential? Most neuroscientists think it is simply the result of the male's larger body size—and not of much other importance (Brannon, 2008).

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

Within the brain, certain structures exhibit sex differences, too. A part of the hypothalamus commonly believed to be associated with sexual behavior and, perhaps, gender identity, is larger in males than in females. Some studies have suggested that male brains are more *lateralized,* while females tend to distribute abilities, such as language, across both hemispheres. This claim is disputed by the results of a recent study (Sommer et al., 2004). If true, however, the difference in lateralization may explain why women are more likely than men to recover speech after a stroke. Other than that, what advantage the difference in lateralization may have is unclear.

At present, no one has nailed down any psychological difference that can be attributed to physical differences between the brains of males and females. The research continues, but your authors suggest interpreting new claims with a liberal dose of critical thinking, being especially wary of bias that may influence the way results are interpreted.

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

We now have all the important pieces of the split-brain puzzle presented at the beginning of the chapter:

- When the corpus callosum has been cut, the two brain hemispheres cannot communicate. As a result, information going into one side of the brain cannot be accessed by the other side of the brain.
- Split-brain patients can verbally identify objects when the information is available only to the left hemisphere. They fail to do so when the information goes only to the right hemisphere.
- The left hemisphere is dominant for language (in most people).
- Because the sensory pathways cross over to the opposite side as they ascend to the cortex, each side of the body communicates with the opposite side of the brain.
- The visual pathways constitute an exception: Information coming from the right side *of the visual field of both eyes* goes to the left side of the retina and on to the left visual cortex; information coming from the left visual field ends up in the right visual cortex.

The Clueless Hemisphere We can now piece together an explanation for the odd symptoms displayed by people with split brains: The hemisphere doing the talking doesn't have a clue when the information has been presented solely to the other hemisphere. Under everyday conditions outside the laboratory, however, people with split brains get along surprisingly well, because they can 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. Under those conditions, the patient can name only objects sensed by the left hemisphere.

Now, to test your understanding of these concepts, look at Figure 2.19 and see if you can explain why the split-brain patient responds as indicated. 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?

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.

Some unexpected effects of having a split brain also showed up in patient reports of their everyday experiences. For example, one told how his left hand would unzip his pants or unbutton his shirt at most inappropriate times, espe-

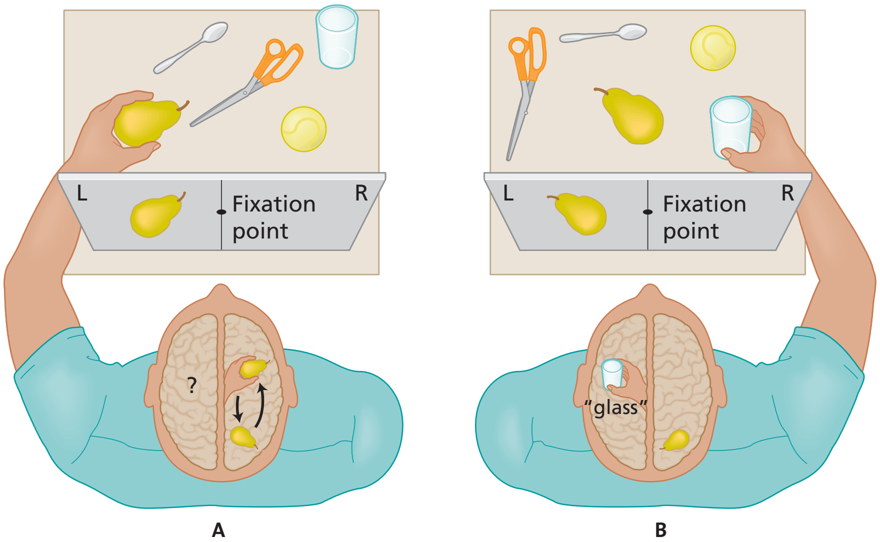


FIGURE 2.19
Testing a Split-Brain Patient

When the split-brain patient uses his left hand to find a match to an object flashed briefly in the left visual field, he is successful because both the visual and tactile (touch) information are registered in the right hemisphere, as shown in A. Nevertheless, the patient cannot *name* the object, because speech is mainly a *left*-hemisphere function. Now consider the same patient asked to perform the same task with the *right* hand, as shown in B. In this case, he is unsuccessful in picking out the object by touch, because the visual information and the tactile information are processed in different hemispheres. In this test, however, the patient is able to name the object in his hand!

cially when he felt stressed. But why? Sperry theorized that the right hemisphere—which has little language ability, but which 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, "I'm here! Look at me!"

Two Consciousnesses Such cerebral antics point to the most interesting finding in Sperry and Gazzaniga's work: the *duality of consciousness* observed in split-brain patients. When the two hemispheres received different information, it was as if the patient were two separate individuals. So, in the experiment shown in Figure 2.19, 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 be more emotional, while the left hemisphere responses were 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. For most people, then, the corpus callosum serves as a connecting pathway that helps our confederation of minds share information. And so we come full circle to the 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).

What's It to *You?* Nearly everybody knows someone who has suffered brain damage from an accident, a stroke, or a tumor. 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 three 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 2.20.)
2. For most people, speech is mainly a left-hemisphere function.
3. Each lobe has special functions:
   - The occipital lobe specializes in vision;
   - The temporal lobe specializes in hearing, memory, and face recognition;

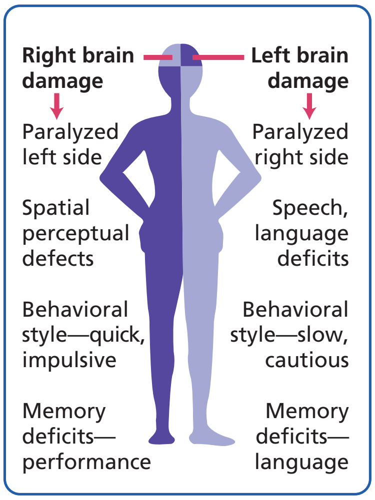


FIGURE 2.20
Contralateral Effects of Damage to the Cerebral Hemispheres

- The parietal lobe specializes in locating sensations in space, including the surface of the body;
- The frontal lobe specializes in motor movement, the production of speech, and certain higher mental functions that we often call "thinking" or "intelligence."

Here's how one of your authors (Bob) applied his knowledge of the brain:

> I hadn't noticed Dad dragging the toe of his right foot ever so slightly as he walked. But my Mom 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 2.21—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. I knew that 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,

FIGURE 2.21
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.

and treatments. 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.

PSYCHOLOGYMATTERS

Using Psychology to Learn Psychology

The old idea that we use only 10 percent of our brains is bunk that probably came from a time when neuroscientists hadn't figured out the functions of many cortical areas. We have since filled in the blanks. Every part of the brain has a known function, and they all get used every day—but not necessarily for intellectual purposes. We now know that much of the brain merely deals with basic biological needs. Therefore, simply finding a way to engage *more* of the brain is not the royal road to increased brainpower.

Have neuroscientists found anything that you can use to improve your memory, especially for the concepts you are learning in your classes? The fact that we employ many different regions of the cerebral cortex in learning and memory may be among their most practical discoveries (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.

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 engage 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.

CheckYourUnderstanding

1. **APPLICATION:** Suppose that you are a neuroscientist interested in comparing what parts of the brain are most active when people are driving and when they are talking on a cell phone. Which imaging technique would be best for your research?

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

3. **APPLICATION:** An fMRI or a PET scan would show activity in a person's _____ during an emotional response.

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

5. **ANALYSIS:** The split-brain patient in Figure 2.13 would have trouble using his _____ hand to select the object flashed on the left side of the screen. (*Hints:* Which hemisphere controls each hand? Which hemisphere processes information from the left side of the visual field?)

6. **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?

ANSWERS: 1. The best would be fMRI, because it not only gives detailed three-dimensional images but also shows different activity levels in different parts of the brain. The driving task, however, would have to be modified so that it could be performed while in the fMRI machine. **2.** the brain stem and cerebellum, the limbic system, the cerebrum **3.** limbic system **4.** See the location of the four lobes in Figure 2.16. The left hemisphere controls language, and the right hemisphere controls your left hand. **5.** right **6.** Examples include the interaction of regions in the four lobes of the cerebral cortex when answering the phone. There are many other examples mentioned in this section.

Critical Thinking Applied: Left Brain vs. Right Brain

The split-brain studies and the resulting discovery that the two sides of the brain process information differently have captured the public's interest in recent years. The press reports claiming that the left hemisphere is logical and the right hemisphere is emotional might easily lead to the mistaken conclusion that your friend Joe, a guy with an analytic bent, lives mostly in his left hemisphere, while his wife Barbara, more sensitive to people's emotions, filters her experience mainly on the right side of her brain.

Knowing a fad when they see it, pseudoscientists have classified people as "right-brained" or "left-brained" and developed workshops to help plodding analytical types get into their "right minds." But is this distinction really accurate?

What Are the Issues?

The idea that people fall neatly into one category or another has a lot of popular appeal, but the facts seldom bear this out. More commonly, we find that people are distributed from one extreme to the other, with most somewhere in the middle. (Think, for example, of intelligence or athletic ability.) So, one issue we should address involves seeing whether people tend to be *either* analytical *or* emotional, but not both. When a claim, such as this, conflicts with prior knowledge, we should be skeptical.

A second issue is whether the brain actually functions as proponents of the left-brain/right-brain claims say it does. That is, do some people mainly use the left side of the brain, while others mainly use the right?

What Critical Thinking Questions Should We Ask?

Is the claim reasonable or extreme? As we have noted, the idea that we can categorize people into neat, either-or categories doesn't fit with what we know about most other psychological characteristics, such as intelligence. This alerts us that we need to look carefully at the evidence.

Neuroscience should be able to tell us how the left and right brain interact—and whether people differ in the activity of one hemisphere or the other. The primary critical thinking question we should ask, then, is: What is the evidence?

What Conclusions Can We Draw?

The evidence—both from the split-brain studies and research on the intact brain—by no means warrants categorizing people in this way. As we have seen, the two hemispheres have somewhat different *processing styles,* but the actual differences between the two hemispheres do not outweigh their similarities (Banich, 1998; Trope et al., 1992). Most important—and what the right-brain/left-brain faddists overlook—is the fact that the two hemispheres of the intact brain cooperate with each other, each by making its own complementary contribution to our mental lives. (See Figure 2.22.)

Unless you have a split brain, you bring the abilities of both sides of your brain to bear on everything you do. Why, then, do people have such obvious differences in the way they approach the same tasks? Some people *do* seem to approach things in a more analytical, logical fashion; others operate from a more "intuitive" and emotional perspective. But now that you know something of how the brain works, you can understand that we cannot account for these differences among people simply by suggesting that they employ one side of the brain or the other. Even split-brain patients use both sides of their brains! A better explanation involves different combinations of experience and brain physiology. People are different because of different combinations of nature and nurture—not because they use opposite sides of the brain.

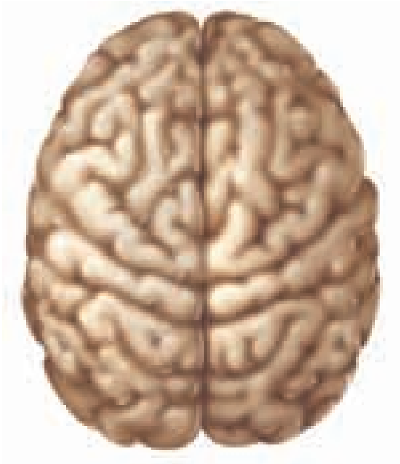


FIGURE 2.22
Specialization of the Cerebral Hemispheres

While each hemisphere communicates with the opposite side of the body, the hemispheres each specialize in controlling different functions. For most people, the left hemisphere specializes in speech and other functions performed in sequence (such as walking, throwing, and reading). The right hemisphere specializes in synthesis: gathering many pieces of information and synthesizing it as a unified whole (as in recognizing faces or shapes).

Chapter Summary

2.1 How Are Genes and Behavior Linked?

Core Concept 2.1 Evolution has fundamentally shaped psychological processes because it favors genetic variations that produce adaptive behavior.

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, as well as the fittest features. This principle underlies human behavior, as well as that of other animals. 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 has been completed, we do not yet know precisely how specific genes influence behavior and mental processes. Genetic research may be nearing the point at which we may alter our genetic makeup or select certain genetic traits for our children. This new knowledge brings with it choices that humans have never had to face before.

Biopsychology (p. 45)	**Gene** (p. 48)
Cerebral hemispheres (p. 43)	**Genotype** (p. 48)
Chromosome (p. 48)	**Natural selection** (p. 47)
Corpus callosum (p. 43)	**Neuroscience** (p. 45)
DNA (p. 48)	**Phenotype** (p. 48)
Evolution (p. 46)	**Sex chromosomes** (p. 50)

MyPsychLab Resources 2.1:

Explore: Building Blocks of Genetics

Watch: How the Human Genome Map Affects You

2.2 How Does the Body Communicate Internally?

Core Concept 2.2 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.

The body's two communication systems are the **nervous system** and the **endocrine system. Neurons** receive messages by means of stimulation of the **dendrites** and **soma.** When sufficiently aroused, a neuron generates an **action potential** along the **axon. Neurotransmitter** chemicals relay the message to receptors on cells across the **synapse.** The nervous system has two main divisions: the **central nervous system** and the **peripheral**

nervous system. The peripheral nervous system, in turn, comprises the **somatic nervous system** (further divided into sensory and motor pathways) and the **autonomic nervous system,** which communicates with internal organs and glands. The **sympathetic division** of the autonomic nervous system 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. Endocrine system 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 by acting as **agonists** or **antagonists.** Unfortunately for people taking psychoactive drugs, many neural pathways in the brain may employ the same neurotransmitter, causing unwanted side effects.

Action potential (p. 55)
Agonists (p. 64)
All-or-none principle (p. 56)
Antagonists (p. 64)
Autonomic nervous system (p. 61)
Axon (p. 55)
Central nervous system (p. 59)
Dendrite (p. 55)
Endocrine system (p. 62)
Glial cell (p. 59)
Hormones (p. 62)
Interneuron (p. 54)
Motor neuron (p. 54)
Nervous system (p. 59)
Neural pathways (p. 65)
Neuron (p. 53)
Neurotransmitter (p. 57)
Parasympathetic division (p. 61)
Peripheral nervous system (p. 60)
Pituitary gland (p. 64)
Plasticity (p. 57)
Reflex (p. 59)
Resting potential (p. 55)
Sensory neuron (p. 54)
Soma (p. 55)
Somatic nervous system (p. 61)
Sympathetic division (p. 61)
Synapse (p. 56)
Synaptic transmission (p. 56)
Terminal buttons (p. 56)

MyPsychLab Resources 2.2:

Explore: The Structure of a Neuron
Explore: Neuronal Transmission
Explore: Action Potential
Explore: The Synapse

2.3 How Does the Brain Produce Behavior and Mental Processes?

Core Concept 2.3 The brain is composed of many specialized modules that work together to create mind and behavior.

In modern times, researchers have opened windows on the brain, using the **EEG** to sense the brain's electrical activity. In recent years, computer technology has led to brain-scanning techniques, such as **CT, PET, MRI,** and **fMRI**—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. Its **frontal lobes** control motor functions, including speech, and higher mental functions. The **parietal lobes** specialize in sensation, especially the senses of touch and body position, as well as the understanding of speech. The **occipital lobes** deal exclusively with vision, while the **temporal lobes** have multiple roles involved in face recognition, hearing, and smell. Even though the functions of the brain are highly localized within specific modules, they normally work seamlessly together: Every mental and behavioral process involves the coordination and cooperation of many brain networks. The **association cortex** integrates the output of the sensory networks and of memory. One of psychology's major mysteries centers on how the brain manages to coordinate these processes. The two cerebral hemispheres are differently specialized with language, analytical thinking, and positive emotions regulated by circuits in the left hemisphere. The right hemisphere specializes in spatial interpretation, visual and musical memory, and negative emotions. The two hemispheres communicate across the corpus callosum. If the hemispheres are surgically severed, as when the corpus callosum is cut in split-brain patients, a duality of consciousness emerges. Because each side of the body has sensory and motor links to the opposite side of the brain, a split-brain patient who "sees" an object in only one hemisphere of the brain will only be able to locate that object by touch, using the hand linked to the same hemisphere.

Amygdala (p. 72)
Association cortex (p. 78)
Brain stem (p. 69)
Cerebellum (p. 71)
Cerebral cortex (p. 73)
Cerebral dominance (p. 79)
CT scanning or computerized tomography (p. 68)
Electroencephalograph or EEG (p. 67)
fMRI or functional magnetic resonance imaging (p. 68)
Frontal lobes (p. 74)

Hippocampus (p. 71)

Hypothalamus (p. 73)

Limbic system (p. 71)

Medulla (p. 70)

Mirror neurons (p. 76)

Motor cortex (p. 74)

MRI or magnetic resonance imaging (p. 68)

Occipital lobes (p. 76)

Parietal lobes (p. 76)

PET scanning or positron emission tomography (p. 68)

Pons (p. 70)

Reticular formation (p. 70)

Somatosensory cortex (p. 76)

Temporal lobes (p. 77)

Thalamus (p. 71)

Visual cortex (p. 77)

MyPsychLab Resources 2.3:

Explore: The Limbic System

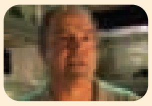
Explore: The Visual Cortex

Simulation: Split-brain Experiments

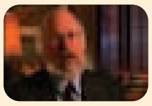
Discovering Psychology Viewing Guide

Watch the following videos by logging into MyPsychLab (www.mypsychlab.com). After you have watched the videos, complete the activities that follow.

PROGRAM 3: THE BEHAVING BRAIN



PROGRAM 4: THE RESPONSIVE BRAIN



PROGRAM 25: COGNITIVE NEUROSCIENCE

PROGRAM REVIEW

1. What section of a nerve cell receives incoming information?
   a. the axon
   b. the terminal button
   c. the synapse
   d. the dendrite
2. In general, neuroscientists are interested in the
   a. brain mechanisms underlying normal and abnormal behavior.
   b. biological consequences of stress on the body.
   c. comparison of neurons with other types of cells.
   d. computer simulation of intelligence.
3. Which section of the brain coordinates body movement and maintains equilibrium?
   a. the brain stem
   b. the cerebellum
   c. the hippocampus
   d. the cerebrum
4. Which brain structure is most closely involved with emotion?
   a. the cortex
   b. the brain stem
   c. the limbic system
   d. the cerebellum

5. Which method of probing the brain produces actual pictures of the brain's inner workings?
   a. autopsies
   b. lesioning
   c. brain imaging
   d. electroencephalograms
6. Research related to acetylcholine may someday help people who
   a. have Alzheimer's disease.
   b. have Parkinson's disease.
   c. suffer spinal cord trauma.
   d. suffer from depression.
7. When we say the relationship between the brain and behavior is reciprocal, we mean that
   a. the brain controls behavior, but behavior can modify the brain.
   b. behavior determines what the brain will think about.
   c. the brain and behavior operate as separate systems with no interconnection.
   d. the brain alters behavior as it learns more about the world.
8. Which of the following is true about how neurons communicate with each other?
   a. All neuronal communication is excitatory.
   b. Neurons communicate with each other by sending electrical discharges across the connecting synapse.
   c. Neurons of any given type can communicate only with other neurons of the same type.
   d. The sum of excitatory and inhibitory signals to a neuron determines whether and how strongly it will respond.
9. Which part of the brain controls breathing?
   a. cerebellum
   b. brain stem
   c. hypothalamus
   d. limbic system
10. The cerebrum
    a. consists of two hemispheres connected by the corpus callosum.
    b. relays sensory impulses to the higher perceptual centers.
    c. releases seven different hormones to the pituitary gland.
    d. controls temperature and blood pressure.
11. After a rod was shot through Phineas Gage's skull, what psychological system was most strongly disrupted?
    a. his emotional responses
    b. his ability to sleep and wake
    c. his language comprehension
    d. his ability to count
12. Which of the following does not provide information about the structure of the brain?
    a. CAT
    b. EEG
    c. MRI
    d. fMRI
13. Which of the following provides the highest temporal and spatial resolution in brain imaging?
    a. ERP
    b. MRI
    c. PET
    d. fMRI
14. Stimuli that pass through the right eye are processed by
    a. the left side of the brain.
    b. the front of the brain.
    c. the right side of the brain.
    d. the brain stem.
15. The process of learning how to read shows that the brain is plastic. What does this mean?
    a. The brain is rigid in what it is designed to do.
    b. Learning how to read reorganizes the brain.
    c. The brain cannot be damaged simply by attempting new mental feats.
    d. The brain can be damaged when it attempts new mental feats.
16. If a scientist was studying the effects of endorphins on the body, the scientist would be likely to look at a participant's
    a. memory.
    b. mood.
    c. ability to learn new material.
    d. motivation to compete in sports.
17. What is the relationship between the results of Saul Schanberg's research and that of Tiffany Field?
    a. Their results are contradictory.
    b. The results of Schanberg's research led to Field's research.
    c. Their results show similar phenomena in different species.
    d. Their results are essentially unrelated.
18. What physical change did Mark Rosenzweig's team note when it studied rats raised in an enriched environment?

   a. a thicker cortex
   b. more neurons
   c. fewer neurotransmitters
   d. no physical changes were noted, only functional changes

19. A scientist who uses the methodologies of brain science to examine animal behavior in natural habitats is a
   a. naturalist.
   b. bioecologist.
   c. neuroethologist.
   d. cerebroetymologist.

20. With respect to the neurochemistry of the brain, all of these are true, *except* that
   a. scopolamine blocks the establishment of long-term memories.
   b. opioid peptides are naturally occurring chemicals in the brain.
   c. physostigmine is responsible for information transmission in the perceptual pathways.
   d. endorphins play a major role in pleasure and pain experiences.

QUESTIONS TO CONSIDER

1. Different technologies for measuring brain activity help psychologists view structures and functioning of the brain. What advantages do these advanced techniques offer?
2. Imagine that you were a relative of Phineas Gage. How do you think you would have reacted to the changes in his behavior in the years following his accident at the railroad construction site? Would you have been willing to believe that the changes were permanent, or that they weren't under Gage's control?
3. Given the advances being made in the imaging of brain activity, will it ever be possible for scientists to "read someone's mind" or to control someone's thoughts?
4. Imagine that you were designing an animal brain. Why would you want to design neurons to have an all-or-none response rather than a graded potential? Why would you want to create a brain that responded to several different neurotransmitters rather than creating one all-purpose neurotransmitter that affected all cells equally?
5. If we have developed techniques that can eventually allow us to fully understand the various pathways of the brain and its neurochemistry, are we close to being able to build a brain from scratch?

ACTIVITIES

1. Can you feel the effects of your hormones? Try this: Imagine yourself falling down the stairs, stubbing your toe, or suddenly losing control of your car on a busy highway. Did your heart skip a beat? Did you catch your breath or feel a tingle up your back? Did the hair on your neck stiffen? Your imagination has caused a biochemical reaction in your brain, and you are feeling the effect of the hormones it produces. Can you name the hormones involved?
2. As science enters an era of allowing researchers to study the brain's activities, our imaginations about what is possible run much faster than the development of neuroimaging and simulation techniques. Watch films such as *The Cell, The Matrix,* and *AI,* and identify several ways in which the "science" they portray is impossible given the current state of the field. Think about which aspects will likely remain impossible even hundreds of years from now.
3. Check out a textbook for a neuroscience or medical course that shows brain images of normal people and various clinical populations such as patients with schizophrenia, patients with Alzheimer's disease, or victims of accidents. Which areas of loss are associated with the loss of which functions?