

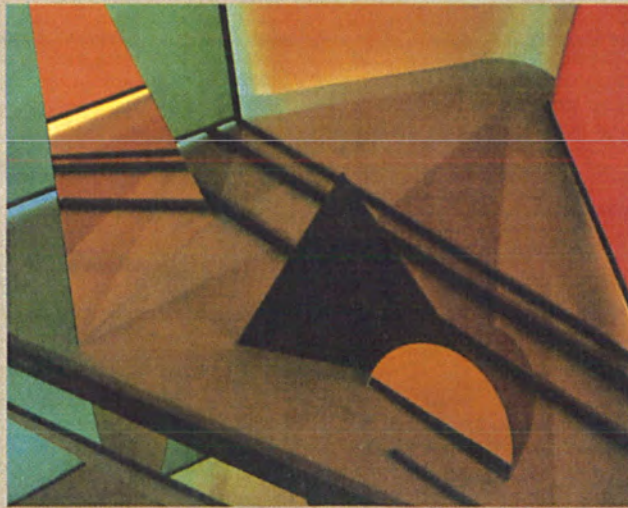
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Themes and Variations

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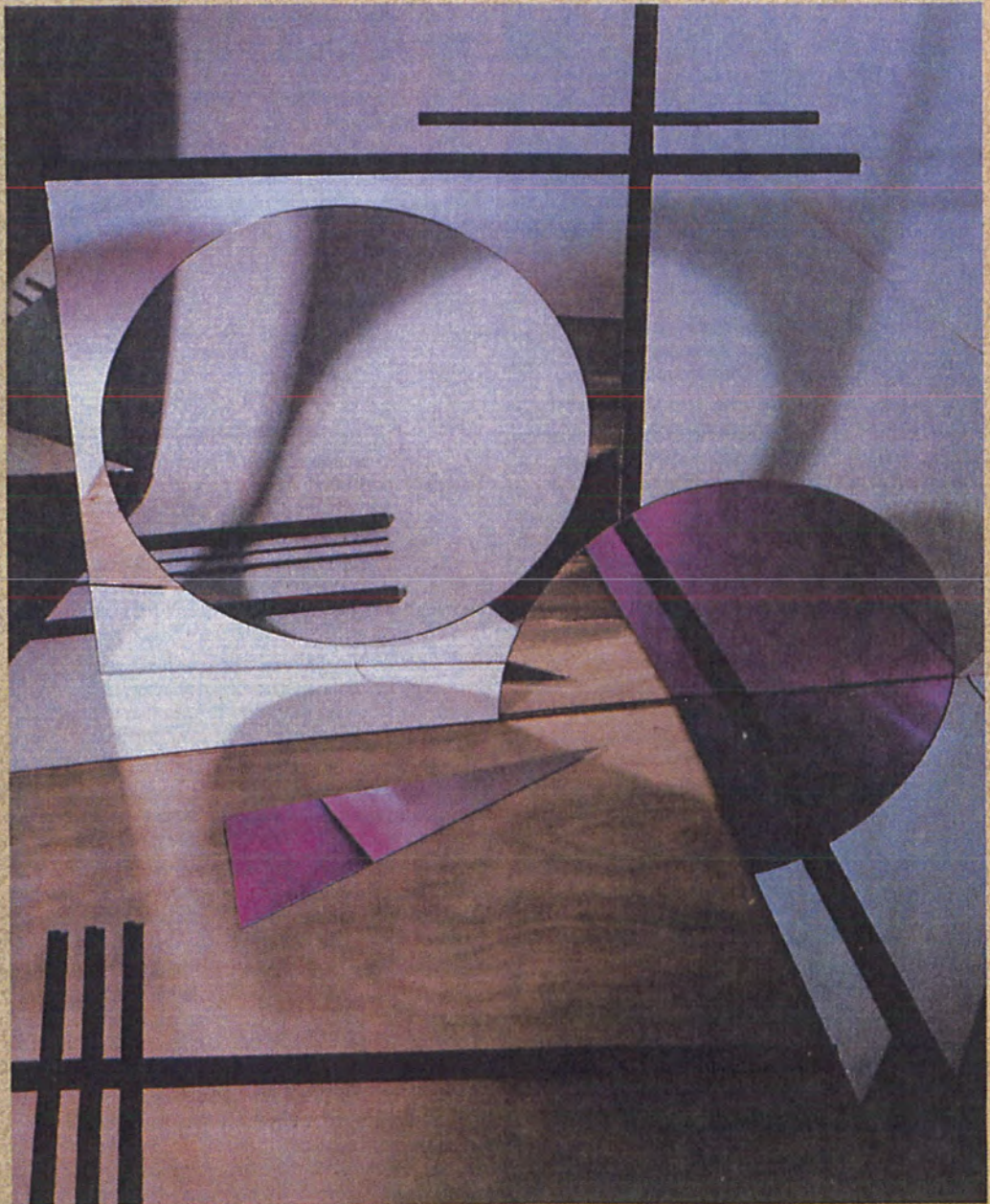
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Complexities and Qualifications

If you have ever visited an aquarium, you may have encountered one of nature's more captivating animals: the octopus. Although this jellylike mass of arms and head appears to be a relatively simple creature, it is capable of a number of interesting behaviors. The octopus has highly developed eyes that enable it to respond to stimuli in the darkness of the ocean. When threatened, it can release an inky cloud to befuddle enemies while it makes good its escape by a kind of jet propulsion. If that doesn't work, it can camouflage itself by changing color and texture to blend into its surroundings. Furthermore, the animal is surprisingly intelligent. In captivity, an octopus can learn, for example, to twist the lid off a jar with one of its tentacles to get at a treat that is inside.

Despite its talents, there are many things an octopus cannot do. An octopus cannot study psychology, plan a weekend, dream about its future, or discover the Pythagorean theorem. Yet the biological processes that underlie these uniquely human behaviors are much the same as the biological processes that enable an octopus to escape from a predator or forage for food. Indeed, some of science's most important insights about how the nervous system works came from studies of a relative of the octopus, the squid.

Organisms as diverse as humans and squid share many biological processes. However, their unique behavioral capacities depend on the differences in their physiological makeup. You and I have a larger repertoire of behaviors than the octopus in large part because we come equipped with a more complex brain and nervous system. The activity of the human brain is so complex that no computer has ever come close to duplicating it. Your nervous system contains as many cells busily integrating and relaying information as there are stars in our galaxy. Whether you are scratching your nose or composing an essay, the activity of those cells underlies what you do. It is little wonder, then, that many psychologists have dedicated themselves to exploring the biological bases of behavior.

How do mood-altering drugs work? Are the two halves of the brain specialized to perform different functions? What happens inside the body when you feel a strong emotion? Are some mental illnesses the result of chemical imbalances in the brain? To what extent is intelligence determined by biological inheritance? These questions only begin to suggest the countless ways in which biology is fundamental to the study of behavior.

In this chapter we will examine the principal biological structures and processes that make be-

havior possible. In the first two sections of the chapter, we'll discuss the workings of the nervous system. We'll then take an extended look at the most important behavioral organ of all, the brain. After completing our review of behavioral physiology with a brief discussion of the endocrine system, we will consider a key issue raised by the importance of biology: the impact of heredity on behavior. Finally, the chapter's Application examines the furor about the specialized abilities of the right and left halves of the brain.

COMMUNICATION IN THE NERVOUS SYSTEM

Imagine that you are watching a scary movie. As the tension mounts, your palms sweat and your heart beats faster. You begin shoveling popcorn into your mouth, carelessly spilling some in your lap. If someone were to ask you what you are doing at this moment, you would probably say, "Nothing—just watching the movie." Yet some very complicated processes are occurring without your thinking about them. A stimulus (the light from the screen) is striking your eye. Almost instantaneously, your brain is interpreting the light stimulus, and signals are flashing to other parts of your body, leading to a flurry of activity. Your sweat glands are releasing perspiration, your heartbeat is quickening, and muscular movements are enabling your hand to find the popcorn and, more or less successfully, lift it to your mouth.

Even in this simple example, you can see that behavior depends on rapid information processing. Information travels almost instantaneously from your eye to your brain, from your brain to the muscles of your arm and hand, and from your palms back to your brain. In essence, your nervous system is a complex communication network in which signals are constantly being received, integrated, and transmitted. The nervous system handles *information*, just as the circulatory system handles blood. In this section, we take a close look at communication in the nervous system.

Nervous Tissue: The Basic Hardware

Your nervous system is living tissue. It is composed entirely of cells, just like the rest of your body. The cells in the nervous system fall into two major categories: *glia* and *neurons*.

Glia: The Support System

Glia are cells found throughout the nervous system that provide structural support and insulation for neurons. Glia (literally "glue") hold the nervous system together and help maintain the chemical environment of the neurons. Among other things, glial cells may supply nutrients to neurons or remove their waste materials. Some glia can also repair damage to the nervous system (Shepherd, 1988). Although glia provide many important services, neurons perform the crucial functions of the nervous system.

Neurons: The Communication Links

Neurons are individual cells in the nervous system that receive, integrate, and transmit information. They are the basic links that permit communication within the nervous system. The vast majority of them are *interneurons*—neurons that communicate only with other neurons. However, a privileged few, called *sensory neurons*, receive signals from outside the nervous system. The entire nervous system depends on these specialized cells for its information about lights, sounds, and other stimuli outside the body and about interior stimuli (a stomachache, for instance). Of course, the plans of action formulated by the brain must get from your brain to the muscles of your body. This communication is handled by *motor neurons*, which carry messages from the nervous system to the muscles that actually move the body.

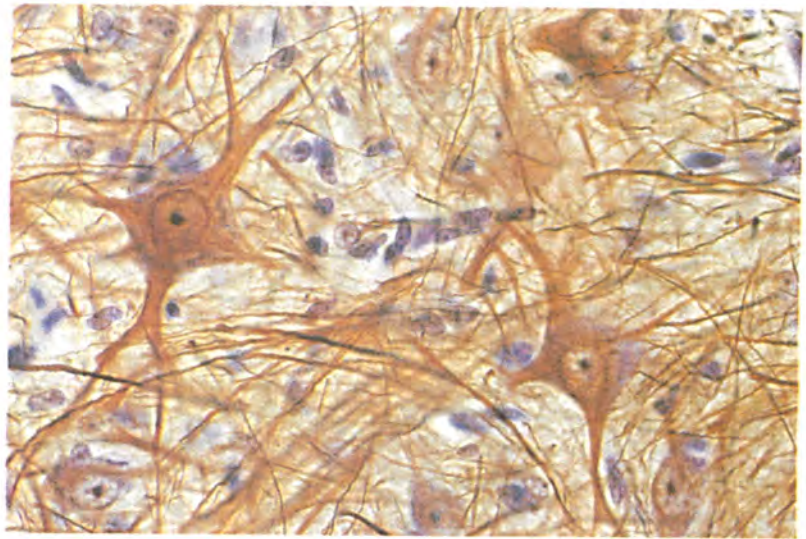
A highly simplified drawing of a few "typical" neurons is shown in Figure 3.1. Actually, neurons come in such a tremendous variety of types and shapes that no single drawing can adequately rep-

resent them. Trying to draw the “typical” neuron is like trying to draw the “typical” tree. In spite of this diversity, the drawing in Figure 3.1 highlights some common features of neurons.

The **soma**, or cell body, contains the cell nucleus and much of the chemical machinery common to most cells (*soma* is Greek for “body”). The rest of the neuron is devoted exclusively to handling information. We usually think of information as flowing from left to right, so the diagram in Figure 3.1 is set up for just such a flow. The neuron at the left has a number of branched, feelerlike structures called **dendritic trees** (*dendrite* is a Greek word for “tree”). Each individual branch is a *dendrite*. **Dendrites are the parts of a neuron that are specialized to receive information.** Most neurons receive information from many other cells—sometimes thousands of others—and so have extensive dendritic trees.

From the many dendrites, information flows into the cell body and then travels away from the soma along the **axon** (from the Greek for “axle”). The **axon is a long, thin fiber that transmits signals away from the soma to other neurons or to muscles or glands.** Axons may be quite long (sometimes several feet), and they may branch off to communicate with a number of other cells.

In humans, many axons are wrapped in a white, fatty substance called **myelin**. The **myelin sheath is insulating material, derived from glial cells, that encases some axons.** This insulation speeds up the transmission of signals that move along axons. Furthermore, if certain axons aren’t properly insulated from each other, signals in the nervous system can get scrambled. The loss of muscle control seen with the disease *multiple sclerosis* appears to be due to a degeneration of myelin sheaths (McKhann, 1987).



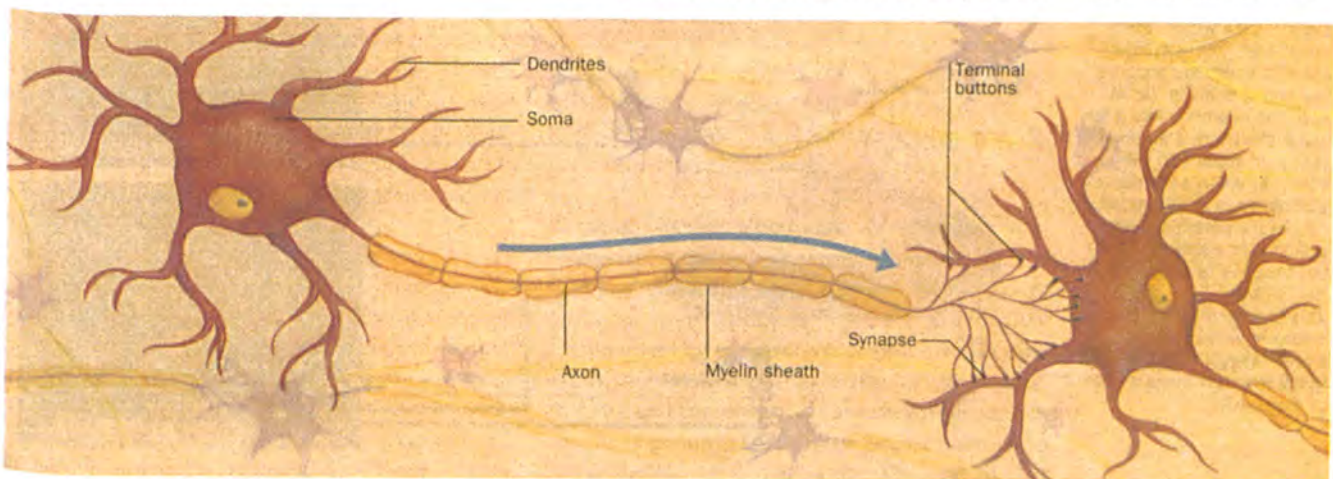
A light micrograph (a photograph taken through a light microscope) of neurons in the spinal cord. These cells have been stained and are magnified approximately 500 times.

The axon ends in a cluster of **terminal buttons**, which are small knobs that secrete chemicals called **neurotransmitters**. These chemicals serve as messengers that may activate neighboring neurons. The points at which neurons interconnect are called **synapses**. A **synapse is a junction where information is transmitted from one neuron to another** (*synapse* is from the Greek for “junction”).

To summarize, information is received at the dendrites, is passed through the soma and along the axon, and is transmitted to the dendrites of other cells at meeting points called synapses. Unfortunately, this nice, simple picture has more exceptions than the U.S. Tax Code. For example, some neurons do not have an axon, while others have multiple axons. Also, although neurons typically synapse on the dendrites of other cells, they may also synapse on a soma or an axon. Despite these and other complexities, however, the fundamental function of neurons is clear: they do the

Figure 3.1
Structure of the neuron.

Neurons are the communication links of the nervous system. This diagram highlights the key parts of a neuron, including specialized receptor areas (dendrites), the cell body (soma), the fiber along which impulses are transmitted (axon), and the junctions across which chemical messengers carry signals to other neurons (synapses). Neurons vary considerably in size and shape and are usually densely interconnected.



work of the nervous system by receiving, integrating, and transmitting informational signals.

The Neural Impulse: Using Energy to Send Information

What happens when a neuron is stimulated? What is the nature of the signal—the *neural impulse*—that moves through the neuron? These were the questions that Alan Hodgkin and Andrew Huxley set out to answer in their experiments with axons removed from squid. Why did they choose to work with squid axons? Because the squid has a pair of “giant” axons that are about a hundred times larger than those in humans (which still makes them only about as thick as a human hair). These giant axons serve the squid well. The thick size speeds up the transmission of messages to the squid’s muscles, enabling it to make its remarkable, jet-propelled escape from its enemies. The axons also serve physiologists well. Their large size permitted Hodgkin and Huxley to insert into them fine wires called *microelectrodes*. By using the microelectrodes to record the electrical activity in individual neurons, Hodgkin and Huxley unraveled the mystery of the neural impulse.

The Neuron at Rest: A Tiny Battery

Hodgkin and Huxley (1952) learned that the neural impulse is a complex electrochemical reaction.

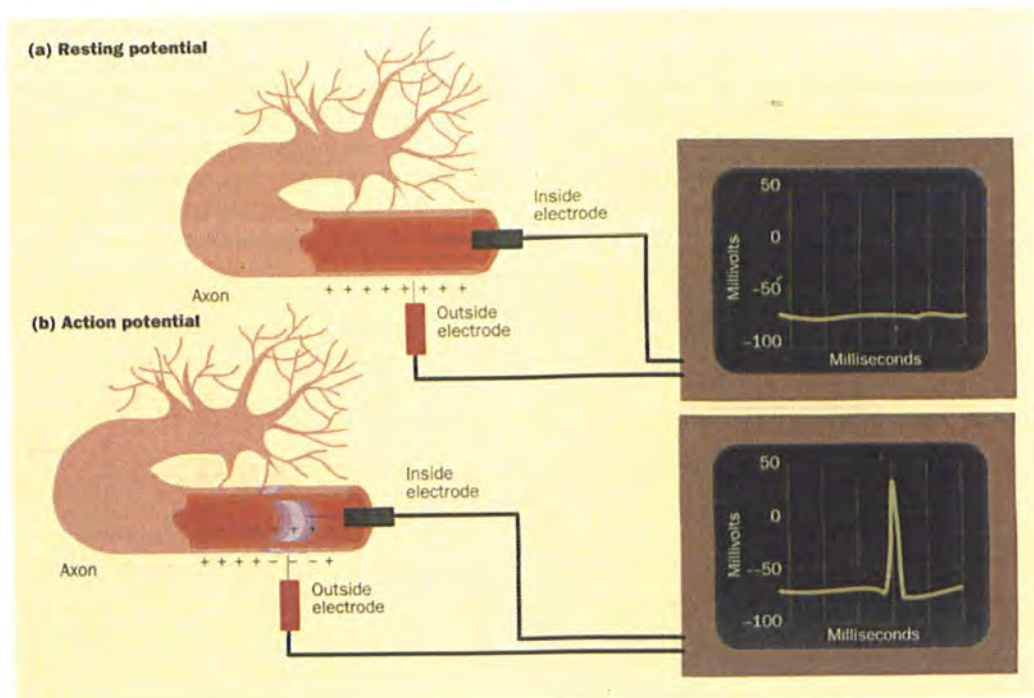
Both inside and outside the neuron are fluids containing electrically charged atoms and molecules called *ions*. Positively charged sodium and potassium ions and negatively charged chloride ions flow back and forth across the cell membrane, but they do not cross at the same rate. The difference in flow rates leads to a slightly higher concentration of negatively charged ions inside the cell. The net result is that the neuron membrane becomes *polarized*—negatively charged on the inside and positively charged on the outside.

The voltage difference that results from this polarization means that the neuron at rest is a tiny battery, a store of potential energy. **The resting potential of a neuron is its stable, negative charge when the cell is inactive.** As shown in Figure 3.2(a), this charge is about -70 millivolts, roughly one-twentieth of the voltage of a flashlight battery.

The Action Potential

As long as the voltage of a typical neuron remains constant, the cell is quiet, and no messages are being sent. However, stimulation of sufficient intensity (signals from other neurons or from sensory stimuli) will disrupt this stability by momentarily altering the permeability of the cell membrane. When the neuron is stimulated, channels in its cell membrane open, briefly allowing positively charged sodium ions to rush in (see Figure 3.3). For an instant, the neuron’s charge is less negative, or

Figure 3.2
The neural impulse. The electrochemical properties of the neuron allow it to transmit signals. The electric charge of a neuron can be measured with a pair of electrodes connected to an oscilloscope, as Hodgkin and Huxley showed with a squid axon. Because of its exceptionally thick axons, the squid has frequently been used by scientists studying the neural impulse. **(a)** At rest, the neuron is like a tiny wet battery with a resting potential of about -70 millivolts. **(b)** When a neuron is stimulated, a brief jump in its electric potential occurs, resulting in a spike on the oscilloscope recording of the neuron’s electrical activity. This change in voltage, called an action potential, travels along the axon like a spark traveling along a trail of gunpowder.



even positive, creating an action potential (Koester, 1991). An **action potential** is a brief change in a neuron's electrical charge. The firing of an action potential is reflected in the voltage spike shown in Figure 3.2(b). Like a spark traveling along a trail of gunpowder, the voltage change races down the axon. The firing of the action potential in one segment of the axon triggers the firing of the action potential in the next segment, and so on down the line, just as a burning grain of gunpowder ignites neighboring grains.

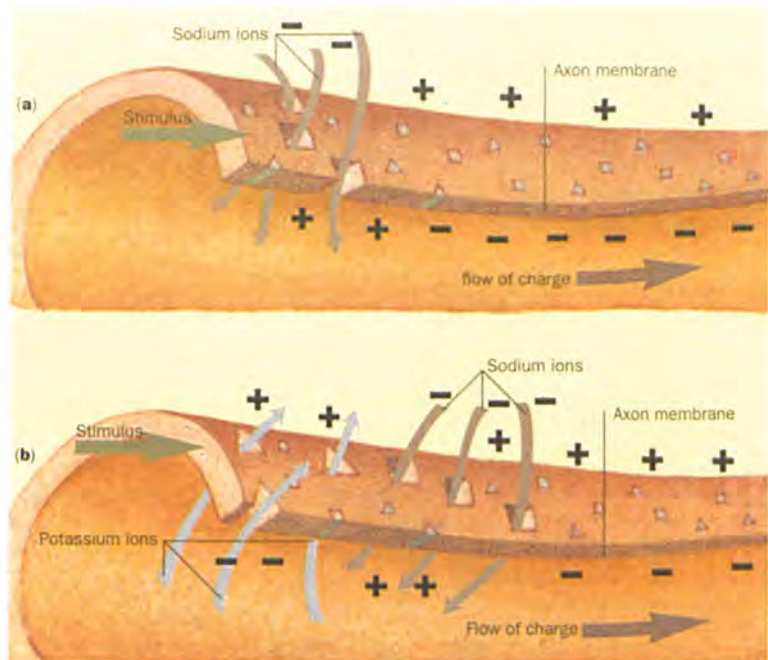
Thus, a neural impulse is an electric current that flows along the axon as a result of an action potential. After the firing of an action potential, the channels in the cell membrane that opened to let in sodium close up. Some time is needed before they are ready to open again. Until they are ready to reopen, the neuron cannot fire. The **absolute refractory period** is the minimum length of time after an action potential during which another action potential cannot begin. This "down time" isn't very long, only 1 or 2 milliseconds. However, much longer periods of neural unresponsiveness can be produced by certain drugs, such as local anesthetics. For example, if your dentist gives you an injection of Novocaine before drilling, the drug exerts its painkilling effects by closing the sodium channels in neurons near the injection site. The result is that sensory neurons that would otherwise send pain signals to the brain are temporarily shut down.

The All-or-None Law

The neural impulse is an all-or-none proposition, like firing a gun. You can't half-fire a gun. The same is true of the neuron's firing of action potentials. Either the neuron fires or it doesn't. A weaker stimulus does not produce a weaker neural impulse.

Even though the action potential is an all-or-nothing event, neurons *can* convey information about the strength of a stimulus. They do so by varying the *rate* at which they fire action potentials. In general, a stronger stimulus will cause a cell to fire a more rapid volley of neural impulses than a weaker stimulus will.

Various neurons transmit neural impulses at different speeds. Because thicker axons have less resistance to electrical current, they conduct action potentials more rapidly than thinner ones do, which is why the squid's thick axons serve their purpose so well. A neural impulse also travels faster on an axon insulated with myelin. Although neural impulses do not travel as fast as electricity along a



wire, they are very fast, moving at up to 100 meters per second, which is equivalent to more than 200 miles per hour. The entire, complicated process of neural transmission takes only a few thousandths of a second. In the time it has taken you to read this description of the neural impulse, billions of such impulses have been transmitted in your nervous system!

The Synapse: Where Neurons Meet

In the nervous system, the neural impulse functions as a signal. For that signal to have any meaning for the system as a whole, it must be transmitted from the neuron to other cells. As noted earlier, this transmission takes place at special junctions called **synapses**. In invertebrates and lower mammals, some synapses simply involve electrical currents that pass directly from cell to cell (Shepherd, 1988). In humans, however, it appears that all synapses depend on **chemical messengers**.

Sending Signals: Chemicals as Couriers

A "typical" synapse is shown in Figure 3.4 (on the next page). The first thing that you should notice is that the two neurons don't actually touch. They are separated by the **synaptic cleft**, a microscopic gap between the terminal button of one neuron and the cell membrane of another neuron. Signals have to jump this gap to permit neurons to communicate. In this situation, the neuron that

Figure 3.3
Biochemical basis of the action potential. (a) An action potential occurs when sodium gates in the membrane of a neuron open, permitting positively charged sodium ions to flow into the axon, thus creating a brief jump in electrical potential at that point. (b) After an action potential occurs, the sodium gates close at that point, but similar gates open at the next point along the axon membrane, allowing the action potential to flow along the axon. In the wake of the action potential, potassium gates in the membrane open to let positively charged potassium ions flow outward, thus reestablishing a negative charge inside. (Adapted from Kalat, 1993)

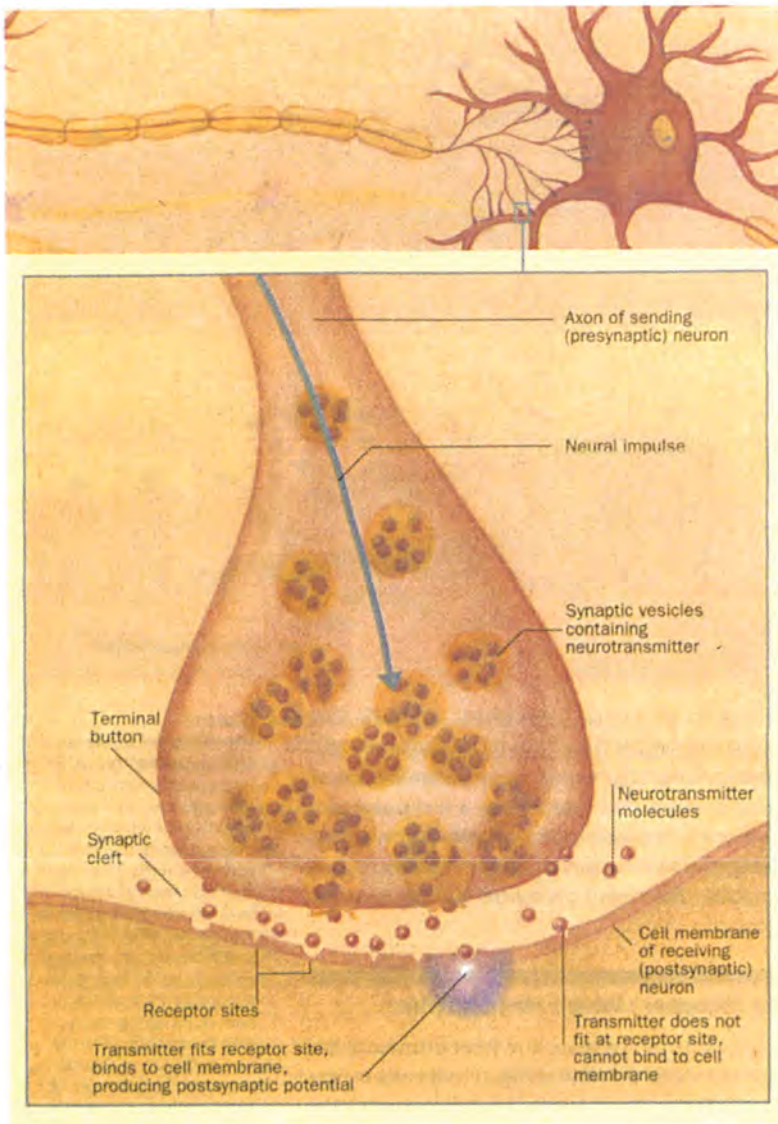


Figure 3.4
The synapse. When a neural impulse reaches an axon's terminal buttons, it triggers the release of chemical messengers called neurotransmitters. The neurotransmitter molecules diffuse across the synaptic cleft and bind to receptor sites on the postsynaptic neuron. A specific neurotransmitter can bind only to receptor sites that its molecular structure will fit into, much like a key must fit a lock.

sends a signal across the gap is called the *presynaptic neuron*, and the neuron that receives the signal is called the *postsynaptic neuron*.

How do messages travel across the gaps between neurons? The arrival of an action potential at an axon's terminal buttons triggers the release of **neurotransmitters**—chemicals that transmit information from one neuron to another. Within the buttons, the chemicals are stored in small sacs, called *synaptic vesicles*. The neurotransmitters are released when a vesicle fuses with the membrane of the presynaptic cell and squeezes its contents into the synaptic cleft. After their release, neurotransmitters diffuse across the synaptic cleft to the membrane of the receiving cell. There they may bind with special molecules in the postsynaptic cell

membrane at various *receptor sites*. These sites are specifically “tuned” to recognize and respond to some neurotransmitters but not to others.

Receiving Signals: Postsynaptic Potentials

When a neurotransmitter and a receptor molecule combine, reactions in the cell membrane cause a **postsynaptic potential (PSP)**, a voltage change at a receptor site on a postsynaptic cell membrane. When a PSP occurs, channels are opened in the cell membrane at the site, allowing specific ions to flood into or rush out of the cell. Postsynaptic potentials do *not* follow the all-or-none law as action potentials do. Instead, postsynaptic potentials are *graded*. That is, they increase or decrease the *probability* of a neural impulse in the receiving cell in proportion to their size (the amount of voltage change).

If the voltage in the postsynaptic neuron shifts in a positive direction, the cell comes closer to its threshold for firing a neural impulse. An **excitatory PSP** is an electric potential that increases the likelihood that the postsynaptic neuron will fire action potentials. If the voltage shifts in a negative direction, the postsynaptic neuron moves farther away from its threshold for firing a neural impulse. This kind of negative shift is an **inhibitory PSP**, an electric potential that decreases the likelihood that the postsynaptic neuron will fire action potentials. Both excitatory and inhibitory PSPs are depicted in Figure 3.5. The direction of the voltage shift, and thus the nature of the PSP (excitatory or inhibitory), depends on which receptor sites are activated in the postsynaptic neuron (Kandel & Schwartz, 1991).

Thus, there are two types of messages that can be sent from cell to cell: excitatory and inhibitory. Both types are essential to the functioning of the nervous system. If cells could only excite other cells, any excitation would grow and reverberate through the nervous system like a nuclear chain reaction. In fact, many kinds of seizures are due to insufficient inhibitory effects at synapses. Strychnine, perhaps the nastiest of poisons, works its deadly effects by disabling many inhibitory synapses. The resulting excitation causes uncontrollable convulsions that can be fatal.

The excitatory or inhibitory effects produced at a synapse last only a fraction of a second. If neurotransmitters remained bound to receptor sites forever, all such sites would soon be occupied and cells would remain permanently at a stable electric potential. Information processing in the nervous system would come to a halt. Why doesn't this happen?

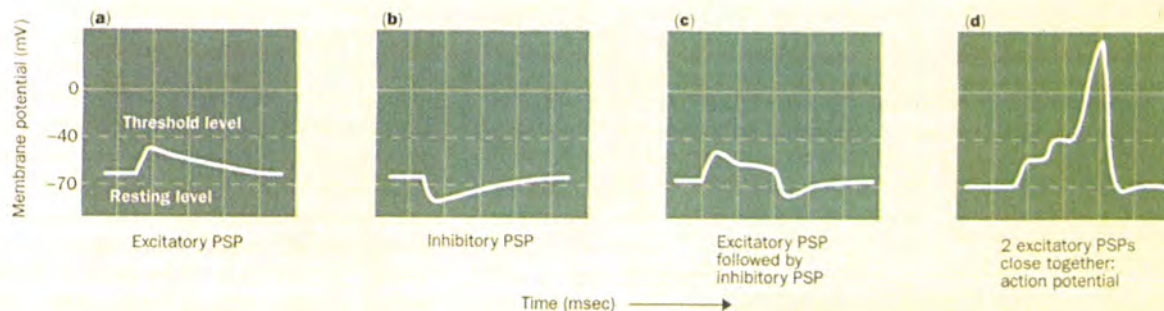


Figure 3.5
Postsynaptic potentials (PSPs). A postsynaptic potential is a change in the voltage of a neuron that occurs when a neurotransmitter binds with a receptor on the neuron. PSPs are either inhibitory or excitatory. **(a)** At some receptor sites, a PSP increases the postsynaptic neuron's voltage (an excitatory effect). **(b)** At other receptor sites, a PSP lowers the neuron's voltage (an inhibitory effect). **(c)** An excitatory PSP and an inhibitory PSP may balance each other out. **(d)** A series of excitatory PSPs may lead to an action potential.

Because neurotransmitters drift away from receptor sites or are inactivated by enzymes that metabolize (convert) them into inactive forms. Most are reabsorbed into the presynaptic neuron through *reuptake*, a process in which neurotransmitters are sponged up from the synaptic cleft by the presynaptic membrane. This process allows synapses to recycle their materials.

The various processes in synaptic transmission are diagrammed in Figure 3.6. As you can see, communication at synapses involves five steps: (1) the synthesis and storage of transmitters, (2) the release of transmitters into the synaptic cleft, (3) the binding of transmitters at receptor sites on the postsynaptic membrane, (4) the inactivation (by enzymes) or removal (drifting away) of transmitters in the

synapse, and (5) the reuptake of transmitters by the presynaptic neuron.

Integrating Signals: A Balancing Act

We have seen how neurons receive signals, transmit signals along axons, and send signals across synaptic clefts to other neurons. Keep in mind, however, that most neurons are interlinked in complex, dense networks. In fact, a neuron may have as many as 15,000 synapses receiving a symphony of signals from thousands of other neurons. The same neuron may pass its messages along to thousands of other neurons as well.

Thus, a neuron must do a great deal more than simply relay messages it receives. It must integrate signals arriving at many synapses before it "de-

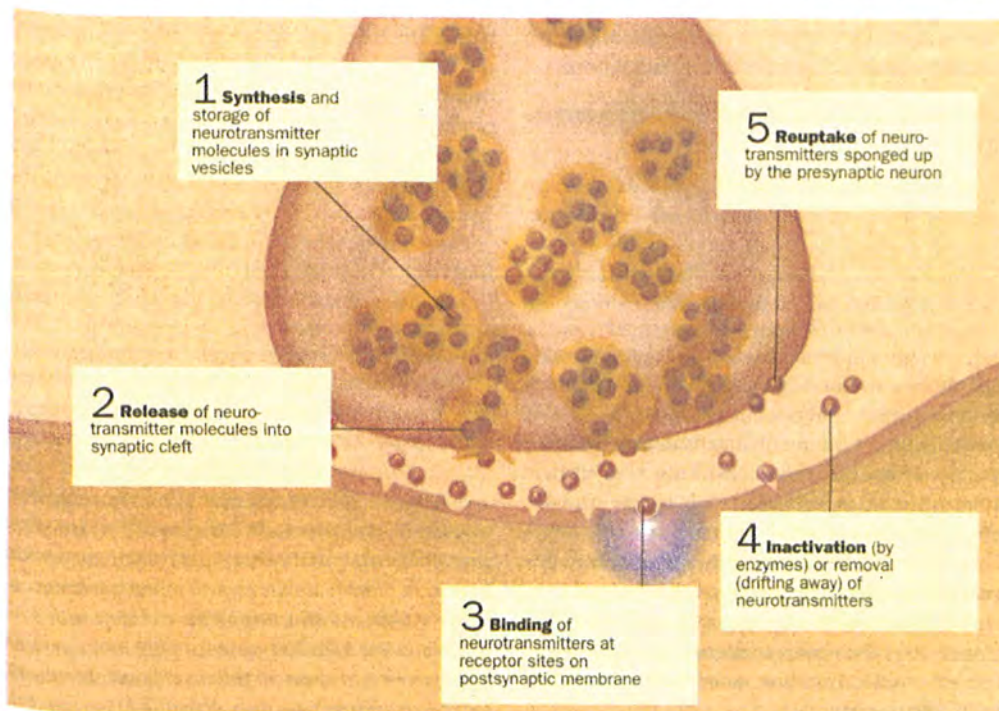
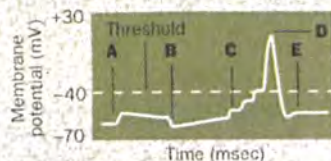


Figure 3.6
Overview of synaptic transmission. The main elements in synaptic transmission are summarized here, superimposed on a blowup of the synapse seen in Figure 3.4. The five key processes involved in communication at synapses are (1) synthesis, (2) release, (3) binding, (4) inactivation, and (5) reuptake of neurotransmitters. As you'll see in this chapter and the remainder of the book, the effects of many phenomena—such as stress, drug use, and some diseases—can be explained in terms of how they alter one or more of these processes (usually at synapses releasing a specific neurotransmitter).

CONCEPT CHECK 3.1

Understanding the Electric Potential(s) of the Neural Impulse

Check your understanding of the neural impulse by trying to identify the various electric potentials depicted in the figure below. The graph diagrams voltage changes in a neuron over a brief period of time. The five letters (A through E) in the figure point to various types of potentials. Match the appropriate letters with the five types of potentials listed below. The answers can be found in the back of the book in Appendix A.



1. A resting potential
2. An action potential
3. An excitatory postsynaptic potential (PSP)
4. A series of excitatory PSPs
5. An inhibitory PSP

icides" whether to fire a neural impulse. If enough excitatory PSPs occur in a neuron, the electrical currents can add up, causing the cell's voltage to reach the threshold at which an action potential will be fired (as shown in panel d of Figure 3.5). However, if many inhibitory PSPs also occur, they will tend to cancel the effects of excitatory PSPs. The state of the neuron is a weighted balance between excitatory and inhibitory influences.

Neurotransmitters and Behavior

As we have seen, the nervous system relies on chemical couriers to communicate information between neurons. These *neurotransmitters* are fundamental to our behavior, playing a key role in everything from our muscle movements to our moods and mental health.

You might guess that the nervous system would require only two neurotransmitters—one for excitatory potentials and one for inhibitory potentials. However, at least ten chemical substances clearly qualify as neurotransmitters (Kolb & Whishaw, 1990). In addition, scientists suspect that a number of other substances *may* function as transmitters, and new candidates are still being discovered. In general, a specific type of neuron contains the chemical factory for manufacturing only one of the transmitters. However, some neurons also release related chemicals called *neuromodulators*, which we'll discuss later.

Specific neurotransmitters work at specific kinds of synapses. You may recall that transmitter substances deliver their messages by binding to receptor sites on the postsynaptic membrane. However, a transmitter cannot bind to just any site. The binding process operates much like a lock and key, as was shown in Figure 3.4. Just as a key has to fit a lock to work, a transmitter has to fit into a receptor site for binding to occur. Hence, specific transmitters can deliver signals only at certain locations on cell membranes. Why are there many different neurotransmitters, each of which works only at certain synapses? This variety and specificity reduces crosstalk between densely packed neurons, making the nervous system's communication more precise.

Tracking Transmitters: Research Methods

Looking for connections between neurotransmitter activity and behavior is a challenging enterprise. The crux of the problem is the difficulty of measuring neurotransmitter activity in an intact human brain. In human subjects, researchers usually monitor neurotransmitter activity indirectly. Typically, the levels of specific transmitters in a person's brain are estimated by measuring metabolic by-products of their action in specimens of urine, blood serum, or *cerebrospinal fluid (CSF)*, a solution that fills the hollow cavities (ventricles) of the brain and circulates around the brain and spinal cord. At best, this is an imperfect approach, not unlike determining what people eat by going through their garbage cans. Although CSF samples provide the best estimates, the required spinal taps are unpleasant. Moreover, even CSF samples yield only rough estimates of transmitter levels in the brain (Nordin, Siwers, & Bertilsson, 1982).

Thus, much of the information on synaptic transmission has been gleaned from studies of animals. Researchers often work directly on brain tissue extracted from animals. For example, Tom O'Donohue, a researcher exploring neurotransmitter activity, has to visit a Baltimore slaughterhouse about every two weeks to replenish his supply of brain tissue. As he explains,

We go there to collect hog brains. We use hog brains for a number of reasons. We are trying to isolate a neurotransmitter that exists in very small amounts in brains. In order to isolate enough of the transmitter to learn its chemical structure we have to start with a lot of brains. We take 200 pounds of pig brain, and we homogenize it in about 50 gallons of liquid. Eventually we end up with micrograms of peptide (the possible

transmitter substance). (Quoted in Restak, 1984, p. 308)

The measurements of neurotransmitter activity in brain tissue extracted from animals are much more precise and revealing than the measurements of neurotransmitter activity available from human subjects. Researchers can also use the neural tissue extracted from animals to perform experiments that would be impossible with humans. For instance, in a *chemical stimulation* study, an investigator can inject a chemical directly into neural tissue to observe its effect on neurotransmitter activity. Thus, animal studies have made critical contributions to science's rapidly growing understanding of how neurotransmitters work. In many cases, findings from animal research on neurotransmitter processes can be cross-checked in humans, albeit with less precision. Let's briefly review some of the most interesting findings about how neurotransmitters regulate behavior.

Acetylcholine

The discovery that cells communicate by releasing chemicals was first made in connection with the transmitter *acetylcholine* (ACh). ACh has been found throughout the nervous system. It is the only transmitter between motor neurons and voluntary muscles. Every move you make—typing, walking, talking, breathing—depends on ACh released to your muscles by motor neurons (Kandel & Schwartz, 1991).

ACh appears to contribute to attention, arousal, and memory processes. An inadequate supply of ACh in the brain has been implicated as a major factor in the memory losses seen with *Alzheimer's disease*. This disease is endured by about 5 to 15 percent of people over the age of 65, as well as some younger people (Albert, 1992). People with Alzheimer's disease gradually lose their ability to remember anything. Eventually, they don't even recognize family members and can't find their way home. Examinations of the brains of people who have died from Alzheimer's disease reveal abnormally low levels of ACh (Goldman & Coté, 1991). Researchers believe that cells responsible for the synthesis of ACh degenerate in victims of Alzheimer's, leaving the brain with a depleted supply of this crucial neurotransmitter (Allen, Dawbarn, & Wilcock, 1988).

The activity of ACh (and other neurotransmitters) may be influenced by other chemicals in the brain. Although synaptic receptor sites are sensitive to specific neurotransmitters, sometimes they

can be "fooled" by other chemical substances. For example, if you smoke tobacco, some of your ACh synapses will be stimulated by the nicotine that arrives in your brain. At these synapses, the nicotine acts like ACh itself. It binds to receptor sites for ACh, causing postsynaptic potentials (PSPs). In technical language, nicotine is an ACh agonist. **An agonist is a chemical that mimics the action of a neurotransmitter.** In other words, an agonist functions as a substitute, producing some of the effects of the regular transmitter.

Not all chemicals that fool synaptic receptors are agonists. Some chemicals bind to receptors but fail to produce a PSP (the key slides into the lock, but it doesn't work). In effect, they temporarily *block* the action of the natural transmitter by occupying its receptor sites, rendering them unusable. Thus, they act as antagonists. **An antagonist is a chemical that opposes the action of a neurotransmitter.** For example, *curare* is an ACh antagonist. It blocks action at the same ACh synapses that are fooled by nicotine. As a result, muscles are unable to move. Some South American natives use a form of curare on arrows. If they wound an animal, the curare blocks the synapses from nerve to muscle, paralyzing the animal.

Biogenic Amines

The *biogenic amines* include three neurotransmitters: dopamine, norepinephrine, and serotonin. Neurons using these transmitters regulate many aspects of everyday behavior. Dopamine (DA), for example, is used by neurons that control voluntary movements. The degeneration of such neurons apparently causes *Parkinsonism*, a disease marked by tremors, muscular rigidity, and reduced control over voluntary movements (Cooper, Bloom, & Roth, 1991).

Neural circuits using serotonin appear to play a prominent role in the regulation of sleep and wakefulness (McGinty & Szymusiak, 1988). The activity of serotonin-releasing neurons is highest when animals are awake and declines as they move into deeper stages of sleep. However, the modulation of physiological arousal is extremely complex. Arousal also appears to be mediated by another of the biogenic amines (norepinephrine), as well as quite a variety of other chemicals in the brain (D. Kelly, 1991; Panksepp, 1986).

Abnormal levels of biogenic amines in the brain have been related to the development of certain psychological disorders. For example, people who suffer from depression appear to have lowered levels of activation at norepinephrine (NE) syn-



"Brain research of the past decade, especially the study of neurotransmitters, has proceeded at a furious pace, achieving progress equal in scope to all the accomplishments of the preceding 50 years—and the pace of discovery continues to accelerate. The final years of the 20th century may witness unparalleled advances in our understanding of the brain and, even more exciting, in our ability to put this understanding to therapeutic use."

SOLOMON SNYDER

apses. Studies suggest that this reduced activation may be due to changes in the sensitivity of NE receptors rather than to decreases in the release of NE (Schildkraut, Green, & Mooney, 1989).

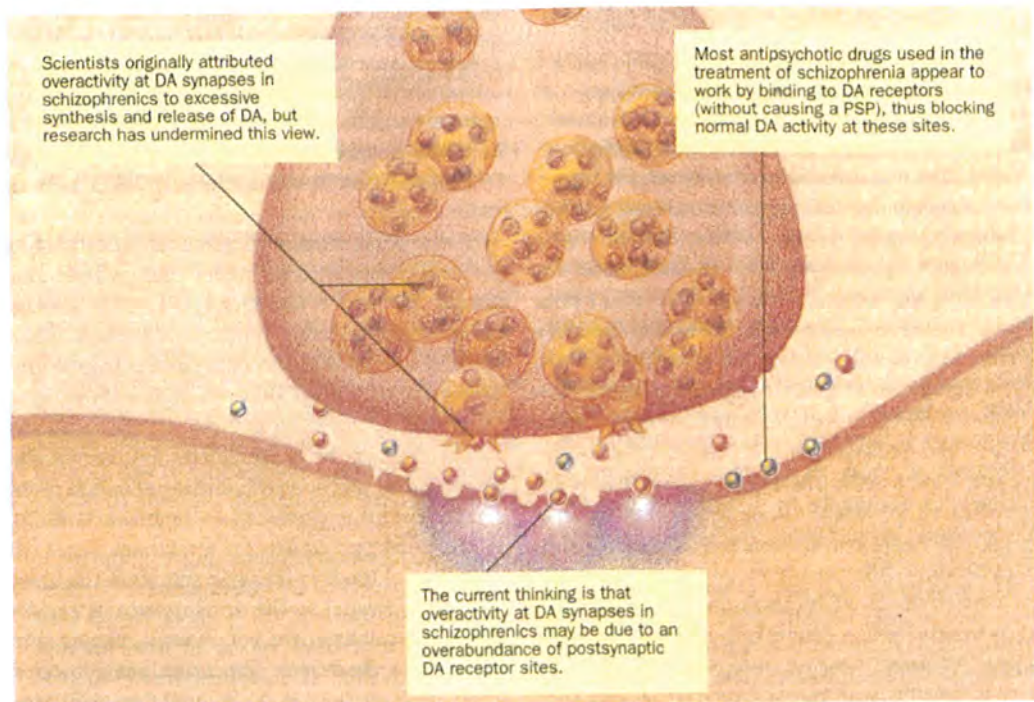
In a similar fashion, alterations in activity at dopamine synapses have been implicated in the development of *schizophrenia*. This severe mental illness is marked by irrational thought, hallucinations, poor contact with reality, and deterioration of routine adaptive behavior. Afflicting roughly 1 percent of the population, schizophrenia requires hospitalization more often than any other psychological disorder. Many investigators believe that the main cause of schizophrenia is overactivity at DA synapses. Why? Primarily because the therapeutic drugs that tame schizophrenic symptoms are known to be DA antagonists that reduce the neurotransmitter's activity. Solomon Snyder (1986) has shown that most of these drugs work by binding to DA receptor sites and blocking normal DA activity at these sites (see Figure 3.7). Unfortunately, the antagonistic effects of these drugs at dopamine synapses often lead to Parkinsonism-like side effects (tremors and muscular rigidity) that make the drugs unpleasant for some patients.

Complexities in the biochemical explanations of depression and schizophrenia continue to be debated (see Chapter 14). Overactivity at dopamine synapses clearly is not the only factor at work in schizophrenia (Kandel, 1991). Some theorists be-

lieve that abnormalities in serotonin and NE activity also play a role (Karson, Kleinman, & Wyatt, 1986). Nonetheless, it's apparent that disturbances in the activity of biogenic amine neurotransmitters make a key contribution to some forms of mental illness.

Altered functioning at biogenic amine synapses also appears to account for the effects of several widely abused drugs, especially amphetamines, cocaine, and LSD (Cooper et al., 1991; Julien, 1992). The stimulant effects of amphetamines and cocaine and the hallucinogenic effects of LSD are described in detail in Chapter 5. At this point, we'll just discuss how the drugs work to further illustrate the enormous variety of phenomena that can be explained in terms of neurotransmitter activity. Amphetamines seem to exert most of their effects by increasing the release of dopamine, norepinephrine, and perhaps serotonin from presynaptic neurons and by slowing the reuptake of DA and NE. Cocaine also elevates activity at DA and NE synapses, but it does so mainly by blocking the reuptake of dopamine and, to a lesser degree, norepinephrine. LSD is less well understood, but theorists believe that it alters serotonin activity by binding to a specific subtype of serotonin receptor. Thus, changes in neurotransmitter activity are the foundation for the dramatic, mysterious, and inexplicably powerful effects of amphetamines, cocaine, and LSD.

Figure 3.7
The dopamine hypothesis as an explanation for schizophrenia. Although other neurotransmitter systems may also be involved, overactivity at dopamine synapses has been implicated as a key cause of schizophrenic disorders. However, the exact mechanisms underlying this DA overactivity are still the subject of considerable debate.



GABA

Another group of transmitters consists of small molecules called *amino acids*. Two of these, *gamma-aminobutyric acid* (GABA) and *glycine*, are notable in that they seem to produce only *inhibitory* post-synaptic potentials. Some transmitters, such as ACh and NE, are versatile. They can produce either excitatory or inhibitory PSPs, depending on the synaptic receptors they bind to. However, GABA and glycine appear to have inhibitory effects at virtually all synapses where either is present. GABA receptors are widely distributed in the brain and may be present at 30 percent of all synapses (Enna & Gallagher, 1983). GABA appears to be responsible for much of the inhibition in the central nervous system.

Studies also suggest that GABA contributes to the regulation of anxiety in humans (Paul, Crawley, & Skolnick, 1986). Generally, the inhibitory effects of GABA keep a lid on neural excitement. However, lowered levels of GABA activity may permit heightened neural excitement that translates into feelings of anxiety. Consistent with this theory, researchers have found that antianxiety drugs, better known as tranquilizers, exert their effects by indirectly increasing inhibitory activity at GABA synapses (Julien, 1992). Ironically, millions of prescriptions were written for tranquilizers (such as Valium) before scientists discovered their mechanism of action in the late 1970s. Although the exact mechanisms remain elusive, abnormalities in the GABA neurotransmitter system probably play a key role in the development of anxiety disorders (Zorumski & Isenberg, 1991).

Endorphins

In 1970, after a horseback-riding accident, Candace Pert, a graduate student in neuroscience, lay in a hospital bed receiving frequent shots of *morphine*, a painkilling drug derived from the opium plant. This experience left her with a driving curiosity about how morphine works. A few years later, she and Solomon Snyder rocked the scientific world by showing that *morphine exerts its effects by binding to specialized receptors in the brain* (Pert & Snyder, 1973).

This discovery raised a perplexing question: Why would the brain be equipped with receptors for morphine, a powerful, addictive opiate drug not normally found in the body? It occurred to Pert and others that the nervous system must have its own, endogenous (internally produced) morphinelike substances. Investigators dubbed these as-yet undiscovered substances “endorphins” (endogenous

morphines). A search for the body's natural opiate ensued. In short order, a number of endogenous, opiatelike substances were identified (Hughes et al., 1975). Subsequent studies revealed that endorphins and their receptors are widely distributed in the human body and that they clearly contribute to the modulation of pain, as well as a variety of other phenomena (E. Simon, 1992).

Research in this area is progressing rapidly, and terminology is evolving as more endogenous opiates are found. Generally, the term **endorphins** refers to the entire family of internally produced chemicals that resemble opiates in structure and effects. Given that opiate drugs are highly addicting, you may be wondering why people don't become addicted to their own endorphins. Apparently, the reason is that endorphins are quickly inactivated by enzymes. Unlike opiate drugs, they don't remain at receptor sites long enough to cause the tissue changes that probably underlie addiction (Snyder, 1986).

All of the endorphins are *neuropeptides*, which are strings of amino acids bound together (Snyder, 1980). Some neuropeptides, such as *substance P*, appear to function as neurotransmitters. Many of the neural circuits that deliver pain signals to the spinal cord and brain seem to use substance P as a transmitter. Although they may serve as transmitters at some synapses, *endorphins seem to function primarily as neuromodulators* (Elliott & Barchas, 1986). **Neuromodulators** are chemicals that increase or decrease (modulate) the activity of specific neurotransmit-



“When human beings engage in various activities, it seems that neurojuices are released that are associated with either pain or pleasure. And the endorphins are very pleasurable.”

CANDACE PERT

CONCEPT CHECK 3.2

Linking Brain Chemistry to Behavior

Check your understanding of relations between brain chemistry and behavior by indicating which neurotransmitters (or neuromodulators) have been linked to the phenomena listed below. Choose your answers from the following list:

(a) acetylcholine, (b) serotonin, (c) norepinephrine, (d) dopamine, (e) GABA, (f) endorphins. Indicate your choice (by letter) in the spaces on the left. You'll find the answers in Appendix A.

- _____ 1. An inhibitory transmitter linked to anxiety; tranquilizers increase the activity of this transmitter.
- _____ 2. A biogenic amine that plays a prominent role in the regulation of sleep and wakefulness.
- _____ 3. A biogenic amine that has been linked to depression.
- _____ 4. Chemicals that resemble opiate drugs in structure and that are involved in feelings of pain and pleasure.
- _____ 5. A neurotransmitter for which abnormal levels have been implicated in Parkinsonism and schizophrenia.
- _____ 6. The only neurotransmitter between motor neurons and voluntary muscles; it also plays a role in memory.

ters. Some endorphins, for instance, appear to reduce pain by preventing the release of substance P, so that fewer pain signals are sent to the brain.

The discovery of endorphins has led to revolutionary new theories and findings on the neurochemical bases of pain and pleasure. In addition to their painkilling effects, opiate drugs such as morphine and heroin produce highly pleasurable feelings of euphoria. This euphoric effect explains why heroin is so widely abused. Researchers suspect that the body's natural endorphins may also be capable of producing feelings of pleasure. This capacity might explain why joggers sometimes experience a "runner's high." The pain caused by a long run may trigger the release of endorphins, which neutralize some of the pain and create a feeling of exhilaration

(Colt, Wardlaw, & Frantz, 1981). Experts can't help but wonder whether endorphins might be the chemical basis for other pleasant emotions as well (Hopson, 1988).

In this section we have highlighted just a few of the more interesting connections between neurotransmitters and behavior. These highlights barely begin to convey the rich complexity of biochemical processes in the nervous system. Most aspects of behavior are probably regulated by several types of transmitters, and most transmitters appear to be involved in many aspects of behavior (Panksepp, 1986). Although scientists have learned a great deal about neurotransmitters and behavior, much still remains to be discovered.

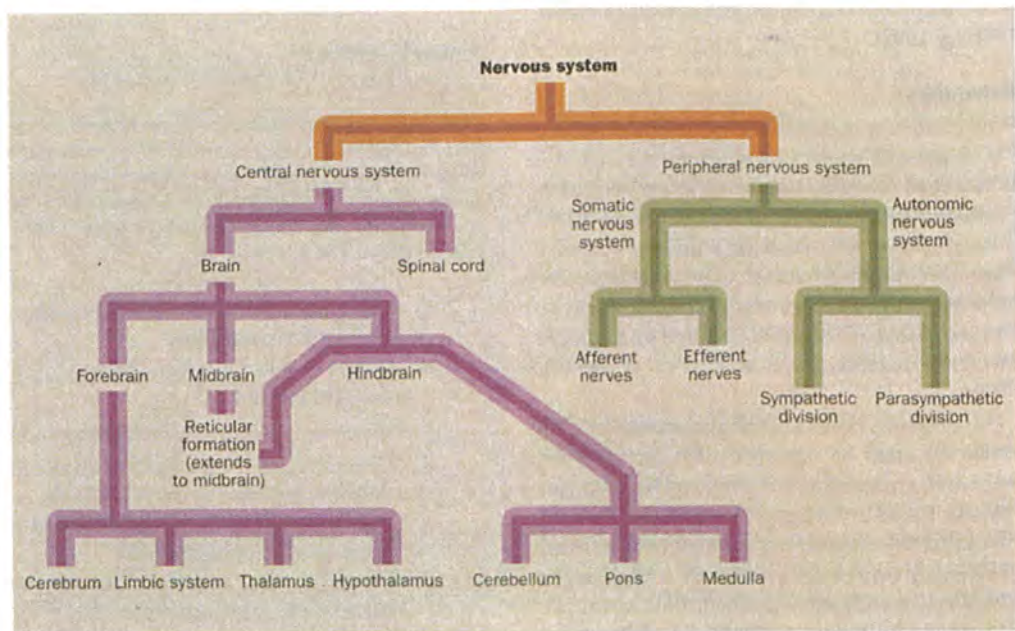
ORGANIZATION OF THE NERVOUS SYSTEM

Clearly, communication in the nervous system is fundamental to behavior. So far we have looked at how individual cells communicate with one another. In this section, we examine the organization of the nervous system as a whole.

Experts believe that there are *100 to 180 billion* neurons in the human brain (Hubel, 1979; Kolb & Whishaw, 1990). Obviously, this is only an *estimate*. If you counted them nonstop at the rate of

one per second, you'd be counting for about 6000 years! The multitudes of neurons in your nervous system have to work together to keep information flowing effectively. To see how the nervous system is organized to accomplish this end, we will perform a series of "cuts" that will divide it into parts. In many instances, the parts will be cut once again. Figure 3.8 presents an organizational chart that shows the relationships of all the parts of the nervous system.

Figure 3.8
Organization of the human nervous system. The central nervous system is composed mostly of the brain, which is traditionally divided into three regions: the hindbrain, the midbrain, and the forebrain. All three areas control vital functions, but it's the highly developed forebrain that differentiates humans from lower animals. The reticular formation runs through both the midbrain and hindbrain on its way up and down the brainstem. These and other parts of the brain are discussed in detail later in the chapter. The peripheral nervous system is made up of the somatic nervous system, which controls voluntary muscles and sensory receptors, and the autonomic nervous system, which controls smooth muscles, blood vessels, and glands.



The Peripheral Nervous System

The first and most important cut separates the *central nervous system* (the brain and spinal cord) from the *peripheral nervous system* (see Figure 3.9). The *peripheral nervous system* is made up of all those nerves that lie outside the brain and spinal cord. *Nerves* are bundles of neuron fibers (axons) that are routed together in the peripheral nervous system. This portion of the nervous system is just what it sounds like, the part that extends to the periphery (the outside) of the body. The peripheral nervous system can be subdivided into the *somatic nervous system* and the *autonomic nervous system*.

The Somatic Nervous System

The *somatic nervous system* is made up of nerves that connect to voluntary skeletal muscles and to sensory receptors. These nerves are the cables that carry information from receptors in the skin, muscles, and joints to the central nervous system and that carry commands from the CNS to the muscles. These functions require two kinds of nerve fibers. *Afferent nerve fibers* are axons that carry information inward to the central nervous system from the periphery of the body. *Efferent nerve fibers* are axons that carry information outward from the central nervous system to the periphery of the body. Each body nerve contains many axons of each type. Thus, somatic nerves are “two-way streets” with incoming (afferent) and outgoing (efferent) lanes. The somatic nervous system lets you feel the world and move around in it.

The Autonomic Nervous System

The *autonomic nervous system (ANS)* is made up of nerves that connect to the heart, blood vessels, smooth muscles, and glands. As its name hints, the autonomic system is a separate (autonomous) system, although it is ultimately controlled by the central nervous system. The autonomic nervous system controls automatic, involuntary, visceral functions that people don’t normally think about, such as heart rate, digestion, and perspiration.

The autonomic nervous system mediates much of the physiological arousal that occurs when people experience emotions. For example, imagine that you are walking home alone one night when a seedy-looking character falls in behind you and begins to follow you. If you feel threatened, your heart rate and breathing will speed up. Your blood pressure may surge, you may get goose bumps, and your palms may begin to sweat. These difficult-to-

control reactions are aspects of autonomic arousal.

Walter Cannon (1932), one of the first psychologists to study this reaction, called it the *fight-or-flight response*. Cannon carefully monitored this response in cats—after confronting them with dogs. He concluded that organisms generally respond to threat by preparing physically for attacking (fight) or fleeing (flight) from the enemy. Unfortunately, as you will see in Chapter 13, this fight-or-flight response can backfire if stress leaves a person in a chronic state of autonomic arousal. Prolonged autonomic arousal can eventually contribute to the development of physical diseases (Selye, 1974).

The autonomic nervous system can be subdivided into two branches: the sympathetic division and the parasympathetic division (see Figure 3.10 on the next page). The *sympathetic division* is the branch of the autonomic nervous system that mobilizes the body’s resources for emergencies. It creates the fight-or-flight response. Activation of the sympathetic division slows digestive processes and drains blood from the periphery, lessening bleeding in the case of an injury. Key sympathetic nerves send signals to the adrenal glands, triggering the release of hormones that ready the body for exertion. In contrast, the *parasympathetic division* is the branch of the autonomic nervous system that generally conserves bodily resources. It activates processes that allow the body to save and store energy. For example, actions by parasympathetic nerves slow heart rate, reduce blood pressure, and promote digestion.

The Central Nervous System

The central nervous system is the portion of the nervous system that lies within the skull and spinal column. Thus, the *central nervous system (CNS)* consists of the brain and the spinal cord. It is protected by enclosing sheaths called the *meninges* (hence *meningitis*, the name for the disease in which the meninges become inflamed).

In addition, the central nervous system is bathed in its own special nutritive “soup,” the cerebrospinal fluid (see Figure 3.11 on the next page). This fluid nourishes the brain and provides a protective cushion for it. Although derived from the blood, the CSF is carefully filtered. To enter the CSF, substances in the blood have to cross the *blood-brain barrier*, a semipermeable membrane-like mechanism that stops some chemicals from passing between the bloodstream and the brain. This barrier prevents some drugs from entering the CSF and affecting the brain.



Figure 3.9
The central and peripheral nervous systems. The human nervous system is divided into the central nervous system, which consists of the brain and the spinal cord, and the peripheral nervous system, which consists of the remaining nerves that fan out throughout the body.

Figure 3.10
The autonomic nervous system (ANS). The ANS is composed of the nerves that connect to the heart, blood vessels, smooth muscles, and glands. The ANS is divided into the sympathetic division, which mobilizes bodily resources in times of need, and the parasympathetic division, which conserves bodily resources. Some of the key functions controlled by each division of the ANS are summarized in the diagram.

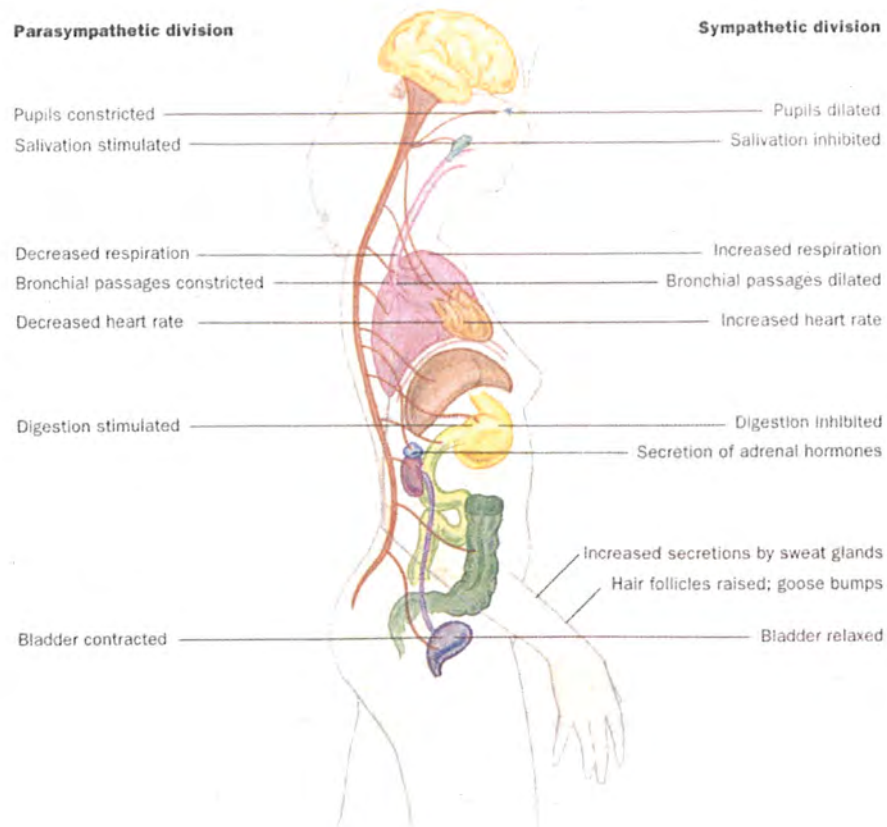
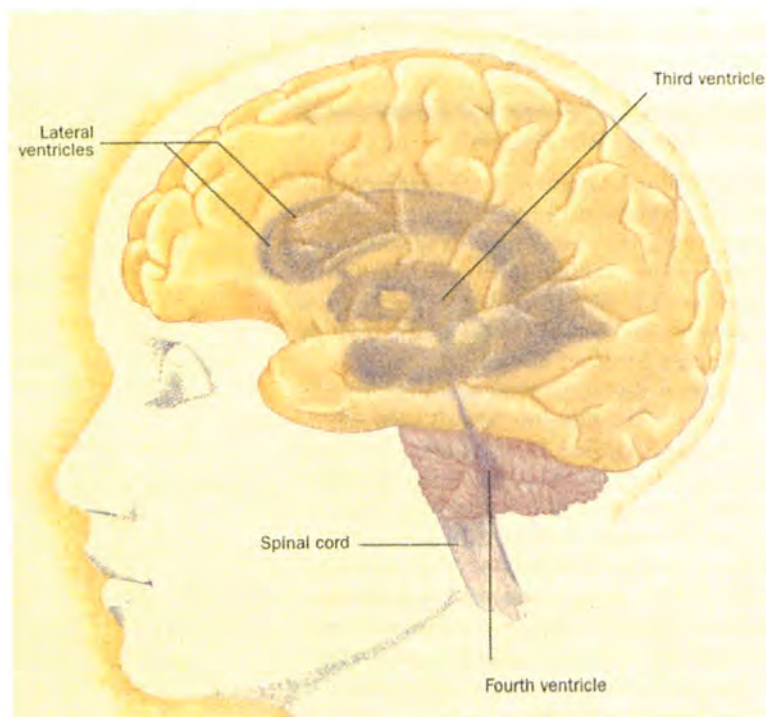


Figure 3.11
The ventricles of the brain. Cerebrospinal fluid (CSF) circulates around the brain and the spinal cord. The hollow cavities in the brain filled with CSF are called ventricles. The four ventricles in the human brain are depicted here.



The Spinal Cord

The *spinal cord* connects the brain to the rest of the body through the peripheral nervous system. Although the spinal cord looks like a cable from which the somatic nerves branch, it is part of the central nervous system. Like the brain, it is enclosed by the meninges and bathed in CSF. In short, the spinal cord is an extension of the brain.

The spinal cord runs from the base of the brain to just below the level of the waist. It houses bundles of axons that carry the brain's commands to peripheral nerves and that relay sensations from the periphery of the body to the brain. Many forms of paralysis result from spinal cord damage, a fact that underscores the critical role the spinal cord plays in transmitting signals from the brain to the motor neurons that move the body's muscles.

The Brain

The crowning glory of the central nervous system is, of course, the *brain*. Anatomically, the brain is the part of the central nervous system that fills the upper portion of the skull. Although it weighs only about three pounds and could be held in one hand,

the brain contains billions of interacting cells that integrate information from inside and outside the body, coordinate the body's actions, and enable us to talk, think, remember, plan, create, and dream.

Because of its central importance for behavior, the brain is the subject of the next three sections of the chapter. We begin by looking at the remarkable methods that have enabled researchers to unlock some of the brain's secrets.

LOOKING INSIDE THE BRAIN: RESEARCH METHODS

Scientists who want to find out how parts of the brain are related to behavior are faced with a formidable task. The geography, or *structure*, of the brain can be mapped out relatively easily by examining and dissecting brains removed from animals or from deceased humans who have donated their bodies to science. Mapping out brain *function*, however, requires a working brain. Thus, special research methods are needed to discover relations between brain activity and behavior.

Investigators who conduct research on the brain or other parts of the nervous system are called *neuroscientists*. Often, such research involves collaboration by neuroscientists from several disciplines, including anatomy, physiology, biology, pharmacology, neurology, neurosurgery, psychiatry, and psychology. Neuroscientists use many specialized techniques to investigate connections between the brain and behavior. Among the methods they have depended on most heavily are electrical recordings, lesioning, and electrical stimulation. In addition, new brain-imaging techniques have recently been developed that may eventually revolutionize brain research.

Electrical Recordings

The electrical activity of the brain can be recorded, much as Hodgkin and Huxley recorded the electrical activity of individual neurons. Recordings of single cells in the brain have proven valuable, but scientists also need ways to record the simultaneous activity of many of the billions of neurons in the brain. Fortunately, in 1929 a German psychiatrist named Hans Berger invented a machine that could record broad patterns of brain electrical activity. The *electroencephalograph (EEG)* is a device that monitors the electrical activity of the brain over time by means of recording electrodes attached to the surface of the scalp (see Figure 3.12). An EEG electrode sums and amplifies electric potentials occurring in many thousands of brain cells.



Figure 3.12
The electroencephalograph (EEG). Recording electrodes attached to the surface of the scalp permit the EEG to record the brain's electrical activity over time. The EEG provides output in the form of line tracings called brain waves. Brain waves vary in frequency (cycles per second) and amplitude (measured in voltage). Various states of consciousness are associated with different brain waves. Characteristic EEG patterns for alert wakefulness, drowsiness, and deep, dreamless sleep are shown here. The use of the EEG in research is discussed in more detail in Chapter 5.

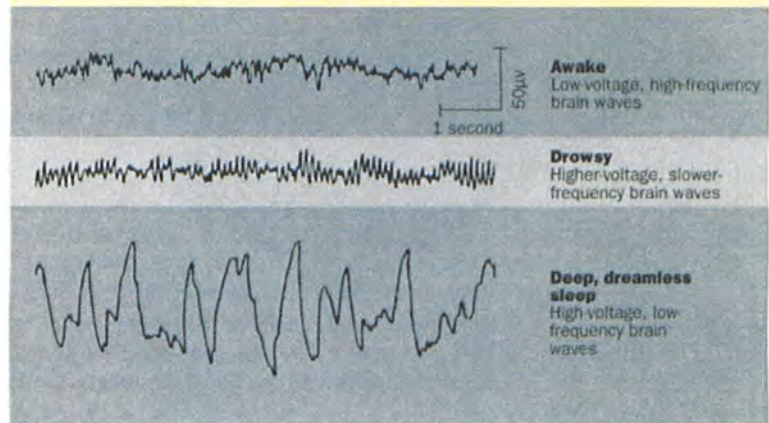
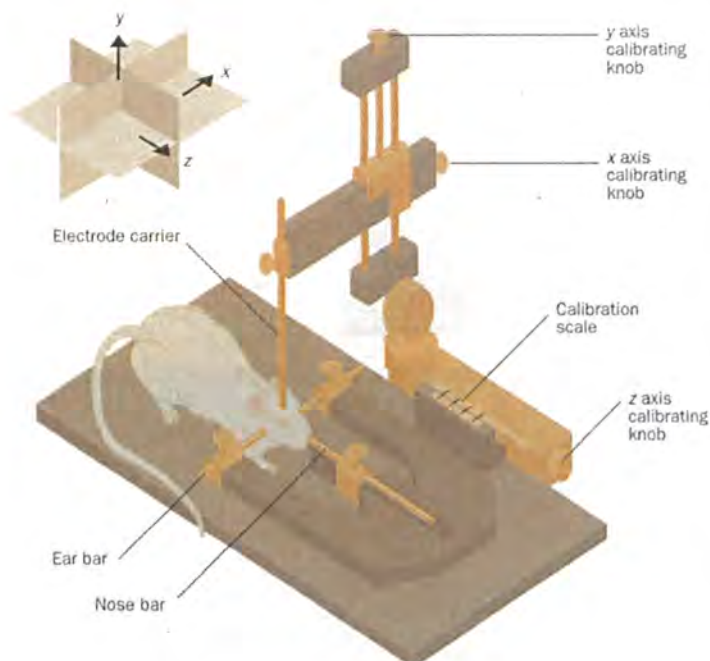


Figure 3.13
An anesthetized rat in a stereotaxic instrument.
 This rat is undergoing brain surgery. After consulting a detailed map of the rat brain, researchers use the control knobs on the apparatus to position an electrode along the three axes (x, y, and z) shown in the upper left corner. This precise positioning allows researchers to implant the electrode in an exact location in the rat's brain.



Usually, six to ten recording electrodes are attached (with paste) at various places on the skull. The resulting EEG recordings are translated into line tracings, commonly called *brain waves*. These brain-wave recordings provide a useful overview of the electrical activity in the brain. Different brain-wave patterns are associated with different states of mental activity (Martin, 1991), as shown in Figure 3.12. The EEG is often used in the clinical diagnosis of brain damage and neurological disorders. In research applications, the EEG can be used to identify patterns of brain activity that occur when subjects engage in specific behaviors, ranging from daydreaming to working on math problems. One recent study even found a correlation between EEG patterns and personality (Jones & Fox, 1992). As you'll see in Chapter 5, the EEG has been invaluable to researchers exploring the physiology of sleep.

Lesioning

Brain tumors, strokes, head injuries, and other misfortunes often produce brain damage in people. Many major insights about brain-behavior rela-

tions have resulted from observations of behavioral changes in people who have suffered damage in specific brain areas (H. Gardner, 1975). However, this type of research has its limitations. Subjects are not plentiful, and neuroscientists can't control the location or severity of their subjects' brain damage. Furthermore, variations in the subjects' histories create a host of extraneous variables that make it difficult to isolate cause-and-effect relationships between brain damage and behavior.

To study the relations between brain and behavior more precisely, scientists sometimes observe what happens when specific brain structures in animals are purposely disabled. **Lesioning** involves destroying a piece of the brain. This is typically done by inserting an electrode into a brain structure and passing a high-frequency electric current through it to burn the tissue and disable the structure.

Lesioning requires researchers to get an electrode to a particular place buried deep inside the brain. They do so with a **stereotaxic instrument**, a device used to implant electrodes at precise locations in the brain. The use of this surgical device is described in Figure 3.13. Of course, appropriate anesthetics are used to minimize pain and discomfort for the animals. The lesioning of brain structures in animals has proven invaluable in neuroscientists' research on brain functioning.

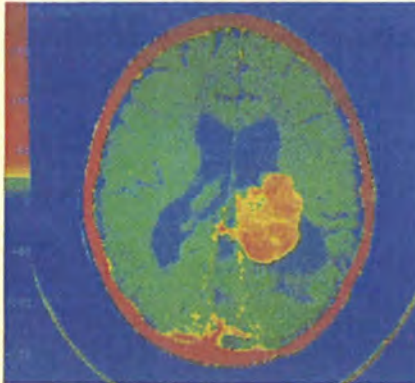
Electrical Stimulation of the Brain

Electrical stimulation of the brain (ESB) involves sending a weak electric current into a brain structure to stimulate (activate) it. The current is delivered through an electrode, but the current is different from that used in lesioning. This sort of electrical stimulation does not exactly duplicate normal electrical signals in the brain. However, it is usually a close enough approximation to activate the brain structures in which the electrodes are lodged. If areas deep within the brain are to be stimulated, the electrodes are implanted with the same stereotaxic techniques used in lesioning procedures.

Most ESB research is conducted with animals. However, ESB is occasionally used on humans in the context of brain surgery required for medical purposes. After a patient's skull is opened, the surgeons may stimulate areas to map the individual patient's brain (to some extent, each of us is unique), so that they don't slice through critical areas. The patient is awake and describes the feelings pro-

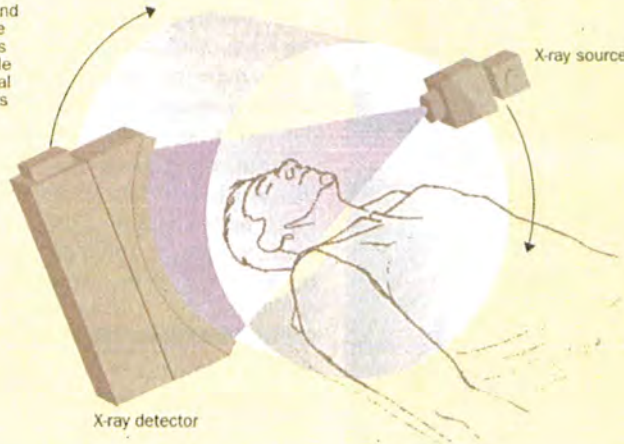


(a) The patient's head is positioned in a large cylinder, as shown here.



(c) A computer combines X rays to create an image of a horizontal slice of the brain. This scan shows a tumor (in red) on the right.

(b) An X-ray beam and X-ray detector rotate around the patient's head, taking multiple X rays of a horizontal slice of the patient's brain.



duced by each stimulation. As various areas are stimulated, the patient reports visual sensations, muscular twitches, memories, and so forth.

What is the patient doing awake in the midst of major surgery? This procedure is not unusual. Neurosurgeons often prefer their patients to be awake to provide feedback, which can have enormous diagnostic value. Hence, they use only a local anesthetic to prevent pain as they open the patient's skull. The electrical stimulations of the brain are not painful, because brain tissue has no pain receptors.

Brain-Imaging Procedures

In recent years, the invention of new brain-imaging devices has led to spectacular advances in science's ability to look into the brain. Unfortunately, the use of most of these devices is prohibitively expensive, so their availability for research purposes is limited. Even medical use of these devices is judi-

cious. However, this new technology is gradually opening new horizons in brain research.

The *CT (computerized tomography) scan* is a computer-enhanced X ray of brain structure. Multiple X rays are shot from many angles, and the computer combines the readings to create a vivid image of a horizontal slice of the brain (see Figure 3.14). The entire brain can be visualized by assembling a series of images representing successive slices of the brain. Of the new brain-imaging techniques, the CT scan is the least expensive and thus the most widely used in research. For example, many researchers have used CT scans to look for abnormalities in brain structure among people suffering from specific types of mental illness (Andreassen, 1988).

In research on how brain and behavior are related, *PET (positron emission tomography) scans* may prove especially valuable. CT scans can portray only brain *structure*. PET scans can map actual *activity* in the brain over time. PET scans

Figure 3.14
CT technology. CT scans are widely used in research to examine aspects of brain structure. They provide computer-enhanced X rays of horizontal slices of the brain.

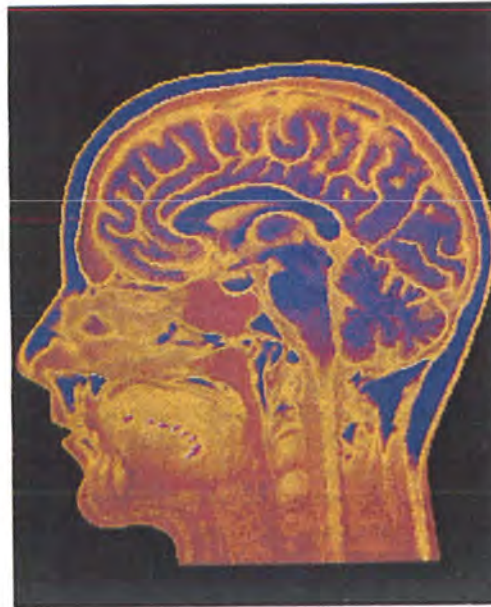
Figure 3.15

PET scans. PET scans are used to map brain activity rather than brain structure. They provide color-coded maps that show areas of high activity in the brain over time. The PET scan shown here pinpointed three areas of high activity (indicated by the color yellow) when a subject worked on a language task.



Figure 3.16

MRI scans. MRI scans can be used to produce remarkably high-resolution pictures of brain structure. A vertical view of the left side of a woman's brain is shown here.



take advantage of the fact that the brain “runs on sugar.” That is, it replenishes its energy supply by burning sugar with oxygen. With PET scans, radioactively tagged sugars are introduced into the brain. They serve as markers of metabolic activity in the brain, which can be monitored with X rays. As brain cells are used in moving, planning, and thinking, the more active cells burn up more of the radioactively tagged sugars. Thus, a PET scan can provide a color-coded map indicating which areas of the brain become ac-

tive when subjects clench their fist, sing, or contemplate the mysteries of the universe (see Figure 3.15). In this way, neuroscientists are using PET scans to better pinpoint the brain areas that handle various types of mental activities (Posner et al., 1988). Because PET scans monitor chemical processes, they can also be used to study the activity of specific neurotransmitters (Buchsbaum, 1986). For example, PET scans have helped researchers map the locations of dopamine synapses in the human brain. Research with PET scans has given neuroscientists a new appreciation of the complexity and interdependence of brain organization. The opportunity to look at ongoing brain function has revealed that even simple, routine mental operations depend on coordinated activation of several or more areas in the brain (Volkow & Tancredi, 1991).

The more recently developed *MRI (magnetic resonance imaging) scan* uses magnetic fields, radio waves, and computerized enhancement to map out brain structure and brain function (Martin, Brust, & Hilal, 1991). MRI scans provide much better images of brain structure than CT scans, producing three-dimensional pictures of the brain that have remarkably high resolution (see Figure 3.16). Unfortunately, this technology is very new and very expensive (the initial cost of an MRI scanner is \$1–\$3 million). Thus far, relatively little behavioral research has been done with the small number of MRI scanners available (Andreassen, 1988). However, MRI technology has enormous potential in behavioral research. For example, one recent study (Suddath et al., 1990) has provided compelling new evidence that there may be an association between enlarged ventricles (the hollow, fluid-filled cavities) in the brain and schizophrenic disturbance. Previous CT studies had found enlarged ventricles in only about 20–25 percent of the schizophrenic persons tested (Weinberger, Wagner, & Wyatt, 1983). Critics argued that these findings were too weak and inconsistent to conclusively demonstrate a link between enlarged ventricles and schizophrenia. However, working with far more precise images from MRI scans, Suddath and associates found a much higher prevalence of enlarged ventricles in their sample of schizophrenic patients. This study highlights the exciting promise of the new brain-imaging technologies. Science depends on observation. Improvements in our ability to observe the brain should result in increased knowledge of how the brain is related to behavior.

THE BRAIN AND BEHAVIOR

Now that we have examined the techniques of brain research, let's look at what researchers have discovered about the functions of different parts of the brain.

The brain can be divided into three major regions: the hindbrain, the midbrain, and the forebrain. The principal structures found in each of these regions are listed in the organizational chart of the nervous system in Figure 3.8. You can see where these regions are located in the brain by looking at Figure 3.17 (on the next page). They can be found easily in relation to the *brainstem*. The brainstem looks like its name—it appears to be a stem from which the rest of the brain “flowers,” like a head of cauliflower. At its lower end it is contiguous with the spinal cord. At its higher end it lies deep within the brain.

We'll begin at the brain's lower end, where the spinal cord joins the brainstem. As we proceed upward, notice how the functions of brain structures go from the regulation of basic bodily processes to the control of “higher” mental processes.

The Hindbrain

The *hindbrain* includes the cerebellum and two structures found in the lower part of the brainstem: the medulla and the pons. The *medulla*, which attaches to the spinal cord, has charge of largely unconscious but essential functions, such as breathing, maintaining muscle tone, and regulating circulation. The *pons* (literally “bridge”) includes a bridge of fibers that connects the brainstem with the cerebellum. The pons also contains several clusters of cell bodies involved with sleep and arousal.

The *cerebellum* (literally “little brain”) is a relatively large and deeply folded structure located adjacent to the back surface of the brainstem. The cerebellum is critical to the coordination of movement and to the sense of equilibrium, or physical balance (Ghez, 1991). Although the actual commands for muscular movements come from higher brain centers, the cerebellum plays a key role in the execution of these commands. It is your cerebellum that allows you to hold your hand out to the side and then smoothly bring your finger to a stop on your nose. This is a useful roadside test for drunken driving because the cerebellum is one of the structures first depressed by alcohol. Damage to the

cerebellum disrupts fine motor skills, such as those involved in writing, typing, or playing tennis.

The Midbrain

The *midbrain* is the segment of the brainstem that lies between the hindbrain and the forebrain. The midbrain is concerned with certain sensory processes, such as locating where things are in space. For instance, when a sound triggers a reflexive turning of the head, an area in the midbrain is at work (Middlebrooks & Knudsen, 1984). An important system of dopamine-releasing neurons that projects into various higher brain centers originates in the midbrain. Among other things, this dopamine system is involved in the performance of voluntary movements. The decline in dopamine synthesis that causes Parkinsonism is due to degeneration of a structure located in the midbrain (Coté & Crutcher, 1991).

Running through both the hindbrain and the midbrain is the *reticular formation*. Lying at the central core of the brainstem, the reticular formation contributes to the modulation of muscle reflexes, breathing, and pain perception (Role & Kelly, 1991). It is best known, however, for its role in the regulation of sleep and wakefulness. Activity in the ascending fibers of the reticular formation is essential to maintaining an alert brain (Steriade et al., 1980). Indeed, damage to this area can cause a coma.

The Forebrain

The *forebrain* is the largest and most complex region of the brain, encompassing a variety of structures, including the thalamus, hypothalamus, limbic system, and cerebrum. This list is not exhaustive, and some of these structures have their own subdivisions, as you can see in the organizational chart of the nervous system (Figure 3.8). The thalamus, hypothalamus, and limbic system form the core of the forebrain. All three structures are located near the top of the brainstem. Above them is the *cerebrum*—the seat of complex thought. This relatively large structure may contain 70 percent of the neurons in the CNS. The wrinkled surface of the cerebrum is the *cerebral cortex*—the outer layer of the brain, the part that looks like a cauliflower.

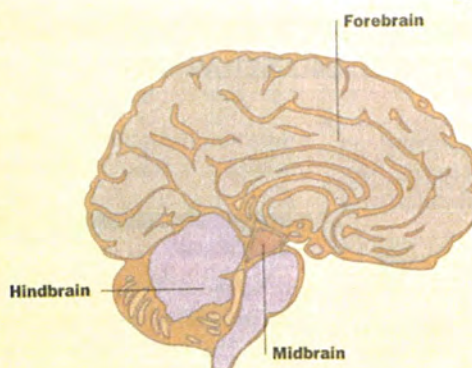
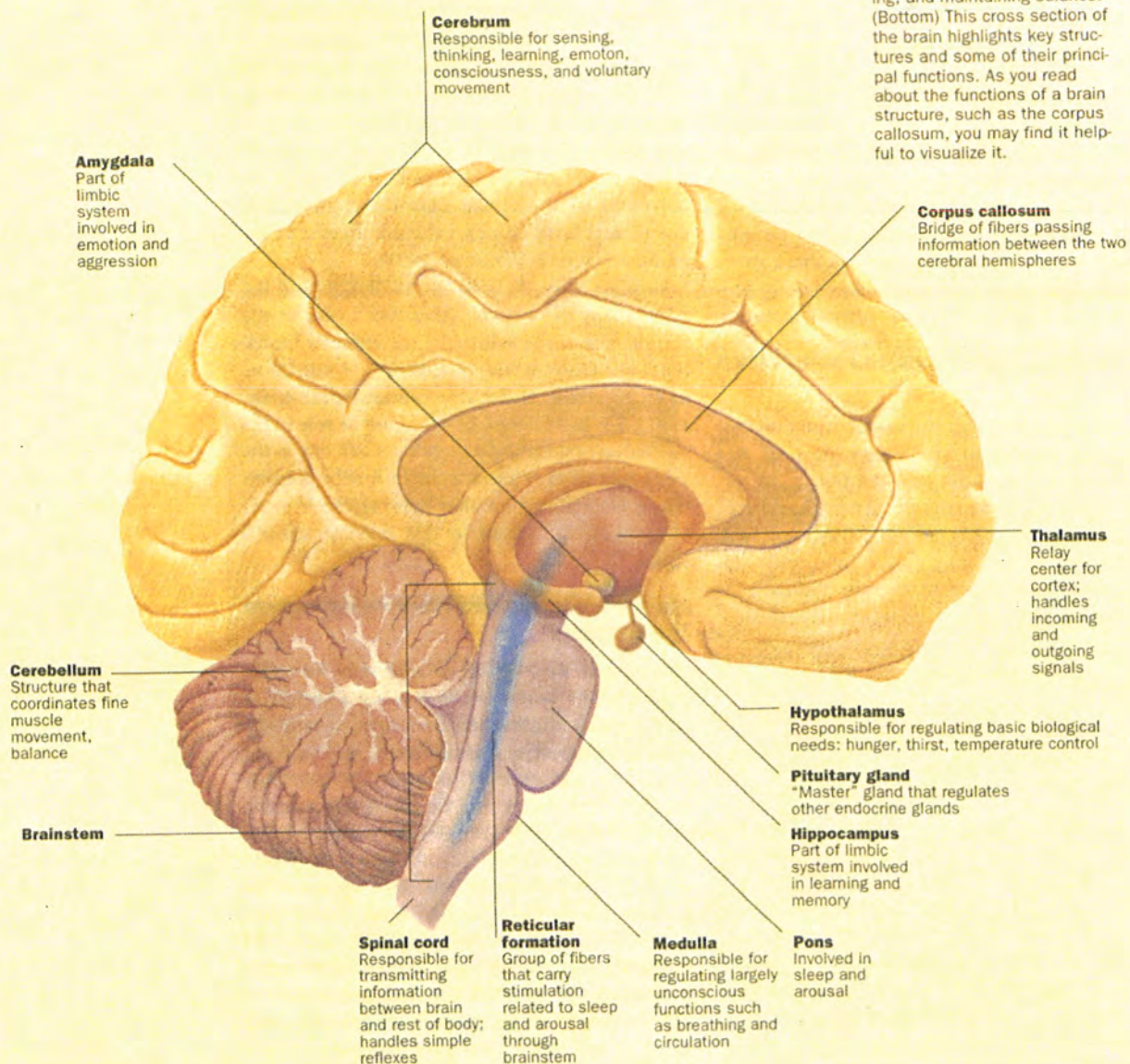


Figure 3.17.

Structures and areas in the human brain.

(Top left) This photo of a human brain shows many of the structures discussed in this chapter. (Top right) The brain is divided into three major areas: the hindbrain, midbrain, and forebrain. These subdivisions actually make more sense for animals' brains than for humans' brains. In humans, the forebrain has become so large it makes the other two divisions look trivial. However, the hindbrain and midbrain aren't trivial; they control such vital functions as breathing, waking, remembering, and maintaining balance. (Bottom) This cross section of the brain highlights key structures and some of their principal functions. As you read about the functions of a brain structure, such as the corpus callosum, you may find it helpful to visualize it.



The Thalamus: A Way Station

The *thalamus* is a structure in the forebrain through which all sensory information (except smell) must pass to get to the cerebral cortex. This way station is made up of a number of clusters of cell bodies, or somas. Each cluster is concerned with relaying sensory information to a particular part of the cortex. However, it would be a mistake to characterize the thalamus as nothing more than a passive relay station. The thalamus also appears to play an active role in integrating information from various senses.

The Hypothalamus: A Regulator of Biological Needs

The *hypothalamus* is a structure found near the base of the forebrain that is involved in the regulation of basic biological needs. The hypothalamus lies beneath the thalamus (*hypo* means “under,” making the hypothalamus the area under the thalamus). Although no larger than a kidney bean, the hypothalamus contains various clusters of cells that have many key functions. One such function is to control the autonomic nervous system. In addition, the hypothalamus serves as a vital link between the brain and the endocrine system (a network of hormone-producing glands, discussed later in this chapter).

The hypothalamus plays a major role in the regulation of basic biological drives related to survival, including the so-called “four F’s”: fighting, fleeing, feeding, and mating. For example, when researchers lesion the lateral areas (the sides) of the hypothalamus, animals lose interest in eating. The animals must be fed intravenously or they starve, even in the presence of abundant food. In contrast, when electrical stimulation (ESB) is used to activate the lateral hypothalamus, animals eat constantly and gain weight rapidly (Grossman et al., 1978; Keesey & Powley, 1975). Does this mean that the lateral hypothalamus is the “hunger center” in the brain? Not necessarily. The regulation of hunger turns out to be complex and multifaceted, as you’ll see in Chapter 10. Nonetheless, the hypothalamus clearly contributes to the control of hunger and other basic biological processes, including thirst, sex drive, and temperature regulation (Kupfermann, 1991).

The Limbic System: The Seat of Emotion

The *limbic system* is a loosely connected network of structures located roughly along the border between the cerebral cortex and deeper subcortical areas (hence the term *limbic*, which means

“edge”). First described by Paul MacLean (1954), the limbic system is *not* a well-defined anatomical system with clear boundaries. Indeed, scientists disagree about which structures should be included in the limbic system. Broadly defined, the limbic system includes parts of the thalamus and hypothalamus, the *hippocampus*, the *amygdala*, the *septum*, and other structures shown in Figure 3.18 (on the next page). The limbic system is involved in the regulation of emotion, memory, and motivation.

The hippocampus appears to play a role in the formation of memories (Berger, 1984). Consistent with this notion is the fact that it is significantly damaged in patients suffering from Alzheimer’s disease (Hyman et al., 1984). However, many other brain structures contribute to memory processes, and the exact role of the hippocampus is not yet fully understood.

Similarly, there is ample evidence linking the limbic system to the experience of emotion, but the exact mechanisms of control are not yet well understood (Pridmore, 1981). The limbic system is one of the areas in the brain that appear to contain emotion-tinged “pleasure centers.” This intriguing possibility first surfaced, quite by chance, in brain stimulation research with rats. James Olds and Peter Milner (1954) accidentally discovered that a rat would press a lever repeatedly to send brief bursts of electrical stimulation to a specific spot in its brain where an electrode was implanted (see Figure 3.19 on the next page). They thought that they had inserted the electrode in the rat’s reticular formation. However, they learned later that the electrode had been bent during implantation and ended up elsewhere (probably in the hypothalamus). Much to their surprise, the rat kept coming back for more self-stimulation in this area. Subsequent studies showed that rats and monkeys would press a lever *thousands of times per hour* to stimulate certain brain sites. Although the experimenters obviously couldn’t ask the animals about it, they *inferred* that the animals were experiencing some sort of pleasure.

Brain surgery cases have afforded neuroscientists a few opportunities to probe for similar pleasure centers in human subjects. Since they’re often conscious during brain surgery, human subjects can be asked about their feelings, and electrically activated pleasure centers have indeed been found in humans (Delgado, 1969; Heath, 1964). However, the emotional reactions in humans have not been as strong as anticipated, given the ferocious way laboratory animals work to earn stimulation of pleasure centers (Valenstein, 1973).

Figure 3.18

The limbic system. The limbic system is a network of interconnected structures that play a role in emotion, motivation, memory, and many other aspects of behavior. These structures fall mostly along the border between the cortex and deeper, subcortical structures.

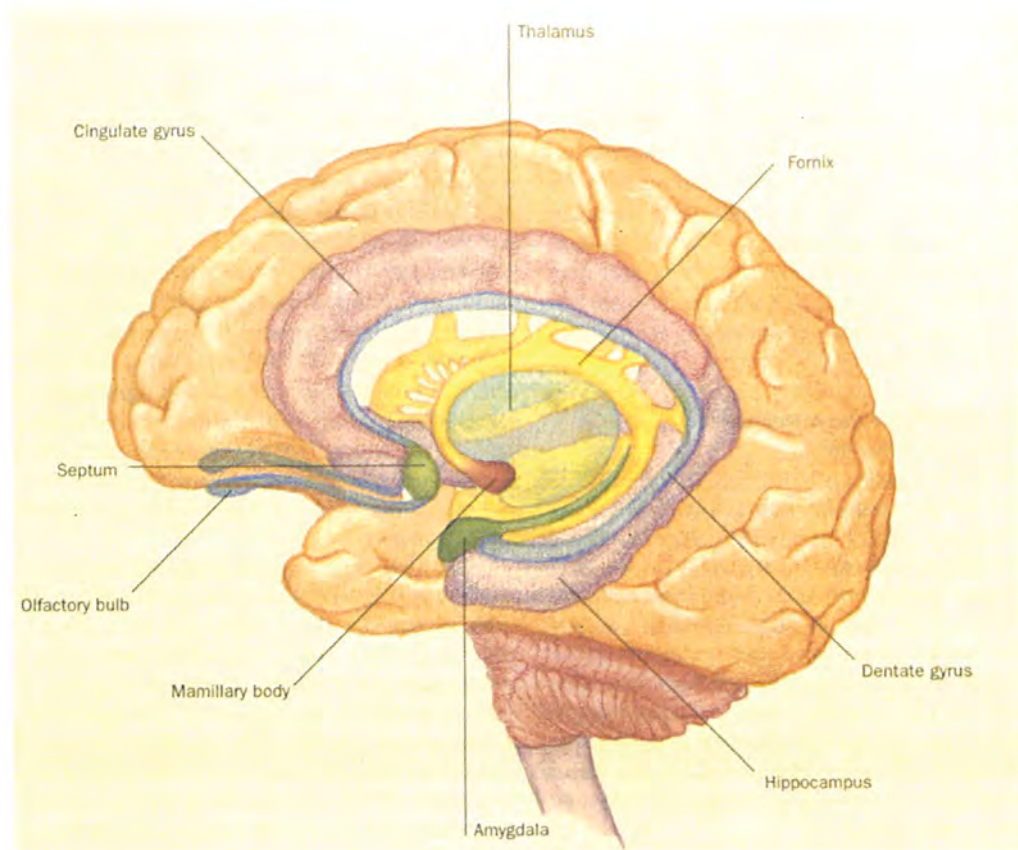
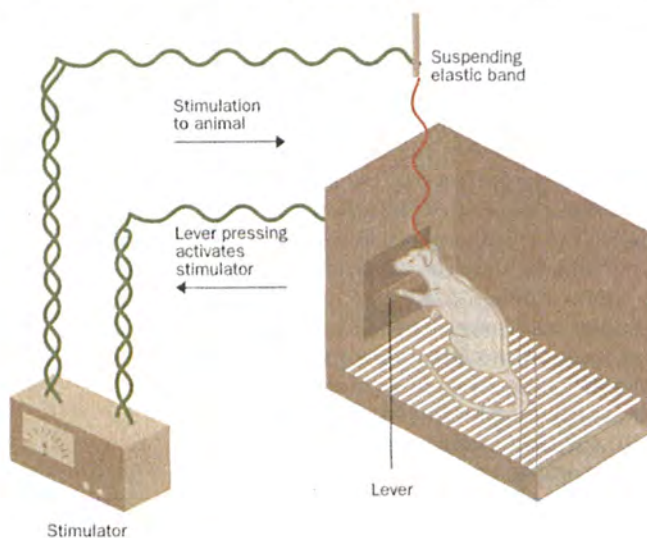


Figure 3.19

Electrical stimulation of the brain (ESB) in the rat.

Olds and Milner (1954) were using an apparatus like that depicted here when they discovered self-stimulation centers, or "pleasure centers," in the brain of a rat. In this setup, the rat's lever pressing earns brief electrical stimulation that is sent to a specific spot in the rat's brain where an electrode has been implanted.



Where are the pleasure centers located in the brain? Many self-stimulation sites have been found in the limbic system (Olds & Fobes, 1981). The heaviest concentration appears to be where the *medial forebrain bundle* (a bundle of axons) passes through the hypothalamus. The medial forebrain

bundle is rich in dopamine-releasing neurons. The rewarding effects of ESB at self-stimulation sites may be largely mediated by the activation of these dopamine circuits (Wise & Rompre, 1989). The rewarding, pleasurable effects of opiate and stimulant drugs (cocaine and amphetamines) may also depend on excitation of this dopamine system (Wise & Bozarth, 1987). Theorists caution that this dopamine system is *not* the ultimate biological basis for *all* reward (the brain is never that simple). Nonetheless, recent evidence suggests that the brain's "pleasure centers" may not be anatomical centers so much as neuron circuits using dopamine.

The Cerebrum: The Seat of Complex Thought

The *cerebrum* is the largest and most complex part of the human brain. It includes the brain areas that are responsible for our most complex mental activities, including learning, remembering, thinking, and consciousness itself. The *cerebral cortex* is the convoluted outer layer of the cerebrum. The cortex is folded and bent, so that its large surface area—about 1.5 square feet—can be packed into the limited volume of the skull (Hubel & Wiesel, 1979).

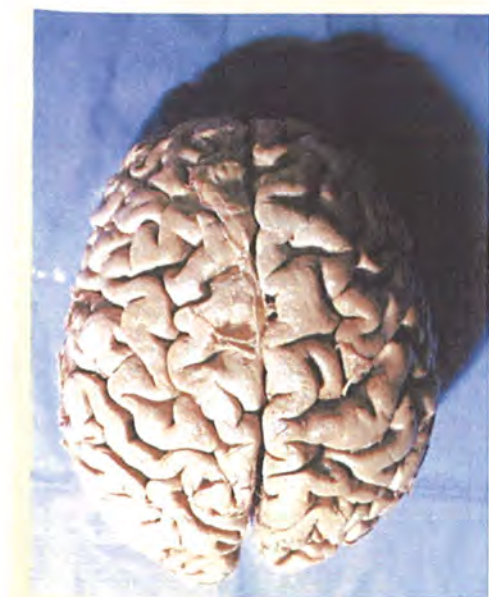


Figure 3.20
The cerebral hemispheres and the corpus callosum. (Left) As this photo shows, the longitudinal fissure running down the middle of the brain (viewed from above) separates the left and right halves of the cerebral cortex. (Right) In this drawing the cerebral hemispheres have been “pulled apart” to reveal the corpus callosum. This band of fibers is the communication bridge between the right and left halves of the human brain.

The cerebrum is divided into two halves called hemispheres. Hence, **the cerebral hemispheres are the right and left halves of the cerebrum** (see Figure 3.20). The hemispheres are separated in the center of the brain by a longitudinal fissure that runs from the front to the back of the brain. This fissure descends to a thick band of fibers called the *corpus callosum* (also shown in Figure 3.20). **The corpus callosum is the structure that connects the two cerebral hemispheres.** We'll discuss the functional specialization of the cerebral hemispheres in the next section of this chapter.

Each cerebral hemisphere is divided into four parts called *lobes*, more for our convenience than because there really are four distinct pieces. To some extent, each of these lobes is dedicated to specific purposes. The location of these lobes can be seen in Figure 3.21 (on the next page).

The *occipital lobe*, at the back of the head, includes the cortical area, where most visual signals are sent and visual processing is begun. This area is called the *primary visual cortex*. We will discuss how it is organized in Chapter 4.

The *parietal lobe* is forward of the occipital lobe. It includes the area that registers the sense of touch, called the *primary somatosensory cortex*. Various sections of this area receive signals from different regions of the body. When ESB is delivered in these parietal lobe areas, people report physical sensations—as if someone actually touched them on the arm or cheek, for example. The parietal lobe is also

involved in integrating visual input and in monitoring the body's position in space.

The *temporal lobe* (meaning “near the temples”) lies below the parietal lobe. Near its top, the temporal lobe contains an area devoted to auditory processing, called the *primary auditory cortex*. As we will see momentarily, damage to an area in the temporal lobe on the left side of the brain can impair the comprehension of speech and language.

Continuing forward, we find the *frontal lobe*, the largest lobe in the human brain. It contains the principal areas that control the movement of muscles, called the *primary motor cortex*. ESB applied in these areas can cause actual muscle contractions. The amount of motor cortex allocated to the control of a body part depends not on the part's size but on the diversity and precision of its movements. Thus, more of the cortex is given to parts we have fine control over, such as fingers, lips, and the tongue. Less of the cortex is devoted to larger parts that make crude movements, such as the thighs and shoulders (see Figure 3.22 on the next page). The large portion of the frontal lobe to the front of the motor cortex is something of a mystery. It was once assumed to house the highest, most abstract intellectual functions, but this view turned out to be an oversimplification. Damage to this area of the brain can affect a remarkably diverse array of behavioral functions, ranging from basic (motor coordination) to complex (personality).

Figure 3.21

The cerebral cortex in humans. The cerebrum is divided into right and left halves, called cerebral hemispheres. This diagram provides a view of the right hemisphere. The cerebral cortex is the outer layer of the cerebrum. It can be thought of as a huge sheet of neural tissue crammed and folded into a small space. The cerebral cortex handles many "higher" intellectual functions. Each cerebral hemisphere can be divided into the four lobes shown in the diagram. Each lobe has areas that handle particular functions, such as visual processing or speech comprehension.

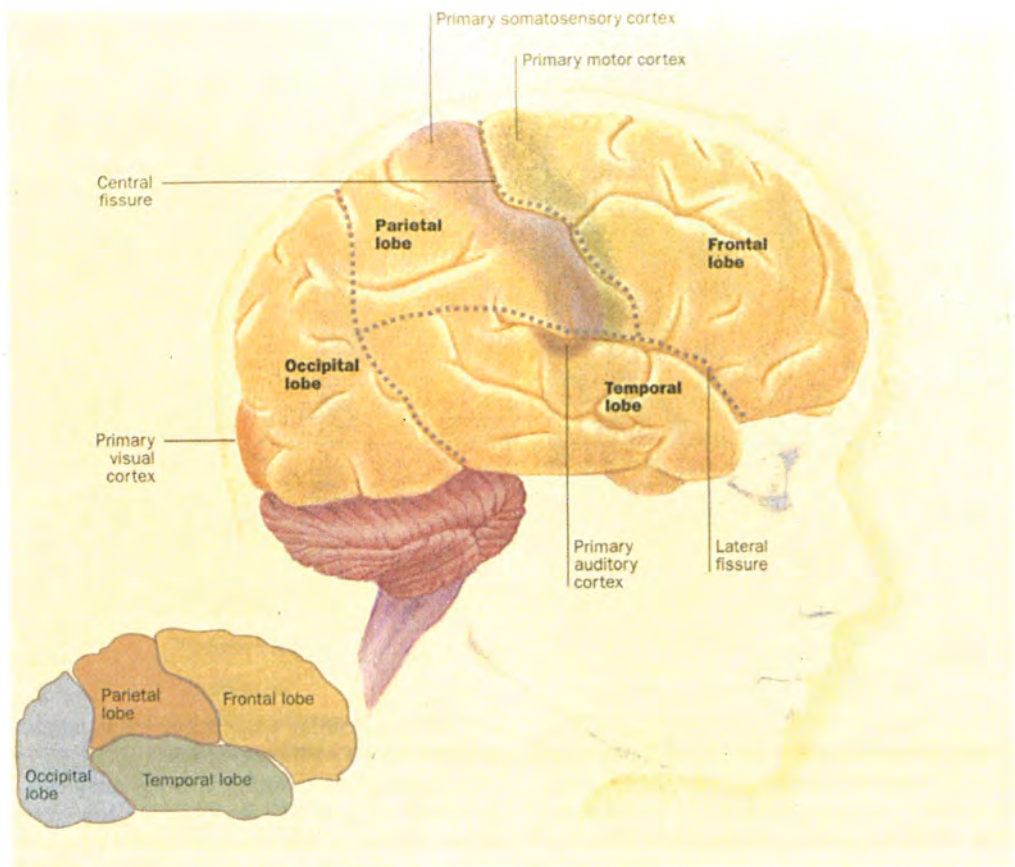
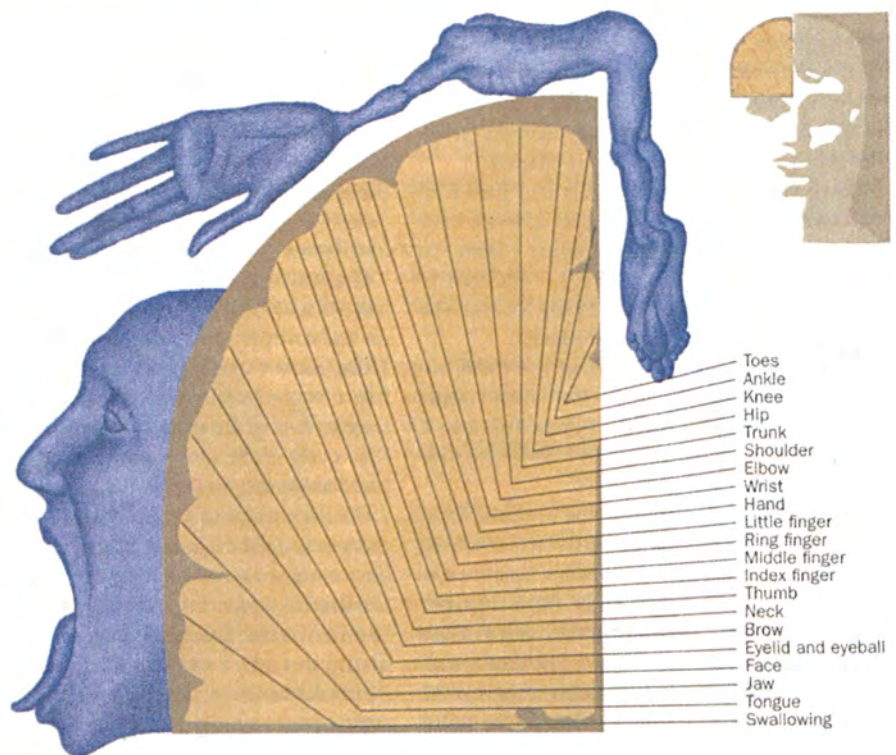


Figure 3.22

The primary motor cortex.

If we were to remove the frontal lobe from the right hemisphere of the human brain and slice off the back portion of this section, we would cut out the right half of the primary motor cortex, the area in the brain that controls the movement of muscles. This diagram shows the amount of motor cortex devoted to the control of various muscles and limbs. A greater area of cortex is devoted to muscle groups that must make relatively precise movements.



RIGHT BRAIN/LEFT BRAIN: CEREBRAL LATERALITY

As we noted a moment ago, the cerebrum—the seat of complex thought—is divided into two separate hemispheres (see Figure 3.20). In recent decades, an exciting flurry of research has focused on *cerebral laterality*—the degree to which the left or right hemisphere controls various cognitive and behavioral functions. Research on laterality has revealed that the two hemispheres have very different abilities. Indeed, some theorists have gone so far as to suggest that we really have two brains in one!

Hints of this hemispheric specialization have been available for many years, from cases in which one side of a person's brain has been damaged. The left hemisphere was implicated in the control of language as early as 1861, by Paul Broca, a French surgeon. Broca was treating a patient who had been unable to speak for 30 years. After the patient died, Broca showed that the probable cause of his speech deficit was a localized lesion on the left side of the frontal lobe. Since then, many similar cases have shown that this area of the brain—known as *Broca's area*—plays an important role in the *production* of speech (see Figure 3.23). Another major language center—*Wernicke's area*—was identified in the temporal lobe of the left hemisphere in 1874. Damage in Wernicke's area (see Figure 3.23) usually leads to problems with the *comprehension* of language.

Evidence that the left hemisphere usually processes language led scientists to characterize it as the “dominant” hemisphere. Because thoughts are usually coded in terms of language, the left hemisphere was given the lion's share of credit for handling the “higher” mental processes, such as reasoning, remembering, planning, and problem solving. Meanwhile, the right hemisphere came to be viewed as the “nondominant,” or “dumb” hemisphere, lacking any special functions or abilities.

This characterization of the left and right hemispheres as major and minor partners in the brain's work began to change in the 1960s. It all started with landmark research by Roger Sperry, Michael Gazzaniga, and their colleagues who studied “split-brain” patients: individuals whose cerebral hemispheres had been surgically disconnected (Gazzaniga, Bogen, & Sperry, 1965; Gazzaniga, 1970; Levy, Trevarthen, & Sperry, 1972; Sperry, 1982). In 1981 Sperry received a Nobel prize in physiology/medicine for this work.

Bisecting the Brain: Split-Brain Research

In *split-brain surgery* the bundle of fibers that connects the cerebral hemispheres (the corpus callosum) is cut to reduce the severity of epilep-

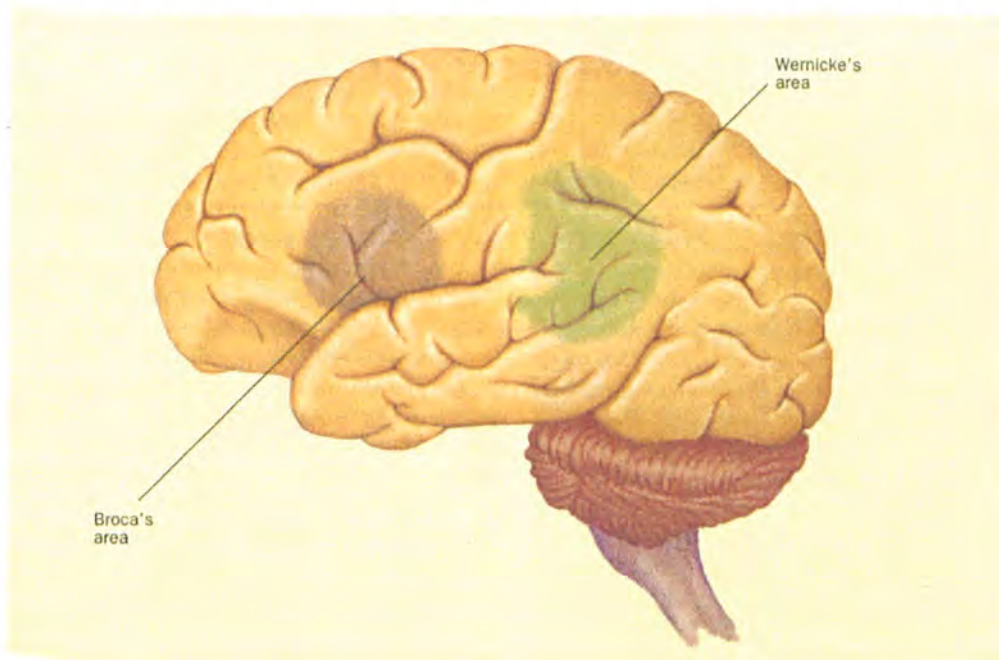
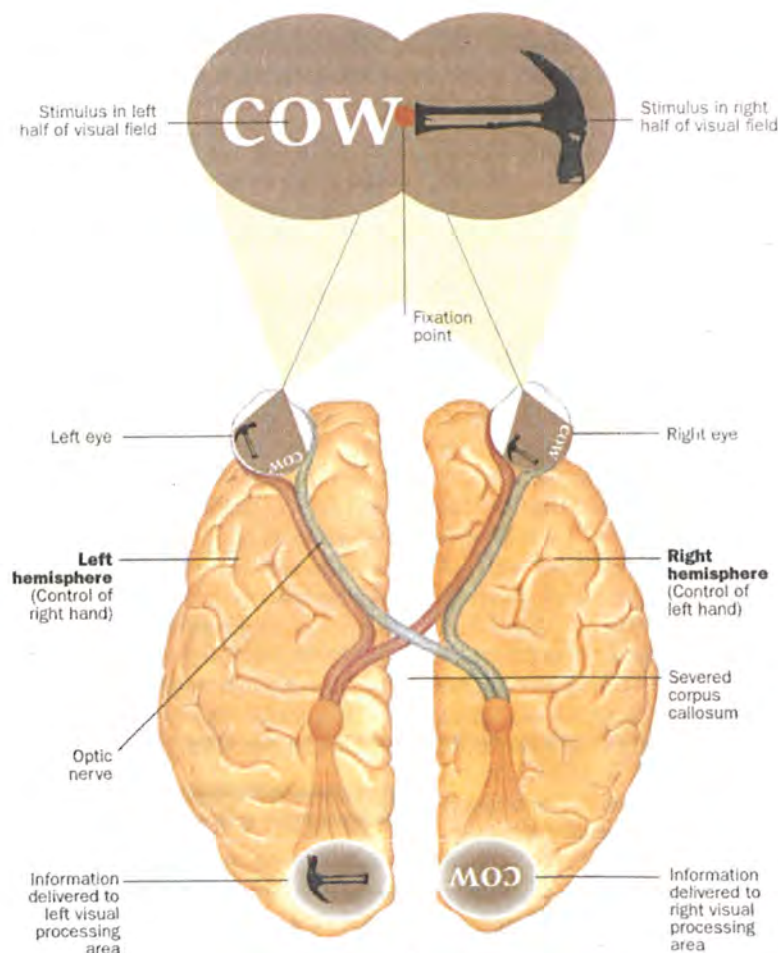


Figure 3.23
Language processing in the brain. This view of the left hemisphere highlights the location of two centers for language processing in the brain: Broca's area, which is involved in speech production, and Wernicke's area, which is involved in language comprehension.

Figure 3.24

Visual input in the split brain.

If a subject stares at a fixation point, the point divides the subject's visual field into right and left halves. Input from the right visual field strikes the left side of each eye and is transmitted to the left hemisphere. Input from the left visual field strikes the right side of each eye and is transmitted to the right hemisphere. Normally, the hemispheres share the information from the two halves of the visual field, but in split-brain patients, the corpus callosum is severed, and the two hemispheres cannot communicate. Hence, the experimenter can present a visual stimulus to just one hemisphere at a time.



tic seizures. It is a radical procedure that is chosen only in exceptional cases that have not responded to other forms of treatment. But the surgery provides scientists with an unusual opportunity to study people who have had their brain literally split in two.

To appreciate the logic of split-brain research, you need to understand how sensory and motor information is routed to and from the two hemispheres. *Each hemisphere's primary connections are to the opposite side of the body.* Thus, the left hemisphere controls, and communicates with, the right hand, right arm, right leg, right eyebrow, and so on. In contrast, the right hemisphere controls, and communicates with, the left side of the body.

Vision and hearing are more complex. Both eyes deliver information to both hemispheres, but there still is a separation of input. Stimuli in the right half of the visual field are registered by receptors on the left side of each eye, which send signals to the left hemisphere. Stimuli in the left half of the visual

field are transmitted by both eyes to the right hemisphere (see Figure 3.24). Auditory inputs to each ear also go to both hemispheres. However, connections to the opposite hemisphere are stronger or more immediate. That is, sounds presented to the right ear are registered in the left hemisphere first, while sounds presented to the left ear are registered more quickly in the right hemisphere.

For the most part, people don't notice this asymmetric, "crisscrossed" organization because the two hemispheres are in close communication with each other. Information received by one hemisphere is readily shared with the other via the corpus callosum. However, when the two hemispheres are surgically disconnected, the functional specialization of the brain becomes apparent.

In their classic study of split-brain patients, Gazzaniga, Bogen, and Sperry (1965) presented visual stimuli such as pictures, symbols, and words in a single visual field (the left or the right), so that the stimuli would be sent to only one hemisphere.



"Both the left and right hemispheres of the brain have been found to have their own specialized forms of intellect."

ROGER SPERRY



Barbara McClintock, a Nobel prize-winning geneticist, and Georgia O'Keeffe, a famed painter, exemplify the differing creative thinking of the scientist and the artist. Did the talents of each arise from a different brain hemisphere? Can people really be characterized as left-brained or right-brained? For more information, see the Application for this chapter.

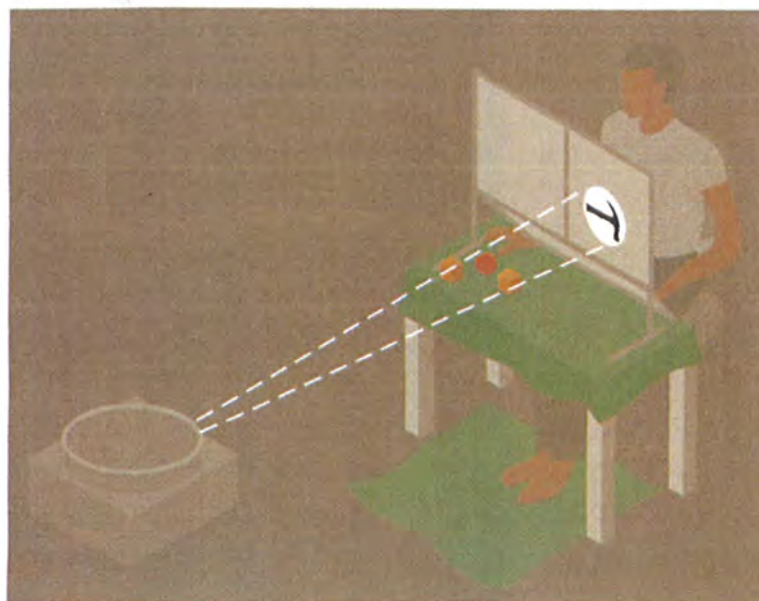
Figure 3.25
Experimental apparatus in split-brain research. On the left is a special slide projector that can present images very briefly, before the subject's eyes can move and thus change the visual field. Images are projected on one side of the screen to present stimuli to just one hemisphere. The portion of the apparatus beneath the screen is constructed to prevent subjects from seeing objects that they may be asked to handle with their right or left hand, another procedure that can be used to send information to just one hemisphere.

The stimuli were projected onto a screen in front of the subjects, who stared at a fixation point (a spot) in the center of the screen (see Figure 3.25). The images were flashed to the right or the left of the fixation point for only a split second. Thus, the subjects did not have a chance to move their eyes, and the stimuli were only glimpsed in one visual field.

When pictures were flashed in the right visual field and thus sent to the left hemisphere, the split-brain subjects were able to name and describe the objects depicted (such as a cup or spoon). However, the subjects were *not* able to name and describe the same objects when they were flashed in the left visual field and sent to the right hemisphere. In a similar fashion, an object placed out of view in the right hand (communicating with the left hemisphere) could be named. However, the same object placed in the left hand (right hemisphere) could not be. These findings supported the notion that language is housed in the left hemisphere.

Although the split-brain subjects' right hemisphere was not able to speak up for itself, further tests revealed that it *was* processing the information presented. If subjects were given an opportunity to *point out a picture* of an object they had held in their left hand, they were able to do so. They were also able to point out pictures that had been flashed to the left visual field. Furthermore, the right hemisphere (left hand) turned out to be *superior* to the left hemisphere (right hand) in assembling little

puzzles and copying drawings, even though the subjects were right-handed. These findings provided the first compelling demonstration that the right hemisphere has its own special talents. Subsequent studies of additional split-brain patients showed the right hemisphere to be better than the left on a variety of visual-spatial tasks, including discriminating colors, arranging blocks, and recognizing faces.



In the split-brain studies, the other major finding was that subjects whose hemispheres were disconnected showed signs of having two minds in one brain (Bogen, 1969). Many split-brain patients reported that sometimes each hemisphere seemed to have a mind of its own. One patient reported that if he shifted a book from his right to his left hand, it would put the book down even though he was wrapped up in it. Apparently his right hemisphere just wasn't interested in reading. Another patient reported that when he angrily reached for his wife with his left hand, his right hand darted out to stop the left. A third patient found her right and left brains competing to dress her, as they chose different clothes to wear. Sometimes her left hand would unbutton a blouse nearly as fast as her right hand buttoned it. Thus, to some extent split-brain patients experience two independent streams of consciousness.

CONCEPT CHECK 3.3

Relating Disorders to the Nervous System

Imagine that you are working as a neuropsychologist at a clinic. You are involved in the diagnosis of the cases described below. You are asked to identify the probable cause(s) of the disorders in terms of nervous system malfunctions. Based on the information in this chapter, indicate the probable location of any brain damage or the probable disturbance of neurotransmitter activity. The answers can be found in the back of the book in Appendix A.

Case 1. Mirjam is exhibiting language deficits. In particular, she does not seem to comprehend the meaning of words.

Case 2. Camille displays spastic motor coordination and is diagnosed as having Parkinsonism.

Case 3. Neal, a 72-year-old retired dockworker, has gradually seen his everyday memory deteriorate badly. Sometimes he can't even find his way home from the grocery store a few blocks away. He is diagnosed as having Alzheimer's disease.

Case 4. Wendy is highly irrational, has poor contact with reality, and reports hallucinations. She is given a diagnosis of schizophrenic disorder.

Hemispheric Specialization in the Intact Brain

The problem with the split-brain operation, of course, is that it creates an abnormal situation. The vast majority of us remain "neurologically intact." Moreover, the surgery is done only with people who suffer from prolonged, severe cases of epilepsy. These people may have had somewhat atypical brain organization even before the operation. Thus, theorists couldn't help wondering whether it was safe to generalize broadly from the split-brain studies. For this reason, researchers developed methods that allowed them to study cerebral specialization in the intact brain.

One method involves looking at *perceptual asymmetries*—left-right imbalances between the cerebral hemispheres in the speed of visual or auditory processing. As we just discussed, it is possible to present visual stimuli to just one visual field so they are sent to a particular hemisphere. It is also possible, as shown by Doreen Kimura (1967), to use a dichotic listening task to present auditory stimuli so that they arrive in a specific hemisphere first. In a *dichotic listening task*, different auditory inputs are simultaneously presented to each ear through headphones. In normal individuals with an intact corpus callosum, visual and auditory inputs sent to one hemisphere are quickly shared with the other. However, subtle differences in the "abilities" of the two hemispheres can be detected by precisely measuring how quickly and accurately subjects process different types of stimuli.

For instance, when verbal stimuli are presented to the right visual field or right ear (and thus sent to the *left hemisphere* first), they are identified more quickly and more accurately than when they are presented to the left visual field or left ear (right hemisphere). The faster reactions in the left hemisphere presumably occur because it can recognize verbal stimuli on its own, while the right hemisphere has to take extra time to "consult" the left hemisphere. In contrast, the *right hemisphere* is faster than the left on *visual-spatial* tasks, such as locating a dot or recognizing a face. The right hemisphere is also better at identifying environmental sounds (such as a bell, a cough, or a whistle) and melodies (Bradshaw, 1989; Bryden, 1982).

Researchers have also used a variety of other approaches to explore hemispheric specialization in normal people. Ultimately, they have concluded that the two hemispheres handle different cognitive tasks (Springer & Deutsch, 1993). *The left hemisphere usually handles verbal processing, such as*

language, speech, reading, and writing. The right hemisphere usually handles nonverbal processing, such as that required by spatial, musical, and visual recognition tasks. These findings have interesting implications for our understanding of mental processes, which we will discuss in the Application.

Handedness and Laterality

Another aspect of human laterality that may be related to the hemispheric organization of the brain is **handedness**—a preference for using one's right or left hand in most activities. Although handedness is much easier to measure and observe than

cerebral specialization, it may be just as complex. Contrary to popular belief, hand preference is not absolute. A person who writes with the right hand might use the left hand to throw a ball or wield scissors. To assess handedness effectively, researchers give people questionnaires that ask about their preferences in executing a variety of tasks. When researchers conduct a thorough assessment of handedness, they find that not everyone can be neatly categorized as right- or left-handed. Typically, about 90 percent of subjects are found to be right-handed, about 7–8 percent are left-handed, and the remainder display mixed-handedness (Iaccino, 1993). This distribution varies a little from one culture to

These highly accomplished "lefties" from a variety of fields offer evidence against the many popular negative images frequently held about the small minority of the world's population who are left handed. Clockwise from top left: rock star Jimi Hendrix, United States President Bill Clinton, tennis champion Martina Navratilova, American statesman Benjamin Franklin, singer Judy Garland, and the well-known historical French leader Napoleon Bonaparte.





"The composite picture that we have painted seems to indicate that left-handers may deviate from the physiological norm because of some developmental or pathological irregularity that may contribute to their reduced longevity. Furthermore, their interactions with the environment are apt to be more fraught with risk."

STANLEY COREN AND
DIANE HALPERN

another, but overall, it's pretty consistent across societies. There are no cultures where left-handers even come close to being a majority. Moreover, the examination of people depicted in ancient works of art suggests that right-handedness has dominated for over 50 centuries (Coren & Porac, 1977).

Origins of Handedness

What determines a person's hand preference and why are the vast majority of us right-handed? These questions have proven more perplexing than you might guess. Both environmental and genetic theories have failed to provide convincing explanations for observed patterns of handedness.

Environmental theories argue that people are born into a "right-handed world," where they are pressured into depending on their right hand. According to this view, most people become right-handed because tools, equipment, desks, pencil sharpeners, and so forth are designed for right-handers and because parents, teachers, and coaches push children to use their right hand in various activities—especially writing (Porac & Coren, 1981). Although environmental pressures can undoubtedly influence hand preference, environmental theories cannot account for the consistency in the prevalence of right- and left-handedness across cultures. Some societies have systematically worked to stamp out left-handedness but have enjoyed only modest success. The most tenacious programs typically produce a moderate decline in the use of the left hand for socially monitored activities, such as writing in school, but have little impact on less obvious manifestations of left-handedness (Annett, 1985). In other societies that have been pretty open-minded about permitting left-handedness, it has increased only slightly (Harris, 1990). If handedness were simply a function of social pressures, there would be more cross-cultural variability in the prevalence of right- and left-handedness.

A number of genetic theories provide models of how handedness might be inherited (Annett, 1972; Levy & Nagylaki, 1972). The notion that hand preference is biologically built-in fits nicely with the cross-cultural consistency seen in patterns of handedness. However, genetic models have difficulty accounting for a number of findings. For instance, left-handedness appears to be a recessive trait, which would mean that the children of two left-handed parents should all be left-handed. In reality, when both parents are left-handed, the probability of a left-handed child is only about 35 percent (Coren, 1992). Some of the more complicated genetic models can handle these findings,

but even they cannot account for handedness patterns among identical and fraternal twins. If handedness is largely genetic, the probability of similar handedness should be greater in identical twins than in fraternal twins and greater in fraternal twins than in unrelated people (the logic underlying twin studies is explained on p. 109). However, the data show that identical twins are not any more similar in handedness than fraternal twins, who are not any more similar than unrelated people (Coren & Halpern, 1991). Thus, although genetic theories of handedness appear more plausible than environmental theories, they leave much to be explained.

The difficulties with environmental and genetic models of handedness have led theorists to look elsewhere for an explanation of hand preference. Many theorists suspect that handedness is somehow connected to the functional asymmetry of the human brain. Corballis (1991), for instance, asserts that "handedness is fundamentally a manifestation of cerebral rather than bodily asymmetry" (p. 105). However, the exact mechanisms that might link hand preference to lateralization in the brain remain a mystery.

Correlates of Handedness

Over the years, left-handedness has been linked to everything under the sun, from criminality to homosexuality. Many of these associations have not stood the test of time and replication, but some very interesting correlates of handedness have emerged. For example, there is an association between hand preference and patterns of cerebral specialization. In right-handers, language processing is almost always housed in the left hemisphere. However, atypical lateralization of language (in the right hemisphere or both hemispheres) is found in a significant minority of left-handers (Bradshaw, 1989).

Investigators have also found associations between left-handedness and a surprising variety of pathological conditions. For example, left-handers are overrepresented in groups suffering from autism (Bryson, 1990), schizophrenia (Flor-Henry, 1990), dyslexia (Porac & Coren, 1981), mental retardation (Pipe, 1990), alcoholism (London, 1990), and immune disorders (Searleman & Fugagli, 1987). These associations are weak, and it is important to emphasize that the vast majority of left-handers do not exhibit these disorders. Nonetheless, these correlations raise disturbing questions about the significance of left-handedness. Most disturbing of all, however, are the recent findings of Stanley Coren and Diane Halpern linking handedness to longevity, the subject of our Featured Study.

Do Left-Handers Die Younger?

Chapter 3 Featured Study

In an earlier study, Stanley Coren had unexpectedly discovered a correlation between age and the prevalence of left-handedness. In a diverse sample of over 5000 subjects, they noticed that the percentage of left-handers dwindled from 13 percent at age 20 to 5 percent at age 50 and less than 1 percent at age 80 (see Figure 3.26). Although the idea seemed both macabre and implausible, Coren felt compelled to investigate the possibility that this age trend might be attributable to increased mortality among left-handers. In a preliminary effort to evaluate this possibility, Coren and Diane Halpern conducted archival research on over 2000 males who had played professional baseball (Halpern & Coren, 1988). This unusual sample was chosen because excellent data on their hand preference, age of birth, and age of death were readily available in *The Baseball Encyclopedia*. These data yielded a modest association between right-handedness and longer survival. However, Halpern and Coren wondered whether their findings might be peculiar to their unusual sample, so they set out to conduct a similar study with a more representative sample.

Method

Technically, the subjects were a random sample of recently deceased individuals, although the data were actually provided by their relatives. Inquiries were sent to the next of kin listed on 2875 death certificates posted in two counties in southern California. Given the sensitive nature of the situation, no effort was made to follow up on these inquiries, which yielded 987 usable responses. Information on the length of the subjects' life span was taken from their death certificates. Data on the subjects' hand preference were collected from their next of kin, who filled out a handedness questionnaire that was kept very short (three items) to make responding as brief and painless as possible.

Results

In the key analysis, subjects were classified as right-handers if their relatives indicated that they wrote, drew, and threw a ball with their right hand. The remaining subjects, who exhibited left-handedness or mixed-handedness, were lumped together and compared to the right-handers. The results of these comparisons are shown for males and females in Figure 3.27. As you can see, left- and mixed-handedness was associated with reduced longevity of 5 years in females and 10 years in males.

Discussion

What could account for this peculiar link between left-handedness and reduced survival? Coren and Halpern review five considerations that might contribute to elevated mortality among left-handers. We'll discuss the two factors that appear most crucial. First, recent studies suggest that left-handers may be more accident prone than right-handers, not because they're clumsy or spacey, but because they have to function in a right-handed world where safety levers, emergency brakes, and so forth are located poorly for them. Consistent with this view, Coren (1989b) found an 85 percent elevation in traffic accidents and 51 percent elevation in tool-related accidents among left-handers.

Investigators: Stanley Coren (University of British Columbia) and Diane F. Halpern (California State University, San Bernardino)

Source: Left-handedness: A marker for decreased survival fitness. *Psychological Bulletin*, 1991, 109, 90-106.

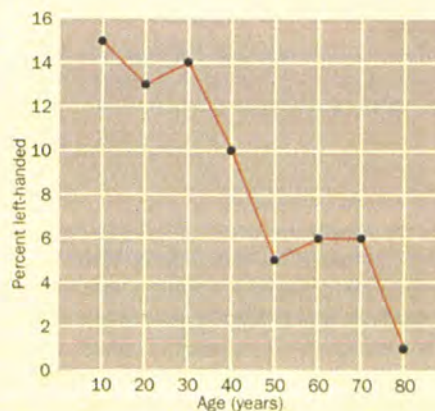


Figure 3.26
The prevalence of left-handedness as a function of age. Based on a sample of 5147 subjects, the percentage of the population that is left-handed is plotted as a function of age. As you can see, the percentage of left-handers declines precipitously in older age groups. (Source: Coren, 1992)

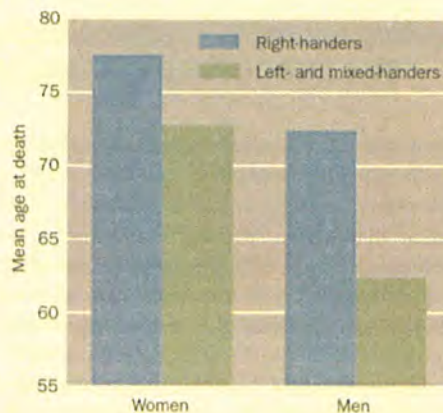


Figure 3.27
Average age of death as a function of handedness. Based on a sample of 987 death records, Coren and Halpern (1991) found that the mean age at death is noticeably younger in left-handers as opposed to right-handers for both females and males. The factors underlying left-handers' shorter life span are the subject of considerable speculation and debate.

Second, left-handedness may be a marker associated with neurological damage due to birth stress, and this neurological damage may predispose left-handers to various disorders that affect their longevity. Some theorists believe that birth-related trauma (premature birth, prolonged labor, breech delivery, oxygen deprivation, and so on) may sometimes cause subtle, undetectable neurological damage that disrupts the development of normal hemispheric organization in the brain, resulting in left- or mixed-handedness (Bakan, 1990). Consistent with this view, quite a number of studies have found an elevated incidence of birth stress among left-handers. This theory could explain why atypical cerebral specialization is found in left-handers more than right-handers. Subtle neurological abnormalities resulting from birth stress might also contribute to the elevated incidence of autism, mental retardation, dyslexia, and schizophrenia observed in left-handers.

Comment

This study provides a nice example of how researchers often stumble onto perplexing findings, such as the age-related decrease in left-

handedness, and then scramble to explain them by conducting more research. Many important lines of research have begun in this way. Coren and Halpern's work also illustrates the need for scientists to be open-minded, to entertain implausible or unpleasant possibilities, and to think the unthinkable.

Of course, thinking the unthinkable can cause consternation in some quarters, and this study generated considerable controversy when it was published. Left-handers have long complained about being stereotyped as clumsy and inept. Even our language subtly equates left-handedness with inferiority. For example, a *left-handed compliment* isn't much of a compliment, but a *right-hand man* is invaluable. Understandably, then, left-handers felt that this study poured salt into their wounds. Many were particularly offended by the theory linking left-handedness to brain damage, leading Stanley Coren (1992) to subsequently note, "I am not saying that every left-hander is some form of neurological cripple" (p. 151). Coren and Halpern have merely suggested—and many reputable laterality experts disagree (Bryden, 1993)—that there may be a modest statistical association between left-handedness and neurological anomalies.

Is the correlation between left-handedness and longevity cause for panic among left-handers? Concern, yes; panic, no. To put the findings in perspective, it may help to note that left-handers' decreased longevity is roughly similar to males' decreased longevity when compared to females, a well-known and better-documented phenomenon that has not led to panic in the streets. Moreover,

awareness of their increased risk may motivate many left-handers—like many men—to alter their lifestyles in ways that may eventually narrow the longevity gap. In any case, it is apparent that human laterality has far-reaching and sometimes controversial implications, which we will return to in our upcoming Application. For now, however, let's turn our attention to the endocrine system.

THE ENDOCRINE SYSTEM: ANOTHER WAY TO COMMUNICATE

The major way the brain communicates with the rest of the body is through the nervous system. However, the body has a second communication system that is also important to behavior. **The endocrine system consists of glands that secrete chemicals into the bloodstream that help control bodily functioning.** The messengers in this communication network are called hormones. **Hormones are the chemical substances released by the endocrine glands.** The endocrine system tends to be involved in the long-term regulation of basic bodily processes, as its action can't match the high speed of neural transmission. The major endo-

crine glands and their hormones are shown in Figure 3.28.

In a way, endocrine glands are like chemical synapses with distant receptors. Once released, the hormonal transmitters diffuse through the bloodstream and bind to special receptors on distant target cells. In fact, some chemical substances do double duty, functioning as hormones when they're released in the endocrine system and as neurotransmitters in the nervous system (norepinephrine, for example). There are some 30 different hormones in the human body. Some have specific target cells, while others affect a great many cells throughout the body.

Endocrine glands	Functions regulated by secretion
Anterior pituitary	Produces hormones that influence secretions of the thyroid, pancreas, adrenal cortex, and gonads; also secretes growth hormones
Posterior pituitary	Regulates water metabolism; salt metabolism
Thyroid	Produces hormones that regulate metabolic rate
Pancreas	Produces insulin and glucagon to control sugar metabolism
Adrenal glands	
Adrenal cortex (outer layer)	Controls salt and carbohydrate metabolism; controls inflammatory reactions
Adrenal medulla (inner layer)	Secretes hormones active in emotional arousal and sleep
Gonads	
Ovaries (in females)	
Testes (in males)	Produce hormones that affect bodily development and that maintain reproductive organs in adults

Some hormones are released in response to changing conditions in the body and act to regulate those conditions. For example, hormones released by the stomach and intestines help control digestion. Kidney hormones play a part in regulating blood pressure. And pancreatic hormone (insulin) is essential for cells to use sugar from the blood.

Much of the endocrine system is controlled by the nervous system through the *hypothalamus*. This structure at the base of the forebrain has intimate connections with the pea-sized *pituitary gland*, to which it is adjacent. The *pituitary gland* releases a great variety of hormones that fan out around the body, stimulating actions in the other endocrine glands. In this sense, the pituitary is the “master gland” of the endocrine system, although the hypothalamus is the real power behind the throne.

The intermeshing of the nervous system and the endocrine system can be seen in the fight-or-flight response described earlier. In times of stress, the hypothalamus sends signals along two pathways—through the autonomic nervous system and through the pituitary gland—to the adrenal glands (Sapolsky, 1992). In response, the adrenal glands secrete hormones that radiate throughout the body, preparing it to cope with an emergency (see Chapter 13).

Hormones also play important roles in modulating human physiological development. For example, among the more interesting hormones released by the pituitary are the *gonadotropins*, which affect the *gonads*, or sexual glands. Prior to birth, these hormones direct the formation of the external sexual organs in the developing fetus (Breedlove, 1992). Thus, your sexual identity as a male or female was shaped during prenatal development by the actions of hormones. At puberty, increased levels of sexual hormones are responsible for the emergence of secondary sexual characteristics, such as male facial hair and female breasts (Chumlea, 1982). The actions of other hormones are responsible for the spurt in physical growth that occurs around puberty (see Chapter 11).

These developmental effects of hormones illustrate how genetic programming has a hand in behavior. Obviously, the hormonal actions that shaped your sex were determined by your genetic makeup. Similarly, the hormonal changes in early adolescence that launched your growth spurt and aroused your interest in sexuality were pre-programmed over a decade earlier by your genetic inheritance. Which brings us to the role of heredity in shaping behavior.

Figure 3.28
The endocrine system. The endocrine glands secrete hormones into the bloodstream. As summarized here, these hormones regulate a variety of physical functions and may affect many aspects of behavior.

HEREDITY AND BEHAVIOR: IS IT ALL IN THE GENES?

As you have learned throughout this chapter, your biological makeup is intimately related to your behavior. That is why your genetic inheritance, which shapes your biological makeup, may have much to do with your behavior. Most people realize that physical characteristics such as height, hair color, blood type, and eye color are largely shaped by heredity. But what about psychological characteristics, such as intelligence, moodiness, impulsiveness, and shyness? To what extent are people's behavioral qualities molded by their genes? These questions are the central focus of *behavioral genetics*—an interdisciplinary field that studies the influence of genetic factors on behavioral traits.

As we saw in Chapter 1, questions about the relative importance of heredity versus environment are very old ones in psychology. However, research in behavioral genetics has grown by leaps and bounds since the 1970s, and this research has shed new light on the age-old nature versus nurture debate. Ironically, although behavioral geneticists have mainly sought to demonstrate the influence of heredity on behavior, their recent work has also highlighted the importance of the environment (Plomin, 1993), as we shall see in this section.

Basic Principles of Genetics

Every cell in your body contains enduring messages from your mother and father. These messages are found on the *chromosomes* that lie within the nucleus of each cell.

Chromosomes and Genes

Chromosomes are threadlike strands of DNA (deoxyribonucleic acid) molecules that carry genetic information (see Figure 3.29). Every cell in humans, except the sex cells (sperm and eggs), contains 46 chromosomes. These chromosomes operate in 23 pairs, with one chromosome of each pair being contributed by each parent. Parents make this contribution when fertilization creates a *zygote*, a one-celled organism formed by the union of a sperm and an egg. The sex cells that form a zygote each have 23 chromosomes; together they contribute the 46 chromosomes that appear in the zygote and in all the body cells that evolve from it. Each chromosome, in turn, contains thousands of biochemical messengers called genes. *Genes* are DNA segments that serve as the key functional units in hereditary transmission.

If all offspring are formed by a union of the parents' sex cells, why aren't family members identical clones? The reason is that a single pair of parents can produce an extraordinary variety of combinations of chromosomes. When sex cells form in each parent, it is a matter of chance as to which member of each chromosome pair ends up in the sperm or egg. Each parent's 23 chromosome pairs can be scrambled in over 8 million (2^{23}) different ways, yielding roughly 70 trillion possible configurations (2^{46}) when sperm and egg unite. Actually, this is a conservative estimate. It doesn't take into account complexities such as *mutations* (changes in the genetic code) or *crossing over* during

The Canseco twins appear to provide a dramatic illustration of how heredity and experience jointly influence many complex behavioral traits—in this case, baseball ability. Jose and Ozzie Canseco are identical twins, and the genetic inheritance that they share probably has much to do with the fact that both have demonstrated exceptional baseball ability by becoming professional baseball players. However, differences in their experiences probably explain why one brother (Jose) has become a superstar, whereas the other (Ozzie) has knocked around in the minor leagues for most of his career.



sex-cell formation (an interchange of material between chromosomes). Thus, genetic transmission is a complicated process, and everything is a matter of probability. Except for identical twins, each person ends up with a unique genetic blueprint.

Like chromosomes, genes operate in pairs, with one gene of each pair coming from each parent. In the *homozygous condition*, the two genes in a specific pair are the same. In the *heterozygous condition*, the two genes in a specific pair are different (see Figure 3.30). In the simplest scenario, a single pair of genes determines a trait. Eye color provides a nice example. When both parents contribute a gene for the same color (the *homozygous condition*), the child will have eyes of that color. When the parents contribute genes for different eye colors (the *heterozygous condition*), one gene in the pair—called the *dominant gene*—overrides or masks the other, called the *recessive gene*. Thus, a *dominant gene* is one that is expressed when paired genes are different. A *recessive gene* is one that is masked when paired genes are different.

Because genes operate in pairs, a child has a 50 percent probability of inheriting a specific gene in a specific gene pair from each parent. Hence, the *genetic relatedness* of parents and children is said to be 50 percent. The genetic relatedness of other types of relatives can be calculated in the same way; the results are shown in Figure 3.31 (on the next page). As you can see, genetic relatedness ranges from 100 percent for identical twins down to 6.25 percent for second cousins. The numbers in Figure 3.31 are purely theoretical, and for a variety of complicated reasons they underestimate the actual genetic overlap among people. But the key to the concept of genetic relatedness is that members of a family share more of the same genes than non-members, and closer relatives share a larger proportion of genes than more distant relatives. These realities explain why family members tend to resemble one another and why this resemblance tends to be greater among closer relatives.

Genotype Versus Phenotype

It might seem that two parents with the same manifest trait, such as brown eyes, should always produce offspring with that trait. However, that isn't always the case. For instance, two brown-eyed parents can produce a blue-eyed child (see Figure 3.32 on the next page). This happens because there are unexpressed recessive genes in the family's gene pool—in this case, genes for blue eyes.

This point brings us to the distinction between genotype and phenotype. *Genotype* refers to a

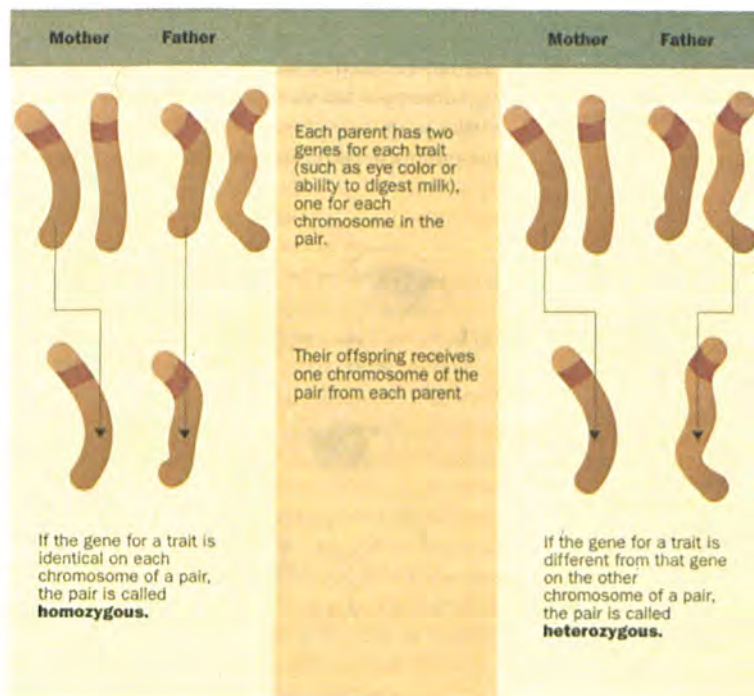


Figure 3.29

Genetic material. This series of enlargements shows the main components of genetic material. (Top) In the nucleus of every cell are chromosomes, which carry the information needed to construct new human beings. (Center) Chromosomes are threadlike strands of DNA that carry thousands of genes, the functional units of hereditary transmission. (Bottom) DNA is a spiraled double chain of molecules that can copy itself to reproduce.

Figure 3.30

Homozygous and heterozygous genotypes (below). Like chromosomes, genes operate in pairs, with one gene in each pair coming from each parent. When paired genes are the same, they are said to be homozygous. When paired genes are different, they are said to be heterozygous. (Adapted from Kalat, 1993)



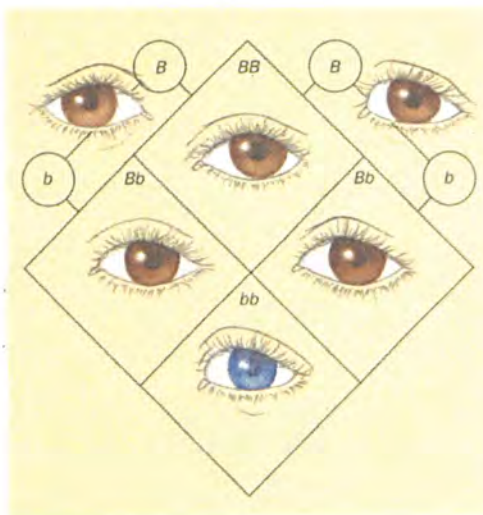
Relationship	Degree of relatedness	Genetic overlap
Identical twins		100% 
Fraternal twins Brother or sister Parent or child	First degree relatives	50% 
Grandparent or grandchild Uncle, aunt, nephew, or niece Half-brother or half-sister	Second degree relatives	25% 
First cousin	Third degree relatives	12.5% 
Second cousin	Fourth degree relatives	6.25% 
Unrelated		0% 

Figure 3.31
Genetic relatedness. Research on the genetic bases of behavior takes advantage of the different degrees of genetic relatedness between various types of relatives. If heredity influences a trait, relatives who share more genes should be more similar with regard to that trait than are more distant relatives, who share fewer genes. Comparisons involving various degrees of biological relationships will come up frequently in later chapters.

person's genetic makeup. *Phenotype* refers to the ways in which a person's genotype is manifested in observable characteristics. Different genotypes (such as two genes for brown eyes as opposed to one gene for brown and one for blue) can yield the same phenotype (brown eyes). Genotype is determined at conception and is fixed forever. In contrast, phenotypic characteristics (hair color, for instance) may change over time. They may also be modified by environmental factors.

Genotypes translate into phenotypic characteristics in a variety of ways. Not all gene pairs operate according to the principles of dominance. In some

Figure 3.32
Dominant and recessive genes. This diagram shows how two brown-eyed parents with a heterozygous genotype (Bb , denoting brown-blue) have a 25 percent chance of producing brown-eyed offspring who are homozygous (BB), a 50 percent chance of producing brown-eyed offspring who are heterozygous (Bb), and a 25 percent chance of producing blue-eyed offspring, who must be homozygous (bb), since blue eye color is recessive. The genetic bases for behavioral traits appear to be much more complex than the simple rules that govern eye color.



instances, when paired genes are different, they produce a blend, an "averaged out" phenotype. In other cases, paired genes that are different strike another type of compromise, and both characteristics show up phenotypically, as in the case of type AB blood.

Polygenic Inheritance

Most human characteristics appear to be *polygenic traits*, or characteristics that are influenced by more than one pair of genes. For example, three to five gene pairs are thought to interactively determine skin color. Complex physical abilities, such as motor coordination, may be influenced by tangled interactions among a great many pairs of genes. Most psychological characteristics that appear to be affected by heredity seem to involve complex polygenic inheritance (Plomin, 1990).

Investigating Hereditary Influence: Research Methods

How do behavioral geneticists and other scientists disentangle the effects of genetics and experience to determine whether heredity affects behavioral traits? Researchers have designed special types of studies to assess the impact of heredity. Of course, with humans they are limited to correlational rather than experimental methods, as they cannot manipulate genetic variables by assigning subjects to mate with each other (this approach, called *selective breeding*, is used in animal studies). The three most important methods in human research are family studies, twin studies, and adoption studies. After examining these classic methods of research, we'll discuss the impact of new developments in genetic mapping.

Family Studies

In *family studies* researchers assess hereditary influence by examining blood relatives to see how much they resemble one another on a specific trait. If heredity affects the trait under scrutiny, researchers should find phenotypic similarity among relatives. Furthermore, they should find more similarity among relatives who share more genes. For instance, siblings should exhibit more similarity than cousins.

Illustrative of this method are the numerous family studies conducted to assess the contribution of heredity to the development of schizophrenic disorders. These disorders strike approximately 1 percent of the population, yet as Figure 3.33 reveals, 9 percent of the siblings of schizophrenic

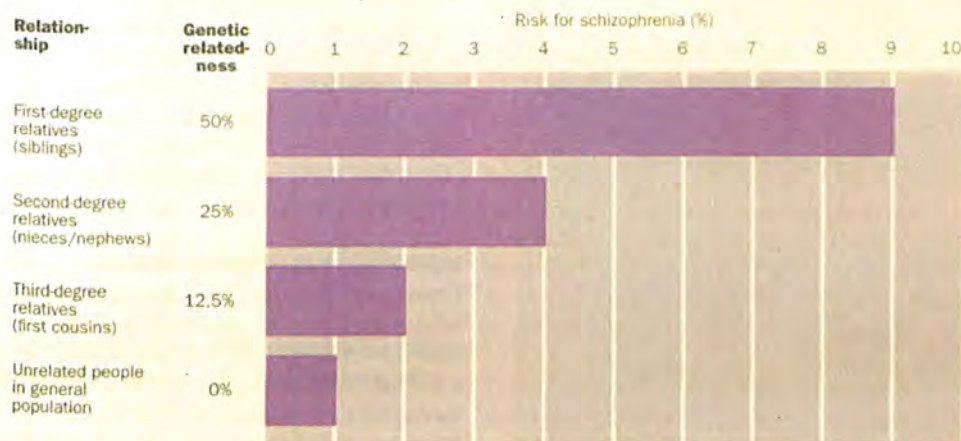


Figure 3.33
Family studies of risk for schizophrenic disorders. First-degree relatives of schizophrenic patients have an elevated risk of developing a schizophrenic disorder. For instance, the risk for siblings of schizophrenic patients is about 9 percent instead of the baseline 1 percent for unrelated people. Second- and third-degree relatives have progressively smaller elevations in risk for this disorder. Although these patterns of risk do not prove that schizophrenia is partly inherited, they are consistent with this hypothesis. (Adapted from data in Gottesman, 1991)

patients exhibit schizophrenia themselves (Gottesman, 1991). Thus, these first-degree relatives of schizophrenic patients show a risk for the disorder that is nine times higher than normal. This risk is greater than that observed for more distantly related, second-degree relatives, such as nieces and nephews (4 percent), who, in turn, are at greater risk than third-degree relatives, such as second cousins (2 percent). This pattern of results is consistent with the hypothesis that genetic inheritance influences the development of schizophrenic disorders (Gottesman, 1993).

Family studies can indicate whether a trait runs in families. However, this correlation does not provide conclusive evidence that the trait is influenced by heredity. Why not? Because family members generally share not only genes but also similar environments. Furthermore, closer relatives are more likely to live together than more distant relatives. Thus, genetic similarity and environmental similarity *both* tend to be greater for closer relatives. Either of these confounded variables could be responsible when greater phenotypic similarity is found in closer relatives. Family studies can offer useful insights about the possible impact of heredity, but they cannot provide definitive evidence.

Twin Studies

Twin studies can yield better evidence about the possible role of genetic factors. In *twin studies* researchers assess hereditary influence by comparing the resemblance of identical twins and fraternal twins with respect to a trait. The logic of twin studies hinges on the genetic relatedness of identical and fraternal twins. *Identical (monozygotic) twins* emerge from one zygote that splits

for unknown reasons. Thus, they have exactly the same genotype; their genetic relatedness is 100 percent. *Fraternal (dizygotic) twins* result when two eggs are fertilized simultaneously by different sperm cells, forming two separate zygotes. Fraternal twins are no more alike in genetic makeup than any two siblings born to a pair of parents at different times. Their genetic relatedness is only 50 percent.

Fraternal twins provide a useful comparison to identical twins because in both cases the twins usually grow up in the same home, at the same time, exposed to the same configuration of relatives, neighbors, peers, teachers, events, and so forth. Thus, both kinds of twins normally develop under equally similar environmental conditions. However, identical twins share more genetic kinship than fraternal twins. Consequently, if sets of identical twins tend to exhibit more similarity on a trait than sets of fraternal twins do, it is reasonable to infer that this greater similarity is probably due to heredity rather than environment.

Twin studies have been conducted to assess the impact of heredity on many different traits. Some representative results are summarized in Figure 3.34 (on the next page). The higher correlations found for identical twins indicate that they tend to be more similar to each other than fraternal twins on measures of general intelligence (McGue et al., 1993) and measures of specific personality traits, such as extraversion (Loehlin, 1992). These results support the notion that intelligence and personality are influenced to some degree by genetic makeup. However, the fact that identical twins are far from identical in intelligence and personality also shows that environment influences these characteristics.

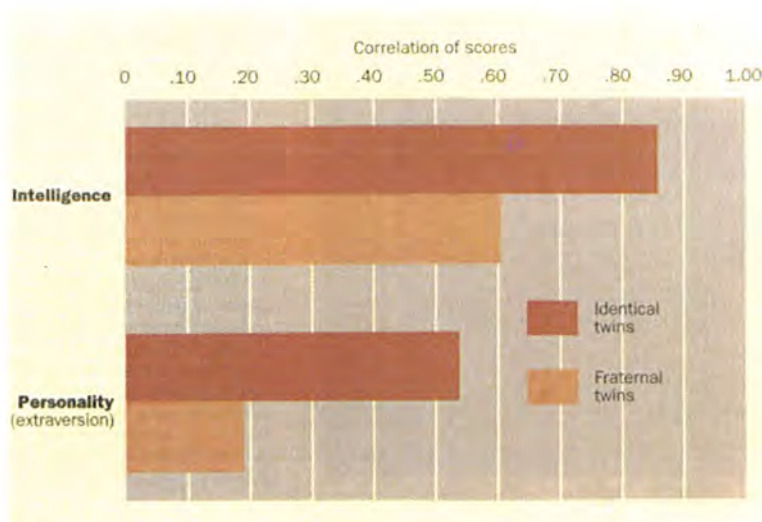


Figure 3.34
Twin studies of intelligence and personality. Identical twins tend to be more similar than fraternal twins (as reflected in higher correlations) with regard to general mental ability and specific personality traits, such as extraversion. These findings suggest that intelligence and personality are influenced by heredity. (Intelligence data from McGue et al., 1993; extraversion data based on Loehlin, 1992)

Adoption Studies

Adoption studies assess hereditary influence by examining the resemblance between adopted children and both their biological and their adoptive parents. Generally, adoptees are used as subjects in this type of study only if they were given up for adoption in early infancy and were raised without having contact with their biological parents. The logic underlying the adoption study approach is quite simple. If adopted children resemble their biological parents on a trait, even though they were not raised by them, genetic factors probably influence that trait. In contrast, if adopted children resemble their adoptive parents, even though they inherited no genes from them, environmental factors probably influence the trait.

In recent years, adoption studies have contributed to science's understanding of how genetics and the

environment influence intelligence. The research shows significant similarity between adopted children and their biological parents, as indicated by an average correlation of .36 (Vandenberg & Vogler, 1985). Interestingly, adopted children resemble their adoptive parents nearly as much (average correlation of .31). These findings indicate that both heredity and environment have an influence on intelligence.

The Cutting Edge: Genetic Mapping

While behavioral geneticists have recently made great progress in documenting the influence of heredity on behavior, *molecular geneticists*, who study the biochemical bases of genetic inheritance, have made even more spectacular advances in their efforts to unravel the genetic code. *Genetic mapping* is the process of determining the location and chemical sequence of specific genes on specific chromosomes. New methods of manipulating DNA are now allowing scientists to create detailed physical maps of the genetic material on chromosomes in plants, animals, and humans. A huge, 15-year international project intended to map out the estimated 100,000 genes found on the 23 pairs of human chromosomes is well under way. Gene maps, by themselves, do not reveal which genes govern which traits. However, the compilation of a precise genetic atlas will produce a quantum leap in the ability of scientists to pinpoint links between specific genes and specific traits and disorders. For example, medical researchers have already identified the genes responsible for cystic fibrosis, Huntington's chorea, and muscular dystrophy (Wingerson, 1990). These discoveries promise to yield dramatic advances in the diagnosis and treatment of these diseases.

Will genetic mapping permit researchers to discover the genetic basis for intelligence, extraversion, musical ability, and other *behavioral* traits? Perhaps eventually, but progress is likely to be very gradual. Thus far, the major medical breakthroughs from genetic mapping have involved dichotomous traits (you either do or do not have the trait, such as muscular dystrophy) governed by a single gene pair. However, most behavioral traits do not involve a dichotomy, as everyone has varying amounts of intelligence, musical ability, and so forth. Moreover, virtually all behavioral traits appear to be *polygenic* traits that are shaped by many genes rather than a single gene. Because of these complexities, scientists are not likely to find the gene that controls intelligence, extraversion, or musical talent (Plomin, 1993). Instead, the challenge will be to identify specific constellations of genes that each exert modest influence over particular aspects of behavior (McClern et al., 1991).

CONCEPT CHECK 3.4

Recognizing Hereditary Influence

Check your understanding of the methods scientists use to explore hereditary influences on specific behavioral traits by filling in the blanks in the descriptive statements below. The answers can be found in the back of the book in Appendix A.

1. The findings from *family studies* indicate that heredity may influence a trait if _____ show more trait similarity than _____.
2. The findings from *twin studies* suggest that heredity influences a trait if _____ show more trait similarity than _____.
3. The findings from *adoption studies* suggest that heredity influences a trait if children adopted at a young age share more trait similarity with their _____ than their _____.
4. The findings from *family studies*, *twin studies*, or *adoption studies* suggest that heredity does not influence a trait when _____ is not related to _____.

In spite of the daunting complexity of human behavior, genetic mapping holds great promise for behavioral genetics. According to Plomin and Rende (1991), by the year 2000 it is likely that "molecular-genetic techniques will have revolutionized human behavioral genetics" (p. 176). What's exciting is that until recently, behavioral geneticists were largely limited to investigating how much heredity influences various traits. Genetic mapping will allow them to begin investigating *how* heredity influences various traits.

The Interplay of Heredity and Environment

We began this section by asking, is it all in the genes? When it comes to behavioral traits, the answer clearly is no. According to Robert Plomin (1993), perhaps the leading behavioral genetics

researcher in the last decade, what scientists find again and again is that heredity and experience jointly influence most aspects of behavior. Moreover, their effects are interactive—they play off each other.

For example, consider what researchers have learned about the development of schizophrenic disorders. Although the evidence indicates that genetic factors influence the development of schizophrenia, it does *not* appear that anyone directly inherits the disorder itself. Rather, what people appear to inherit is a certain degree of *vulnerability* to the disorder (Zubin, 1986). Whether this vulnerability is ever converted into an actual disorder depends on each person's experiences in life. As we will discuss in Chapter 14, certain types of stressful experience seem to evoke the disorder in people who are more vulnerable to it.



"During the 1970s, I found I had to speak gingerly about genetic influence, gently suggesting that heredity might be important in behavior. Now, however, the transformation of the social and behavioral sciences from environmentalism to biological determinism is happening so fast that I find I more often have to say, 'Yes, genetic influences are substantial, but environmental influences are important, too.'"
ROBERT PLOMIN

PUTTING IT IN PERSPECTIVE

Three of our seven themes stood out in this chapter: (1) heredity and environment jointly influence behavior, (2) behavior is determined by multiple causes, and (3) psychology is empirical. Let's look at each of these points.

In Chapter 1, when it was first emphasized that heredity and environment jointly shape behavior, you may have been a little perplexed about how your genes could be responsible for your sarcastic wit or your interest in art. In fact, there are no genes for behavior per se. Experts do not expect to find genes for sarcasm or artistic interest, for example. Insofar as your hereditary endowment plays a role in your behavior, it does so *indirectly*, by molding the physiological machine that you work with. Thus, your genes influence your physiological makeup, which in turn influences your personality, temperament, intelligence, interests, and other traits. Bear in mind, however, that genetic factors do not operate in a vacuum. Genes exert their effects in an environmental context. The impact of genetic makeup depends on environment, and the impact of environment depends on genetic makeup.

It was evident throughout the chapter that behavior is determined by multiple causes, but this reality was particularly apparent in the discussions of schizophrenia. At different points in the chapter we saw that schizophrenia may be a function of (1) abnormalities in neurotransmitter activity (especially dopamine), (2) structural defects in the brain (enlarged ventricles), and (3) genetic vulnerability

to the illness. These findings do not contradict one another. Rather, they demonstrate that a complex array of biological factors are involved in the development of schizophrenia. In Chapter 14, we'll see that a host of environmental factors also play a role in the multifactorial causation of schizophrenia.

The empirical nature of psychology was apparent in the numerous discussions of the specialized research methods used to study the physiological bases of behavior. As you know, the empirical approach depends on precise observation. Throughout this chapter, you've seen how investigators have come up with innovative methods to observe and measure elusive phenomena such as electrical activity in the brain, neural impulses, neurotransmitter activity, brain function, cerebral specialization, and the impact of heredity on behavior. The point is that empirical methods are the lifeblood of the scientific enterprise. When researchers figure out how to better observe something, their new methods usually facilitate major advances in our scientific knowledge. That is why brain-imaging techniques and genetic mapping hold such exciting promise.

The importance of empiricism will also be apparent in the upcoming Application, which looks at popular ideas about the specialized abilities of the right and left halves of the brain as they relate to cognitive processes. You'll see that it is important to learn to distinguish between scientific findings and conjecture based on those findings.

THE BIOLOGICAL BASES OF BEHAVIOR

CHAPTER 3 APPLICATION

Thinking Critically About the Concept of "Two Minds in One"

Answer the following "true" or "false."

- ☐ 1. Our right and left brains give us two minds in one.
- ☐ 2. Each half of the brain has its own special mode of thinking.
- ☐ 3. Some people are left-brained while others are right-brained.
- ☐ 4. Our schools should devote more effort to teaching the overlooked right side of the brain.

Do we have two minds in one that think differently? Do some of us depend on one side of the brain more than the other? Is the right side of the brain neglected? These questions are too

complex to resolve with a simple true or false, but in this Application we'll take a closer look at the issues involved in these proposed applications of the findings on cerebral specialization. You'll learn that some of these ideas are plausible, but in many cases the hype has outstripped the evidence.

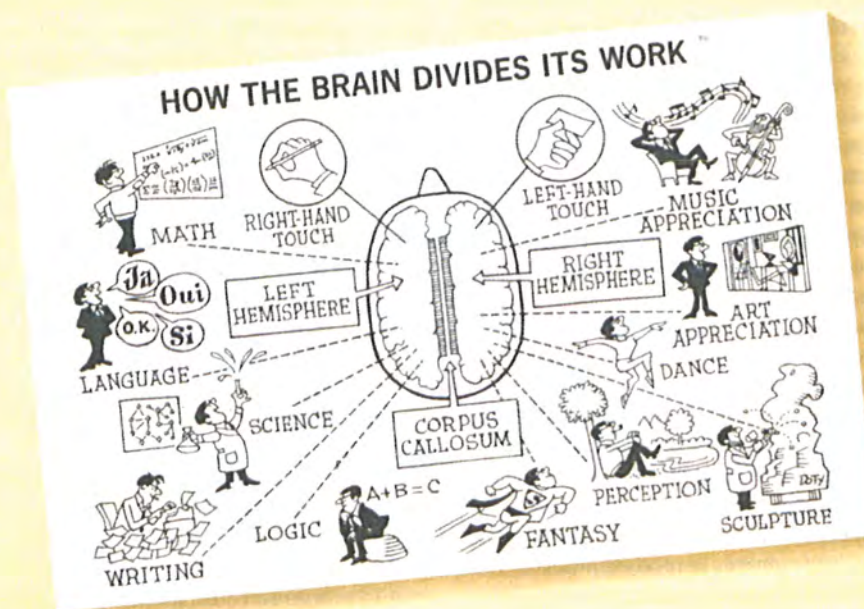
Earlier, we described Roger Sperry's Nobel prize-winning research with split-brain patients, whose right and left hemispheres were disconnected (to reduce epileptic seizures). The split-brain studies showed that the previously underrated right hemisphere has some special talents of its own. This discovery detonated an explosion of research on cerebral laterality.

Cerebral Specialization and Cognitive Processes

Using a variety of methods, scientists have compiled mountains of data on the specialized abilities of the right and left hemispheres. These findings have led to extensive theorizing about how the right and left brains might be related to cognitive processes. Some of the more intriguing ideas include the following:

1. The two hemispheres are specialized to process different types of cognitive tasks (Corballis, 1991; Ornstein, 1977). The findings of many researchers have been widely interpreted as showing that the left hemisphere handles verbal tasks, including language, speech, writing,

Figure 3.35
Popular conceptions of hemispheric specialization. As this *Newsweek* diagram illustrates, depictions of hemispheric specialization in the popular press have often been oversimplified.



math, and logic, while the right hemisphere handles nonverbal tasks, including spatial problems, music, art, fantasy, and creativity. These conclusions have attracted a great deal of public interest and media attention. For example, Figure 3.35 shows a *Newsweek* artist's depiction of how the brain divides its work.

2. *Each hemisphere has its own independent stream of consciousness* (Bogen, 1985; Pucetti, 1981). For instance, Joseph Bogen has asserted, "Pending further evidence, I believe that each of us has two minds in one person" (Hooper & Teresi, 1986, p. 221). Supposedly, this duality of consciousness goes largely unnoticed because of the considerable overlap between the experiences of each independent mind. Ultimately, though, the apparent unity of consciousness is but an illusion. According to some versions of this theory, the two streams of consciousness alternate in controlling overt behavior, sometimes waging a battle for control that supposedly has far-reaching implications. For example, Joseph (1992) states, "In some instances, the left brain interferes with, suppresses, and inhibits right-brain mental processing. . . . When the left brain interferes with the right and tries to dominate all interaction through logic and reason, it causes the person to completely miss the boat when it comes to successful social, emotional, and intimate interactions" (p. 47).

3. *The two hemispheres have different modes of thinking* (Joseph, 1992; Galin, 1974). According to this notion, the documented differences between the hemispheres in dealing with verbal and nonverbal materials are due to more

Figure 3.36
Proposed differences between the left and right hemispheres in cognitive style.

It is popular to suggest that the two hemispheres exhibit different modes of thinking. This summary, adapted from Edwards (1979, 1989), shows that theorists have tried to relate many polarities in cognitive style to the right and left brains. However, as the text explains, there is relatively little direct evidence to support these proposed dichotomies.

Left Hemisphere's Modes of Thinking	Right Hemisphere's Modes of Thinking
Verbal: Using words to name, describe, define	Nonverbal: Showing an awareness of things but minimal connection with words
Analytic: Figuring things out step by step and part by part	Synthetic: Putting things together to form wholes
Symbolic: Using a symbol to stand for something	Analogic: Seeing likenesses between things; understanding metaphoric relationships
Abstract: Taking out a small bit of information and using it to represent a whole thing	Concrete: Relating to things as they are at the present moment
Temporal: Keeping track of time; sequencing one thing after another, doing first things first, second things second, and so forth	Nontemporal: Being without a sense of time
Rational: Drawing conclusions based on reason and facts	Nonrational: Not requiring a basis of reason or facts; willing to suspend judgment
Digital: Using numbers as in counting	Spatial: Seeing where things are in relation to other things and how parts go together to form a whole
Logical: Drawing conclusions based on logic: one thing following another in logical order—for example, developing a mathematical theorem or a well-stated argument	Intuitive: Making leaps of insight, often based on incomplete patterns, hunches
Linear: Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion	Holistic: Seeing whole things all at once; perceiving overall patterns and structures, which often leads to divergent conclusions

basic differences in *how* the hemispheres process information. This theory holds that the reason the left hemisphere handles verbal material well is that it is analytic, abstract, rational, logical, and linear. In contrast, the right hemisphere is thought to be better equipped to handle spatial and musical material because it is synthetic, concrete, nonrational, intuitive, and holistic. These proposed hemispheric differences in cognitive style are summarized in Figure 3.36.

4. *People vary in their reliance on one hemisphere as opposed to the other* (Bakan,

1971; Zenhausen, 1978). Allegedly, some people are "left-brained." Their greater dependence on their left hemisphere supposedly makes them analytic, rational, and logical. Other people are "right-brained." Their greater use of their right hemisphere supposedly makes them intuitive, holistic, and irrational. Being right-brained or left-brained is thought to explain many personal characteristics, such as whether an individual likes to read, is good with maps, or enjoys music. This notion of "brainedness" has even been used to explain occupational choice.

Supposedly, right-brained people are more likely to become artists or musicians, while left-brained people are more likely to become writers or scientists.

5. *Schools should place more emphasis on teaching the right side of the brain* (Prince, 1978; Samples, 1975). "A real reform of the educational system will not occur until the individual teachers learn to understand the true duality of their students' minds," says Thomas Blakeslee (1980, p. 59). Those sympathetic to his view assert that American schools overemphasize logical, analytical left-hemisphere thinking (required by English, math, and science) while shortchanging intuitive, holistic right-hemisphere thinking (required by art and music). These educators have concluded that modern schools turn out an excess of left-brained graduates. They advocate curriculum reform to strengthen the right side of the brain in their students. This line of thinking has also spawned quite a collection of popular, self-help books, such as *Whole-Brain Thinking* (Wonder, 1992), *Unleashing the Right Side of the Brain* (Williams & Stockmyer, 1987), and *Teaching for the Two-Sided Mind* (Williams, 1986).

Complexities and Qualifications

The ideas just outlined are the source of considerable debate among psychologists and neuroscientists. These ideas are intriguing and have clearly captured the imagination of the general public. However, the research on cerebral specialization is complex, and doubts have been raised about many of these ideas (Corballis, 1980; Efron, 1990; Kinsbourne, 1982). Let's examine each point.

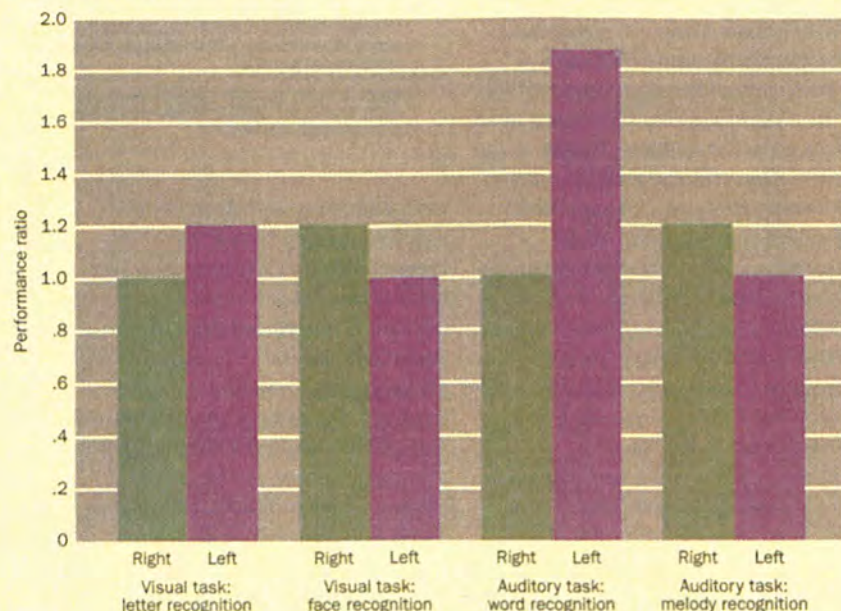
1. There is ample evidence that the right and left hemispheres are specialized to handle different types of cognitive tasks, *but only to a degree*. Doreen Kimura (1973) compared the abilities of the right and left hemispheres to quickly recognize letters, words, faces, and melodies in a series of perceptual asymmetry studies, like those described earlier in the chapter. She found that the superiority of one hemisphere over the other was usually quite modest, as you can see in Figure 3.37, which shows superiority ratios for four cognitive tasks.

Furthermore, in normal individuals, the hemispheres don't work alone. As

Hellige (1993) notes, "In the intact brain, it is unlikely that either hemisphere is ever completely uninvolved in ongoing processing" (p. 23). For instance, the right hemisphere doesn't shut down entirely so the left hemisphere can read a book by itself. Most tasks probably engage *both* hemispheres, albeit to different degrees (Hellige, 1990). For instance, imagine that you are asked the following question: "In what direction are you headed if you start north and make two right turns and a left turn?" In answering this question, you're confronted with a *spatial* task that should engage the right hemisphere. However, first you have to process the wording of the question, a *language* task that should engage the left hemisphere.

Furthermore, people differ in their patterns of cerebral specialization (Springer & Deutsch, 1993). Some people display little specialization—that is, their hemispheres seem to have equal abilities on various types of tasks. Others even reverse the usual specialization, so that verbal processing might be housed in the right hemisphere. These unusual patterns are especially common among left-handed people. For example,

Figure 3.37
Relative superiority of one brain hemisphere over the other in studies of perceptual asymmetry. The performance ratios show the degree to which one hemisphere was "superior" to the other on each type of task in normal subjects. For example, the right hemisphere was 20 percent better than the left hemisphere in quickly recognizing melodic patterns (ratio 1.2 to 1). Most differences in the performance of the two hemispheres are quite small. (Data from Kimura, 1973)



when Rasmussen and Milner (1977) tested subjects for the localization of speech, they found bilateral representation in 15 percent of the left-handers. A reversal of the usual specialization (speech handled by the right hemisphere) was found in another 15 percent of the left-handed subjects (see Figure 3.38). These variations in cerebral specialization are not well understood yet. However, they clearly indicate that the functional specialization of the cerebral hemispheres is not set in concrete.

2. The evidence for the idea that people have a separate stream of consciousness in each hemisphere is really weak. There are signs of such duality among *split-brain patients*. But this duality is probably a unique by-product of the surgical disconnection of their hemispheres (Bradshaw, 1981). In fact, many theorists have been impressed by the degree to which even split-brain patients mostly experience unity of consciousness. There is little empirical basis for the idea that people have two independent streams of awareness neatly housed in the right and left halves of the brain.

3. Similarly, there is little direct evidence to support the notion that each hemisphere has its own mode of thinking, or *cognitive style* (Bradshaw, 1989). This notion is plausible, but far more evidence is needed. The key problem with this idea is that aspects of cognitive style have proven difficult to define and measure (Brownell & Gardner, 1981). For instance, there is great debate about the meaning of analytic versus synthetic thinking, or linear versus holistic thinking.

4. The evidence on the assertion that some people are left-brained while others are right-brained is inconclusive at best (Hellige, 1990). This notion has some plausibility—if it means only that some people consistently display more activation of one hemisphere than the other. However, more research is needed on these possible “preferences” in cerebral activation. The practical significance of any such preferences remains to be determined. At present, researchers do not have convincing data linking brainedness to musical ability, occupational choice, or the like.

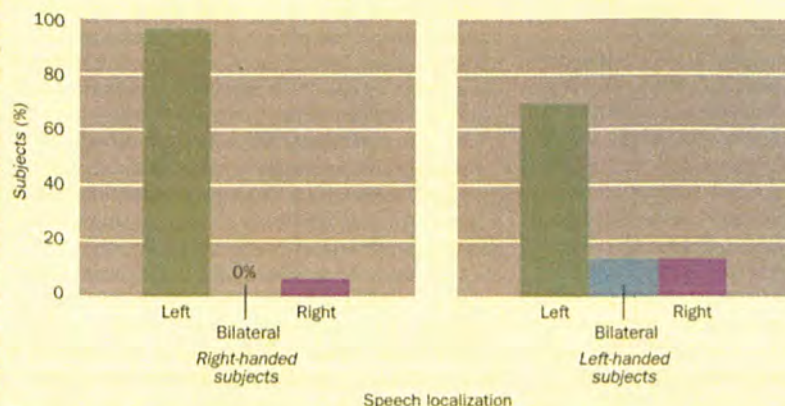
5. The idea that schools should be reformed to better exercise the right side of the brain borders on nonsense. In

neurologically intact people it is impossible to teach just one hemisphere at a time, and there is no evidence that it is beneficial to “exercise” a part of the brain (Levy, 1985). Many sound arguments exist for reforming American schools to encourage more holistic, intuitive thinking, but these arguments have nothing to do with cerebral specialization (Hardyck & Haapanen, 1979).

In summary, the theories linking cerebral specialization to cognitive processes are highly speculative. There's nothing wrong with theoretical speculation. Unfortunately, the tentative, conjectural nature of these ideas about cerebral specialization has gotten lost in the popular book descriptions of research on the right and left hemispheres (Coren, 1992). Popular writers continue to churn out allegedly scientific books, applying brain lateralization concepts to a host of new topics on which there often is little or no real evidence. Thus, one can find books on how to have right-brain sex (Wells, 1991), develop right-brain social skills (Snyder, 1989), and lose weight with a right-brain diet (Sommer, 1987). Commenting on this popularization, Hooper and Teresi (1986) note, “A widespread cult of the right brain ensued, and the duplex house that Sperry built grew into the K mart of brain science. Today our hairdresser lectures us about the Two Hemispheres of the Brain” (p. 223). Cerebral specialization is an important and intriguing area of research. However, it is unrealistic to expect that the hemispheric divisions in the brain will provide a biological explanation for every dichotomy or polarity in modes of thinking.

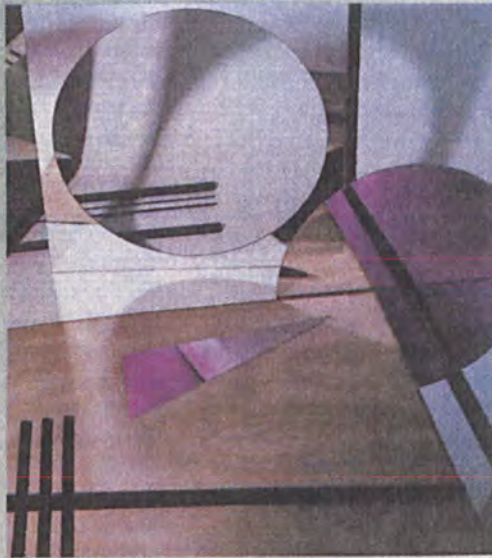
Figure 3.38

Handedness and patterns of speech localization. Left-handed people tend to show more variety in cerebral specialization and more bilateral representation than right-handers. For example, speech processing is almost always localized in the left hemisphere of right-handed subjects. However, Rasmussen and Milner (1977) found the usual pattern of speech localization in only 70 percent of their left-handed subjects.



CHAPTER 3 REVIEW

The Biological Bases of Behavior



KEY IDEAS

Communication in the Nervous System

- ◆ Behavior depends on complex information processing in the nervous system. Cells in the nervous system receive, integrate, and transmit information. Neurons are the basic communication links. They normally transmit a neural impulse (an electric current) along an axon to a synapse with another neuron.
- ◆ The neural impulse is a brief change in a neuron's electrical charge that moves along an axon. It is an all-or-none event. Neurons convey information about the strength of a stimulus by variations in their rate of firing.
- ◆ Action potentials trigger the release of chemicals called neurotransmitters that diffuse across a synapse to communicate with other neurons. Transmitters bind with receptors in the postsynaptic cell membrane, causing excitatory or inhibitory PSPs. Whether the postsynaptic neuron fires a neural impulse depends on the balance of excitatory and inhibitory PSPs. A variety of neurotransmitters bind at specific sites according to a lock-and-key model.
- ◆ Transmitter activity in humans must be measured indirectly, so animal research has been critical to progress in this area. The first transmitter identified was ACh, which plays a key role in muscular movement. Disturbances in the activity of the biogenic amine transmitters have been related to the development of depression and schizophrenia. Cocaine, amphetamines, and LSD appear to exert their main

effects by altering activity at biogenic amine synapses. GABA appears to be involved in the regulation of anxiety. Endorphins contribute to the body's feelings of pain and pleasure.

Organization of the Nervous System

- ◆ The nervous system can be divided into two main subdivisions, the central nervous system and the peripheral nervous system. The central nervous system consists of the brain and spinal cord. The spinal cord plays a critical role in distributing signals between the brain and the peripheral nervous system. The brain plays a crucial role in virtually all aspects of behavior.
- ◆ The peripheral nervous system consists of the nerves that lie outside the brain and spinal cord. It can be subdivided into the somatic nervous system, which connects to muscles and sensory receptors, and the autonomic nervous system, which connects to blood vessels, smooth muscles, and glands. The autonomic nervous system mediates the largely automatic arousal that accompanies emotion and the fight-or-flight response to stress.

Looking Inside the Brain: Research Methods

- ◆ Neuroscientists use a variety of methods to investigate brain-behavior relations. The EEG can record broad patterns of electrical activity in the brain. Lesioning involves destroying a piece of the brain. Another technique is electrical stimulation of areas in the brain in order to activate them. In recent years, new brain-imaging procedures have been developed, including CT scans, PET scans, and MRI scans. These new techniques have enormous potential for exploring brain-behavior relations.

The Brain and Behavior

- ◆ The brain has three major regions: the hindbrain, midbrain, and forebrain. Structures in the hindbrain and midbrain handle essential functions such as breathing, circulation, coordination of movement, and the rhythm of sleep and arousal. The forebrain includes many structures that handle higher functions. The thalamus is primarily a relay station. The hypothalamus is involved in the regulation of basic biological drives such as hunger and sex. The limbic system is a network of loosely connected structures involved in emotion, motivation, and memory.
- ◆ The cerebrum is the brain area implicated in most complex mental activities. The cortex is the cerebrum's convoluted outer layer, which is subdivided into four areas. These areas and their primary known functions are the occipital lobe (vision), the parietal lobe (touch), the temporal lobe (hearing), and the frontal lobe (movement of the body).

Right Brain/Left Brain: Cerebral Laterality

♦ The cerebrum is divided into right and left hemispheres connected by the corpus callosum. Evidence that the left cerebral hemisphere usually processes language led scientists to view it as the dominant hemisphere. However, studies of split-brain patients and perceptual asymmetries revealed that the right and left halves of the brain each have unique talents, with the right hemisphere being specialized to handle visual-spatial functions.

♦ Handedness is an obvious but puzzling aspect of human laterality that may be related to the functional asymmetry of the human brain. Neither environmental nor genetic models can explain why about 90 percent of the population is right-handed. Among the correlates of left-handedness, the most dramatic and controversial is the apparent reduction in longevity discovered in our Featured Study.

The Endocrine System: Another Way to Communicate

♦ The endocrine system consists of the glands that secrete hormones, which are chemicals involved in the regulation of basic bodily processes. The control centers for the endocrine system are the hypothalamus and the pituitary gland.

Heredity and Behavior: Is It All in the Genes?

♦ The basic units of genetic transmission are genes housed on chromosomes. Genes operate in pairs, and when heterozygous, one may be dominant and one recessive. Genotypes are translated into phenotypes in a variety of ways. Most behavioral qualities appear to involve polygenic inheritance.

♦ Researchers assess hereditary influence through a variety of methods, including family studies, twin studies, adoption studies, and genetic mapping. Research indicates that most behavioral qualities are influenced by a complex interaction between heredity and environment.

Putting It in Perspective

♦ Three of the book's unifying themes stand out in this chapter. First, we saw how heredity interacts with experience to govern behavior. Second, the discussions of biological factors underlying schizophrenia highlighted the multifactorial causation of behavior. Third, we saw how innovations in research methods often lead to advances in knowledge, underscoring the empirical nature of psychology.

Application: Thinking Critically About the Concept of "Two Minds in One"

♦ Split-brain research stimulated speculation about relations between cerebral specialization and

cognitive processes. Some theorists believe that each hemisphere has its own stream of consciousness and mode of thinking, which are applied to specific types of cognitive tasks. Some also believe that people vary in their reliance on the right and left halves of the brain and that schools should work more to exercise the right half of the brain.

♦ The cerebral hemispheres are specialized for handling different cognitive tasks, but only to a degree, and people vary in their patterns of hemispheric specialization. Evidence for duality in consciousness divided along hemispheric lines is weak. Evidence on whether people vary in brainedness and whether the two hemispheres vary in cognitive style is inconclusive. There is no evidence that exercising a hemisphere of the brain is useful, so a "right-brain curriculum" is pointless. Popular ideas about the right and left brain have gone far beyond the actual research findings.

KEY TERMS

Absolute refractory period	Hormones
Action potential	Hypothalamus
Adoption studies	Identical (monozygotic) twins
Afferent nerve fibers	Inhibitory PSP
Agonist	Interneurons
Antagonist	Lesioning
Autonomic nervous system (ANS)	Limbic system
Axon	Midbrain
Behavioral genetics	Motor neurons
Blood-brain barrier	Myelin sheath
Central nervous system (CNS)	Nerves
Cerebral cortex	Neuromodulators
Cerebral hemispheres	Neurons
Cerebral lateralization	Neurotransmitters
Cerebrospinal fluid (CSF)	Parasympathetic division
Chromosomes	Perceptual asymmetries
Corpus callosum	Peripheral nervous system
Dendrites	Phenotype
Dominant gene	Pituitary gland
Efferent nerve fibers	Polygenic traits
Electrical stimulation of the brain (ESB)	Postsynaptic potential (PSP)
Electroencephalograph (EEG)	Recessive gene
Endocrine system	Resting potential
Endorphins	Sensory neurons
Excitatory PSP	Soma
Family studies	Somatic nervous system
Forebrain	Split-brain surgery
Fraternal (dizygotic) twins	Stereotaxic instrument
Genes	Sympathetic division
Genetic mapping	Synapse
Genotype	Synaptic cleft
Glia	Terminal buttons
Handedness	Thalamus
Heterozygous condition	Twin studies
Hindbrain	Zygote
Homozygous condition	

KEY PEOPLE

Alan Hodgkin and Andrew Huxley
James Olds and Peter Milner
Candace Pert and Solomon Snyder
Robert Plomin
Roger Sperry and Michael Gazzaniga