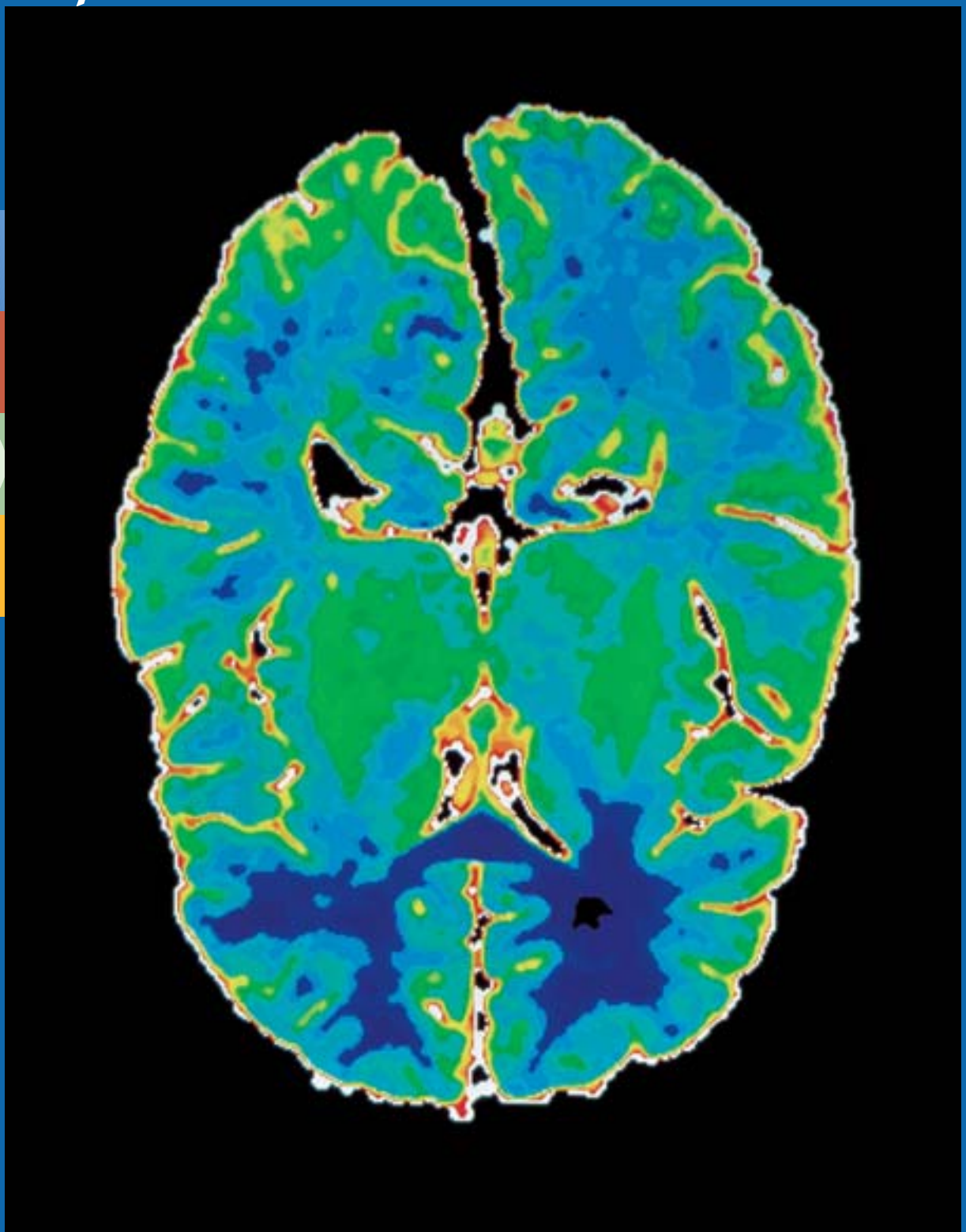
3 Biological Foundations of Behaviour



Chapter Outline

Learning Goals

THE NERVOUS SYSTEM 1

Characteristics
▼
Pathways in the Nervous System
▼
Divisions of the Nervous System

Discuss the nature and basic functions of the nervous system.

NEURONS 2

Specialized Cell Structure
▼
The Neural Impulse
▼
Synapses and Neurotransmitters
▼
Neural Networks

Explain what neurons are and how they process information.

STRUCTURES OF THE BRAIN AND THEIR FUNCTIONS 3

How the Brain and Nervous System Are Studied
▼
Levels of Organization in the Brain
▼
The Cerebral Cortex
▼
The Cerebral Hemispheres and Split-Brain Research
▼
Integration of Function in the Brain

Identify the brain's levels and structures, and summarize the functions of its structures.

THE ENDOCRINE SYSTEM 4

State what the endocrine system is and how it affects behaviour.

BRAIN DAMAGE, PLASTICITY, AND REPAIR 5

The Brain's Plasticity and Capacity for Repair
▼
Brain Tissue Implants

Describe the brain's capacity for recovery and repair.

GENETIC AND EVOLUTIONARY BLUEPRINTS OF BEHAVIOUR 6

Chromosomes, Genes, and DNA
▼
The Study of Genetics
▼
Genetics and Evolution

Explain how genetics and evolutionary psychology increase our understanding of behaviour.

When Brandi Binder was just six years old, surgeons at the University of California at Los Angeles removed the right side of her cerebral cortex (the outermost part and highest level of the brain) in an effort to subdue frequent seizures caused by very severe and uncontrollable epilepsy.

Epileptic seizures like the ones experienced by Brandi are the result of electrical "brainstorms" that flash uncontrollably from one side of the brain to the other. Nerve cells on one side become overactive and stimulate overactivity in nerve cells on the other side. The excess stimulation produces a seizure in which the individual loses consciousness and goes into convulsions. In severe cases, seizures can occur numerous times during the day. Physicians have discovered that by severing the connection between the two sides of the brain or by removing the side of the brain in which the overactivity originates, they can eliminate the seizures or at least reduce their severity. Although not without risks and disadvantages, such surgery may greatly improve an individual's quality of life.

Brandi Binder is evidence of the brain's great power, flexibility, and resilience. Despite having had the right side of her cortex removed, Brandi engages in many activities often portrayed as right-brain activities. She loves music, math, and art; she is shown here working on one of her paintings.

After her surgery, Brandi Binder had almost no control over muscles on the left side of her body, the side controlled by the right side of her brain. She needed years of therapy to regain abilities that she lost with the right side of her brain (Stuss, Winocur, & Robertson, 1999). At age 13, however, Brandi was an A student. She also loved music, math, and art, all of which are commonly associated with the brain's right side.

Brandi's story illustrates how amazingly adaptive and flexible the brain is, especially at an early age. In Brandi's case, the left side of her brain took over functions that are based on the right side. Although her recuperation has not been 100 percent—she never regained the use of her left arm, for example—her recovery is remarkable. Her story shows that if there is a way to compensate for damage, the brain will find it (Nash, 1997).

It is not by coincidence that the human brain is so versatile. It has evolved over millions of years from a small, fairly primitive organ into a very complex network capable of coordinating our body functions, our thoughts, our emotions, and our behaviours. Evolutionary psychologists emphasize that behaviours that increase an organism's reproductive success and enhance the ability to pass one's genes on to the next generation eventually prevail in nature over behaviours that do not promote the organism's survival. From their point of view, the complex human brain has evolved because its increased complexity in some individuals enabled them to behave in ways that gave them and their descendants a better chance of survival—for example, by being able to anticipate adversity and plan for ways to avoid it or cope with it.

This chapter examines important biological foundations of human behaviour. The main focus is the nervous system and its command centre—the brain.

It also explores the genetic and evolutionary processes that have a significant influence on who we are as individuals and how we behave.

1 THE NERVOUS SYSTEM

Characteristics | **Pathways in the Nervous System** | **Divisions of the Nervous System**

What is the nervous system and what does it do?

nervous system The body's electrochemical communication circuitry, made up of billions of neurons.

The **nervous system** is the body's electrochemical communication circuitry. The field that studies the nervous system is called *neuroscience,* and the people who study it are *neuroscientists.*

The human nervous system is made up of billions of interconnected cells, and it is likely the most intricately organized aggregate of matter on planet Earth (Campbell,

Reece, & Mitchell, 2002). A single cubic centimetre of the human brain consists of well over 50 million nerve cells, each of which communicates with many other nerve cells in information processing networks that make the most elaborate computer seem primitive.

Characteristics

The brain and nervous system guide our interaction with the world around us, move the body through the world, and direct our adaptation to our environment. Several extraordinary characteristics allow the nervous system to direct our behaviour: complexity, integration, adaptability, and electrochemical transmission.

Complexity The brain and nervous system are enormously complex. The brain itself is composed of billions of nerve cells. The orchestration of all of these cells to allow people to sing, dance, write, talk, and think is an awe-inspiring task. As Brandi Binder paints a piece of art, her brain is carrying out a huge number of tasks—involved in breathing, seeing, thinking, moving—in which extensive assemblies of nerve cells are participating.

Integration Neuroscientist Steven Hyman (2001) calls the brain the *great integrator.* By this, he means that the brain does a wonderful job of pulling information together. Sounds, sights, touch, taste, hearing, genes, environment—the brain integrates all of these as we function in our world.

The brain and the nervous system have different levels and many different parts. Brain activity is integrated across these levels through countless interconnections of brain cells and extensive pathways that link different parts of the brain. Each nerve cell communicates, on average, with 10,000 others, making up many kilometres of connections (Bloom, Nelson, & Lazerson, 2001; Johnson, 2003). Consider what happens when a mosquito bites your arm. How does your brain know you were bitten and where? Bundles of interconnected nerve cells relay information about the bite from your arm through the nervous system in a very orderly fashion to the highest level of the brain.

Indeed, behaving in just about any way requires many interconnections in your brain. Brandi Binder's painting does not occur because of what is going on in a single brain cell or a single part of her brain but rather because of the coordinated, integrated effort of many different nerve cells and parts of her brain.

Adaptability The world around us is constantly changing. To survive, we must adapt to new conditions (Bloom, Nelson, & Lazerson, 2001). Our brain and nervous system together serve as our agent in adapting to the world. Although nerve cells reside in certain brain regions, they are not fixed and immutable structures. They have a hereditary, biological foundation, but they are constantly adapting to changes in the body and the environment (Wilson, 2003).

The term **plasticity** denotes the brain's special capacity for modification and change. The experiences that we have contribute to the wiring or rewiring of the brain (Blair, 2002; Greenough, 2000; Nash, 1997; Scharfman, 2002). For example, each time a baby tries to touch an object or gazes intently at a face, electrical impulses and chemical messengers shoot through the baby's brain, knitting brain cells together into pathways and networks.

The brain's plasticity is nowhere more evident than in Brandi Binder's case. After she lost much of the right side of her brain, the left side took over many functions that often are thought to reside only in the right side.

Electrochemical Transmission The brain and the nervous system function essentially as an information processing system, powered by electrical impulses and chemical messengers. When people speak to each other, they use words. When neurons communicate with each other, they use chemicals.

plasticity The brain's special capacity for modification and change.

The electrochemical communication system works effectively in most people to allow us to think and act. However, when the electrochemical system is short-circuited, as in the case of Brandi's epilepsy, the flow of information is disrupted, the brain is unable to channel information accurately, and the person cannot effectively engage in mental processing and behaviour. Epileptic seizures are the result of abnormal electrical discharges in the brain. Just as an electrical surge during a lightning storm can disrupt the circuits in a computer, the electrical surge that produces an epileptic seizure disrupts the brain's information processing circuits. The brains of individuals with epilepsy work effectively to process information between seizures, unless the seizures occur with such regularity that they cause brain damage. In about 75 percent of epilepsy cases, seizures do not cause structural damage to the brain.

Pathways in the Nervous System

As we interact with and adapt to the world, the brain and the nervous system receive and transmit sensory input, integrate the information received from the environment, and direct the body's motor activities. Information flows into the brain through sensory input, becomes integrated within the brain, and then moves out of the brain to be connected with motor output (Enger & Ross, 2003).

This flow of information through the nervous system occurs in specialized pathways that are adapted for different functions. These pathways are made up of afferent nerves, neural networks, and efferent nerves. **Afferent nerves,** or sensory nerves, carry information to the brain. The word *afferent* comes from the Latin word meaning "bring to." These sensory pathways communicate information about external and bodily environments from sensory receptors into and throughout the brain.

Efferent nerves, or motor nerves, carry the brain's output. The word *efferent* is derived from the Latin word meaning "bring forth." These motor pathways communicate information from the brain to the hands, feet, and other areas of the body that allow a person to engage in motor behaviour.

Most information processing occurs when information moves through **neural networks** in the central nervous system. The function of these networks of nerve cells is to integrate sensory input and motor output (Peng, Qiao, & Xu, 2002). For example, as you read your class notes, the afferent input from your eye is transmitted to your brain, then passed through many neural networks, which translate (process) your black pen scratches into neural codes for letters, words, associations, and meaning. Some of the information is stored in the neural networks for future associations, and, if you read aloud, some is passed on as efferent messages to your lips and tongue. Neural networks make up most of the brain.

afferent nerves Sensory nerves that transport information to the brain.

efferent nerves Motor nerves that carry the brain's output.

neural networks Clusters of neurons that are interconnected to process information.

central nervous system (CNS) The brain and spinal cord.

peripheral nervous system (PNS) The network of nerves that connects the brain and spinal cord to other parts of the body. It is divided into the somatic nervous system and the autonomic nervous system.

somatic nervous system Division of the PNS consisting of sensory nerves, whose function is to convey information to the CNS, and motor nerves, whose function is to transmit information to the muscles.

Divisions of the Nervous System

When the nineteenth-century American poet and essayist Ralph Waldo Emerson said, "The world was built in order and the atoms march in tune," he must have had the human nervous system in mind. This truly elegant system is highly ordered and organized for effective function.

Figure 3.1 shows the two primary divisions of the human nervous system: the central nervous system and the peripheral nervous system. The **central nervous system (CNS)** is made up of the brain and spinal cord. More than 99 percent of all nerve cells in our body are located in the CNS. The **peripheral nervous system (PNS)** is the network of nerves that connects the brain and spinal cord to other parts of the body. The functions of the peripheral nervous system are to bring information to and from the brain and spinal cord and to carry out the commands of the CNS to execute various muscular and glandular activities.

The peripheral nervous system itself has two major divisions: the somatic nervous system and the autonomic nervous system. The **somatic nervous system** consists of sensory nerves, whose function is to convey information from the skin and muscles to the CNS about conditions such as pain and temperature; and motor nerves, whose func-

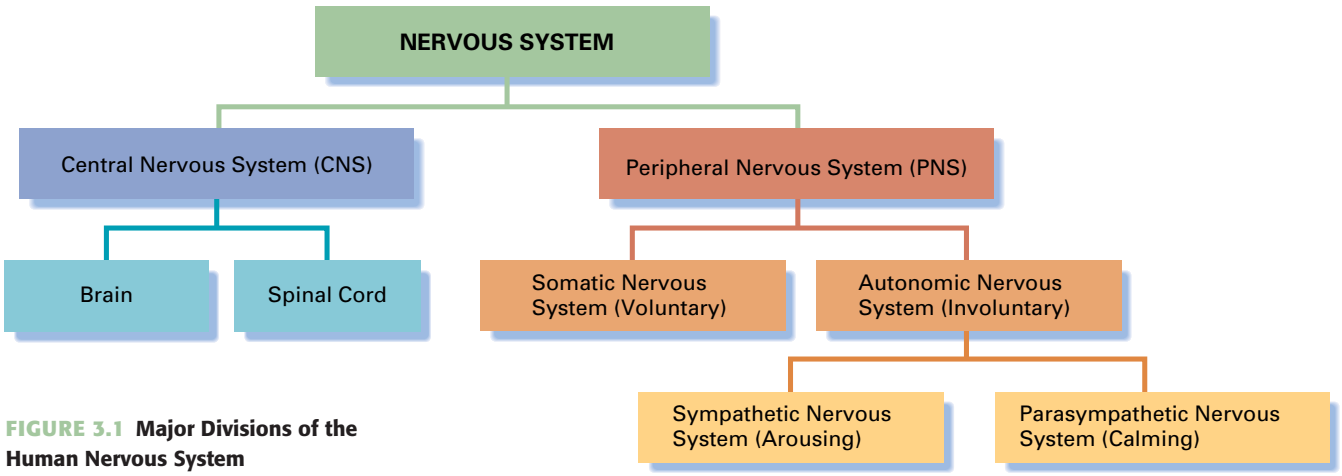


FIGURE 3.1 Major Divisions of the Human Nervous System

tion is to tell muscles what to do. The function of the **autonomic nervous system** is to take messages to and from the body's internal organs, monitoring such processes as breathing, heart rate, and digestion. The autonomic nervous system is also divided into two parts: the **sympathetic nervous system** arouses the body and the **parasympathetic nervous system** calms the body.

To better understand the various divisions of the nervous system, let's see what they do in a particular situation. Imagine that you are preparing to ask a judge to dismiss a parking ticket. As you are about to enter the courtroom, you scan a note card one last time to remember what you plan to say. Your *peripheral nervous system* carries the written marks from the note card to your central nervous system. Your *central nervous system* processes the marks, interpreting them as words, while you memorize key points and plan ways to keep the judge friendly. After studying the notes several minutes longer, you jot down an additional joke that you hope will amuse her. Again your *peripheral nervous system* is at work, conveying to the muscles in your arm and hand the information from your brain that enables you to make the marks on the paper. The information that is being transmitted from your eyes to your brain and to your hand is handled by the *somatic nervous system.* This is your first ticket hearing, so you are a little anxious. Your stomach feels queasy, and your heart begins to thump. This is the *sympathetic* division of the *autonomic nervous system* functioning as you become aroused. You regain your confidence after reminding yourself that you were parked in a legal spot. As you relax, the *parasympathetic* division of the *autonomic nervous system* is working.

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

Review and Sharpen Your Thinking

1 ***Identify the parts of the nervous system and explain their role in behaviour.***

- Identify the fundamental characteristics of the brain and nervous system.
- Name and describe the pathways that allow the nervous system to carry out its three basic functions.
- Outline the divisions of the nervous system and explain their roles.

Try this exercise without looking at Figure 3.1. Suppose you (1) saw a person coming toward you, (2) realized it was someone famous, (3) got excited, (4) waved and shouted, (5) suddenly realized it was not a famous person, and (6) became suddenly calm again. Which part of your nervous system would have been heavily involved at each of these six points?

autonomic nervous system Division of the PNS that communicates with the body's internal organs. It consists of the sympathetic and parasympathetic nervous systems.

sympathetic nervous system The division of the autonomic nervous system that arouses the body.

parasympathetic nervous system The division of the autonomic nervous system that calms the body.

2 NEURONS

- Specialized Cell Structure
- Synapses and Neurotransmitters
- The Neural Impulse
- Neural Networks

What are neurons and how do they communicate?

Within each division of the nervous system, much is happening at the cellular level. Nerve cells, chemicals, and electrical impulses work together to transmit information at speeds of up to 530 kilometres per hour. As a result, information can travel from your brain to your hands (or vice versa) in a matter of milliseconds (Krogh, 2000; Martini, 2001).

There are two types of cells in the nervous system: neurons and glial cells. **Neurons** are the nerve cells that actually handle the information processing function.

The human brain contains about 100 billion neurons. The average neuron is as complex as a small computer and has as many as 10,000 physical connections with other cells. To have even the merest thought requires millions of neurons acting simultaneously (Carter, 1998).

Glial cells provide support and nutritional functions in the nervous system (Lemke, 2001; Meller & others, 2002). Glial cells are not specialized to process information in the way that neurons are, although there are many more of them in the nervous system than there are neurons. In one study, neurons placed in a solution containing glial cells grew more rapidly and prolifically than neurons floating in the same solution without glial cells (Kennedy & Folk-Seang, 1986). This study indicates that glial cells function in a supportive or nutritive role for neurons.

Specialized Cell Structure

Not all neurons are alike. They are specialized to handle different information-processing functions. However, all neurons do have some common characteristics. Most neurons are created very early in life, but their shape, size, and connections can change throughout the life span. Thus the way neurons function reflects a major characteristic of the nervous system that we described at the beginning of the chapter: plasticity. They are not fixed and immutable but can change. Every neuron has a cell body, dendrites, and axon (see figure 3.2).

The **cell body** contains the nucleus, which directs the manufacture of substances that the neuron needs for growth and maintenance.

Dendrites receive and orient information toward the cell body. One of the most distinctive features of neurons is the tree-like branching of their dendrites. Most nerve cells have numerous dendrites, which increase their surface area, allowing each neuron to receive input from many other neurons.

The **axon** is the part of the neuron that carries information away from the cell body toward other cells. Although very thin (1/25,000 of a centimetre), axons can be very long, with many branches. In fact, some extend more than a metre—all the way from the top of the brain to the base of the spinal cord.

The surface of each neuron, including its dendrites and axon, is comprised of a very thin cellular membrane that is much like the skin covering the surface of the human body. Like human skin, neuronal membranes are semi-permeable, meaning that they contain tiny holes or *channels* that only allow certain substances to pass into and out of the neurons.

A **myelin sheath,** a layer of fat cells, encases and insulates most axons. By insulating axons, myelin sheaths speed up transmission of nerve impulses (Mattson, 2002; Paus & others, 2001). Multiple sclerosis, a degenerative disease of the nervous system in which a destruction of myelin tissue occurs, disrupts neuronal communication (Archibald & Fisk, 2000).

neuron Nerve cell that is specialized for processing information. Neurons are the basic units of the nervous system.

glial cells Provide support and nutritional functions in the nervous system.

cell body Part of the neuron that contains the nucleus, which directs the manufacture of substances that the neuron needs for growth and maintenance.

dendrites Branches of a neuron that receive and orient information toward the cell body; most neurons have numerous dendrites.

axon The part of the neuron that carries information away from the cell body to other cells; each neuron has only one axon.

myelin sheath A layer of fat cells that encases and insulates most axons. The myelin sheath speeds up the transmission of nerve impulses.

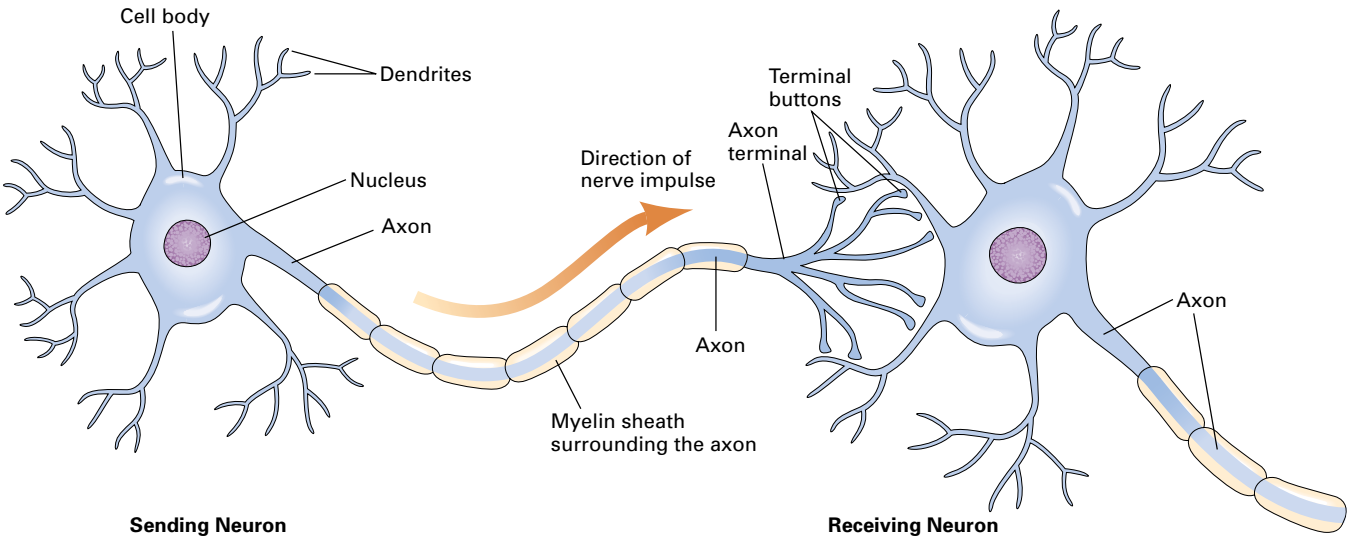


FIGURE 3.2 The Neuron The drawing shows the parts of a neuron and the connection between one neuron and another. Note the cell body, branching of dendrites, and the axon with a myelin sheath.

The myelin sheath developed as the brain evolved. As brain size increased, it became necessary for information to travel over longer distances in the nervous system. Axons without myelin sheaths are not very good conductors of electricity. With the insulation of myelin sheaths, they transmit electrical impulses and convey information much more rapidly. We can compare the myelin sheath's development to the evolution of freeways as cities grew. A freeway is a shielded road. It keeps fast-moving, long-distance traffic from getting snarled by slow local traffic.

The Neural Impulse

A neuron sends information through its axon in the form of brief impulses, or waves, of electricity. In old movies you might have seen telegraph operators tapping out messages one click at a time over a telegraph wire to the next telegraph station. That is what neurons do. To transmit information to other neurons, a neuron sends impulses ("clicks") through its axon to the next neuron. As you reach to turn this page, hundreds of such impulses will stream down the axons in your arm to tell your muscles just when to flex and how vigorously. By changing the rate and timing of the signals or "clicks," the neuron can vary its message.

How does a neuron—a living cell—generate electrical impulses? To answer this question, we need to further examine the nature of a neuron and the fluids in which it floats. Because the neuronal membrane is semipermeable, the composition of the fluid outside the neuron (*the extracellular fluid*) differs from that inside the neuron (*the cytoplasm*). This difference creates a small electrical charge that the neuron uses in order to generate electrical impulses. Floating in the fluids inside and outside the neural membrane are electrically charged particles called *ions*.

Some of these ions, notably sodium (Na^+) and potassium (K^+), carry positive charges. Negatively charged ions of chlorine (Cl^-) and other elements are also present. When the neuron is at rest (not transmitting information), there are more negative ions inside the cell membrane than there are in the surrounding fluids. The membrane prevents positive ions from flowing into the cell. The neuron creates electric signals by moving positive and negative ions back and forth through its outer membrane. How does the movement of ions across the membrane occur? Embedded in the membrane are hundreds of thousands of small gates, known as *ion channels*, that open and close to let various ions pass into and out of the cell. Normally, when the neuron is resting and not sending information, the ion channels prevent positive ions from entering the neuron and a slight negative charge is present along the membrane of the cell. **Resting potential** is the term given to the stable, negative charge of an inactive neuron (see figure 3.3). That potential, by the way, is about −70 millivolts,

resting potential The term given to the stable, negative charge of an inactive neuron.

FIGURE 3.3 The Resting Potential
An oscilloscope measures the difference in electrical potential between two electrodes. When one electrode is placed inside an axon at rest and one is placed outside, the electrical potential inside the cell is −70 millivolts (mV) relative to the outside. This potential difference is due to the separation of positive (+) and negative (−) charges along the membrane.

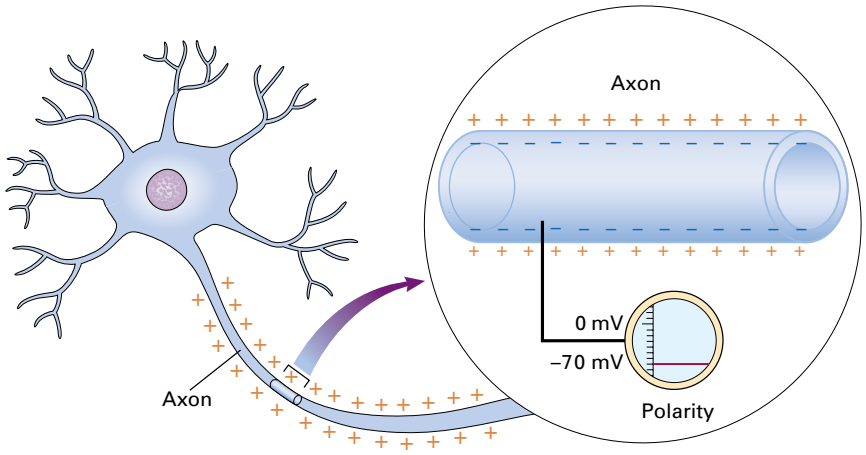
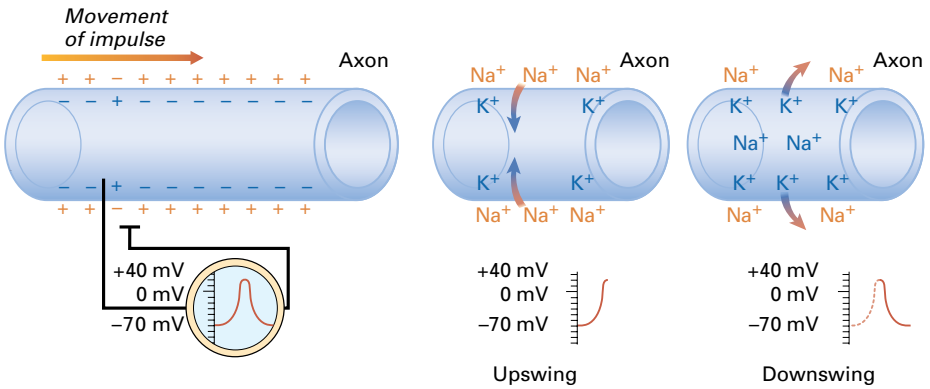


FIGURE 3.4 The Action Potential
An action potential is a wave of localized depolarization that travels down the axon as the ion channels in the axon membrane open and close. (*a*) The action potential causes a change in electrical potential as it moves along the axon. (*b*) The movements of sodium ions (Na^+) and potassium ions (K^+) into and out of the axon cause the electrical changes.



(a) Action potential generated by an impulse received by the neuron

(b) Movement of ions responsible for the action potential

which is about one-fourteenth of a volt, so fourteen neurons could make up a one-volt battery. An electric eel's 8400 neurons could generate 600 volts!

A neuron becomes activated when an incoming impulse, in reaction to, say, a pinprick or the sight of someone's face, raises the neuron's voltage threshold, and the sodium channels at the base of the axon open briefly. This action allows positively charged sodium ions to flow into the neuron, creating a more positively charged neuron and *depolarizing* the membrane by decreasing the charge difference between the fluids inside and outside of the neuron. Then potassium channels open, and positively charged potassium ions move out through the neuron's semipermeable membrane. This returns the neuron to a negative charge. Then the same process occurs as the next group of channels flip open briefly. And so it goes all the way down the axon, just like a long row of cabinet doors opening and closing in sequence.

action potential The term used to describe the brief wave of electrical charge that sweeps down the axon during the transmission of a nerve impulse.

all-or-none principle Once an electrical impulse reaches a certain level of intensity, it fires and moves all the way down the axon without losing any of its intensity.

The term **action potential** is used to describe the brief wave of positive electrical charge that sweeps down the axon (see figure 3.4). An action potential lasts only about one-thousandth of a second, because the sodium channels can stay open for only a very brief time. They quickly close again and become reset for the next action potential. When a neuron sends an action potential down the axon, it is commonly said to be "firing."

The action potential abides by the **all-or-none principle:** Once incoming electrical impulses reach a certain level of intensity, the neuron fires and the action potential moves all the way down the axon without losing any of its intensity. The impulse

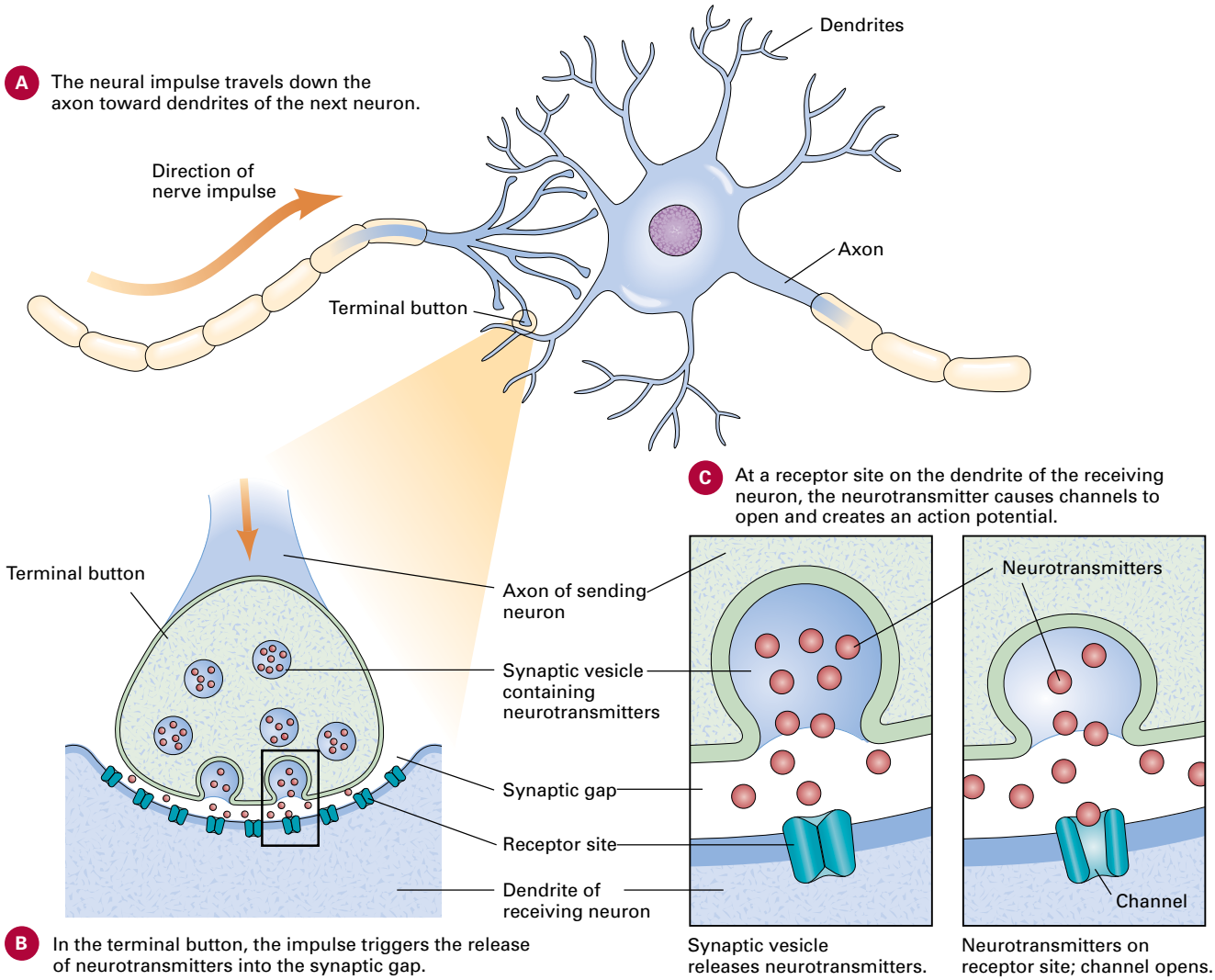


FIGURE 3.5 How Synapses and Neurotransmitters Work (*A*) The axon of the *presynaptic* (sending) neuron meets dendrites of the *postsynaptic* (receiving) neuron. (*B*) This is an enlargement of one synapse, showing the synaptic gap between the two neurons, the terminal button, and the synaptic vesicles containing a neurotransmitter. (*C*) This is an enlargement of the receptor site. Note how the neurotransmitter opens the channel on the receptor site, triggering the neuron to fire.

travelling down an axon can be compared to a burning fuse. It doesn't matter whether a match or blowtorch was used to light the fuse; once the fuse has been lit, the spark travels quickly and with the same intensity down the fuse.

Synapses and Neurotransmitters

What happens when a neural impulse reaches the end of the axon? Neurons do not touch each other directly, but they manage to communicate. The story of the connection between one neuron and another is one of the most intriguing and highly researched areas of contemporary neuroscience (Bi & Poo, 2001). Figure 3.5 gives an overview of how this connection between neurons takes place.

Synaptic Transmission **Synapses** are tiny junctions between neurons; the gap between neurons is referred to as a *synaptic gap*. Most synapses lie between the axon of one neuron and the dendrites or cell body of another neuron. Before the electrical impulse can cross the synaptic gap, it must be converted into a chemical signal.

Each axon branches out into many *axon terminals*, each of which ends in structures called *terminal buttons*. Stored in minute synaptic vesicles (sacs) within the terminal

synapses Tiny junctions between two neurons, generally where the axon of one neuron meets the dendrites or cell body of another neuron.

buttons are substances called **neurotransmitters.** As their name suggests, neurotransmitters transmit or carry information across the synaptic gap to the next neuron. When a nerve impulse reaches the terminal button, synaptic vesicles move to the neuronal membrane, triggering the release of neurotransmitter molecules from the vesicles. The neurotransmitter molecules flood the synaptic gap. Their movements are random, but some of them bump into receptor sites on the next neuron. If the shape of the receptor site corresponds to the shape of the neurotransmitter molecule, the neurotransmitter acts like a key to open an ion channel at the receptor site, triggering the inflow of positive ions, resulting in the possible stimulation of an action potential in the receiving neuron.

Think of the synapse as a river that blocks a road. A grocery truck (the action potential) arrives at one bank of the river, crosses by ferry, and continues its journey to market. Similarly, a message in the brain is "ferried" across the synapse by a neurotransmitter, which pours out of the terminal button when as the message approaches the synapse.

Neurochemical Messengers There are many different neurotransmitters. Each one plays a specific role and functions in a specific pathway. Whereas some neurotransmitters stimulate or excite neurons to fire, others can inhibit neurons from firing (Heim & Nemeroff, 2002). Some neurotransmitters are both excitatory and inhibitory, depending on what is needed. Up to 50,000 neurons can synapse with any particular neuron. As various combinations of excitatory and inhibitory neurotransmitters move across the synaptic gap, they excite and inhibit electrical activity in any particular neuron.

Most neurons secrete only one type of neurotransmitter, but often many different neurons are simultaneously secreting different neurotransmitters into the synaptic gaps of a single neuron. At any given time, a neuron is receiving a mixture of messages from the neurotransmitters. At its receptor sites, the chemical molecules bind to the membrane and either excite the neuron, bringing it closer to the threshold at which it will fire, or inhibit the neuron from firing. Usually the binding of an excitatory neurotransmitter from one neuron will not be enough to trigger an action potential in the receiving neuron. Triggering an action potential often takes a number of neurons sending excitatory messages simultaneously or fewer neurons sending rapid-fire excitatory messages.

So far, researchers have identified more than 50 neurotransmitters, each with a unique chemical makeup. The rapidly growing list likely will grow to more than 100 (Johnson, 2003). In organisms ranging from snails to whales, neuroscientists have found the same neurotransmitter molecules that our own brains use. Many animal venoms, such as that of the black widow spider, actually are neurotransmitter-like substances that do their harm by disturbing neurotransmission. To get a better sense of what neurotransmitters do, let's consider just six that have major effects on our behaviour.

Acetylcholine *Acetylcholine (ACh)* usually stimulates the firing of neurons and is involved in the action of muscles, learning, and memory (Devi & Silver, 2000; McIntyre & others, 2002). ACh is found throughout the central and peripheral nervous systems. The venom of the black widow spider causes ACh to gush through the synapses between the spinal cord and skeletal muscles, producing violent spasms. The drug curare, which some South American Aboriginals apply to the tips of poison darts, blocks receptors for ACh, paralyzing muscles. In contrast, nicotine stimulates acetylcholine receptors. Individuals with Alzheimer's disease, a degenerative brain disorder that involves a decline in memory, have an acetylcholine deficiency. Some of the drugs that alleviate the symptoms of Alzheimer's disease do so by compensating for the loss of the brain's supply of acetylcholine.

GABA *GABA* (gamma aminobutyric acid) is found throughout the central nervous system. It is believed to be the neurotransmitter in as many as one-third of the brain's synapses. GABA is important in the brain because it keeps many neurons from firing (Bou-Flores & Berger, 2001; Ryan, 2001). In this way it helps to control the preciseness of the signal being carried from one neuron to the next. Low levels of GABA are linked with anxiety. Valium and other antianxiety drugs increase the inhibiting effects of GABA.

neurotransmitters Chemicals that carry information across the synaptic gap from one neuron to the next.

Norepinephrine *Norepinephrine* usually inhibits the firing of neurons in the central nervous system, but it excites the heart muscle, intestines, and urogenital tract. Stress stimulates the release of norepinephrine (Zaimovic & others, 2000). This neurotransmitter also helps to control alertness. Too little norepinephrine is associated with depression, too much with agitated, manic states. For example, amphetamines and cocaine cause hyperactive, manic states of behaviour by rapidly increasing brain levels of norepinephrine.

Recall from the beginning of the chapter that one of the most important characteristics of the brain and nervous system is integration. In the case of neurotransmitters, they may work in teams of two or more. For example, norepinephrine works with acetylcholine to regulate states of sleep and wakefulness.

Dopamine *Dopamine* mainly inhibits. It helps to control voluntary movement (Jakel & Marangos, 2000). Dopamine also affects sleep, mood, attention, and learning. Stimulant drugs, such as cocaine and amphetamines, produce excitement, alertness, elevated mood, decreased fatigue, and sometimes increased motor activity mainly by activating dopamine receptors.

Low levels of dopamine are associated with Parkinson's disease, in which physical movements deteriorate (Malapani, Deweer, & Gibbon, 2002). Although Alberta-born actor Michael J. Fox contracted Parkinson's disease in his late 20s, the disease is uncommon before the age of 30 and becomes more common as people age. High levels of dopamine are associated with schizophrenia, a severe mental disorder that is discussed in chapter 14.

Serotonin *Serotonin* also primarily inhibits. Serotonin is involved in the regulation of sleep, mood, attention, and learning. In regulating states of sleep and wakefulness, it teams with acetylcholine and norepinephrine. Lowered levels of serotonin are associated with depression (Kanner & Balabanov, 2002; Wagner & Ambrosini, 2001). The antidepressant drug Prozac works by increasing brain levels of serotonin. Figure 3.6 shows the brain pathways for serotonin.

Endorphins *Endorphins* are natural opiates that mainly stimulate the firing of neurons. Endorphins shield the body from pain and elevate feelings of pleasure. A long-distance runner, a woman giving birth, and a person in shock after a car wreck all have elevated levels of endorphins (Jamurtas & others, 2000).

As early as the fourth century B.C., the Greeks used wild poppies to induce euphoria. More than 2000 years later, the magical formula behind opium's addictive action was finally discovered. In the early 1970s, scientists found that opium plugs into a sophisticated system of natural opiates that lie deep within the brain's pathways (Pert, 1999; A. B. Pert & Snyder, 1973; Spetea & others, 2002). Morphine, an opiate that is sometimes used as a painkiller, mimics the action of endorphins by stimulating receptors in the brain involved with pleasure and pain.

Drugs and Neurotransmitters Most drugs that influence behaviour do so mainly by interfering with the work of neurotransmitters (Beatty, 2001; Mader, 2003). Drugs can mimic or increase the effects of a neurotransmitter, or they can block those effects. An **agonist** is a drug that mimics or increases a neurotransmitter's effects. For example, the drug morphine mimics the actions of endorphins by stimulating receptors in the brain associated with pleasure and pain. An **antagonist** is a drug that blocks a neurotransmitter's effects. For example, alcohol blocks serotonin activity (Fils-Aime & others, 1996).

FIGURE 3.6 Serotonin Pathways
Each of the neurotransmitters in the brain has specific pathways in which they function. Shown here are the pathways for serotonin.

Neural Networks

So far in the coverage of neurons, we have focused mainly on how a single neuron functions and on how a nerve impulse travels from one neuron to another. Now let's look at how large numbers of neurons normally work together to integrate incoming information and coordinate outgoing information.

agonist A drug that mimics or increases a neurotransmitter's effects.

antagonist A drug that blocks a neurotransmitter's effects.

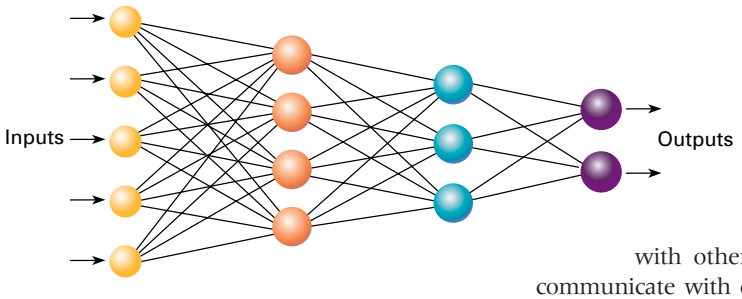


FIGURE 3.7 An Example of a Neural Network Inputs (information from the environment and sensory receptors—as when someone looks at a person's face) become embedded in extensive connections between neurons in the brain, which leads to outputs (such as remembering the person's face).

At the beginning of the chapter, we briefly described neural networks as clusters of neurons that are interconnected to process information. Figure 3.7 shows a simplified drawing of a neural network or pathway (McIntosh, 2000). By looking at this diagram, you can get an idea of how the activity of one neuron is linked with many others.

Some neurons have short axons and communicate with other nearby neurons. Other neurons have long axons and communicate with circuits of neurons some distance away. Researchers have found that these neural networks are not static (Carlson, 2000; Meyer & van Vreeswijk, 2002). They can be altered through changes in the strength of synaptic connections.

Any piece of information, such as a name, might be embedded in hundreds or even thousands of connections between neurons (Lee & Farhat, 2001). In this way, such human activities as being attentive, memorizing, and thinking are distributed over a wide range of interconnected neurons (Bartlett, 2002). The strength of these connected neurons determines how well you remember the information (Golden, 2002; Krause & others, 2000; McClelland & Rumelhart, 1986).

Let's see how the neural network concept might explain a typical memory, such as the name of a new acquaintance. Initially, the processing of the person's face might activate a small number of weak neuronal connections that make you remember a general category ("interesting woman" or "attractive man"). However, repeated experience with that person will increase the strength and possibly the number of those connections. So you may remember the person's name as the neurons activated by the name become connected with the neurons that are activated by the face. Chapter 8 explores the nature of memory at greater length.

Online LearningCentre with PowerWeb

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

Review and Sharpen Your Thinking

2 ***Explain what neurons are and how they process information.***

- Differentiate between neurons and glial cells, and describe the functions of the parts of a neuron.
- Explain what a neural impulse is and how it is generated.
- Discuss how a neural impulse is transmitted from one neuron to another.
- Describe the function of neural networks.

Why is it important to have so many connections and to have integration between neurons?

3 STRUCTURES OF THE BRAIN AND THEIR FUNCTIONS

How the Brain and Nervous System Are Studied | **The Cerebral Cortex** | **Integration of Function in the Brain**

Levels of Organization in the Brain | **The Cerebral Hemispheres and Split-Brain Research**

How is the brain organized?

The extensive and intricate networks of neurons that we have just studied are not visible to the naked eye. Fortunately, technology is available to help neuroscientists form pictures of the structure and organization of neurons and the larger structures they make up without harming the organism being studied. This section explores some of

the techniques that are used in brain research and discusses what they have shown us about the structures and functions of the brain. Special attention is given to the cerebral cortex, the highest region of the brain.

How the Brain and Nervous System Are Studied

Much of our early knowledge of the human brain comes from clinical studies of individuals who suffered brain damage from injury or disease or who had brain surgery to relieve another condition (like Brandi Binder). Modern discoveries have relied largely on sophisticated techniques that enable researchers to "look inside" the brain while it is at work. Let's examine some of these techniques.

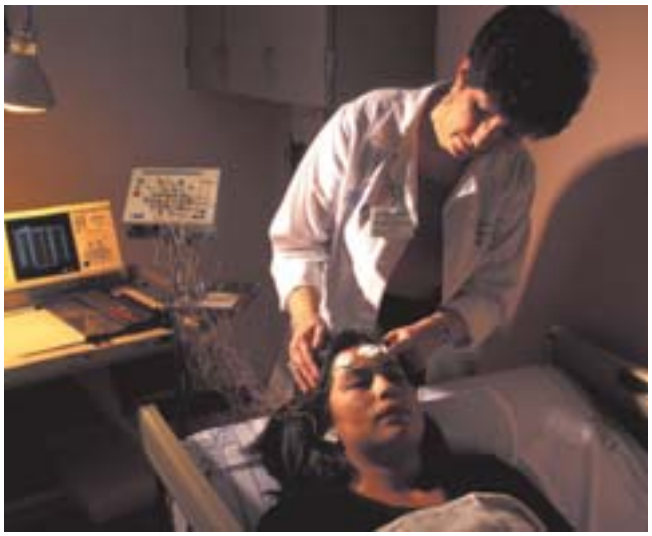


FIGURE 3.8 An EEG Recording
The electroencephalograph (EEG) is widely used in sleep research. It has led to some major breakthroughs in understanding sleep by showing how the brain's electrical activity changes during sleep.

Brain Lesioning *Brain lesioning* is an abnormal disruption in the tissue of the brain resulting from injury or disease. The study of naturally occurring brain lesions in humans has provided considerable information about how the brain functions.

Neuroscientists also produce lesions in laboratory animals to determine the effects on the animal's behaviour (Krauss & Jankovic, 2002). These lesions may be made by surgically removing brain tissue, destroying tissue with a laser, or eliminating tissue by injecting it with a drug. Administering a drug that temporarily inactivates an area of the brain can sometimes make transient lesions. The organism's behaviour can be studied while the area is inactivated; after the effects of the drug have worn off, brain activity in the area returns to normal (Gazzaniga, Ivry, & Mangun, 2002).

Staining A central interest in neuroscience is to identify the pathways of connectivity in the brain and nervous system that allow information to get from one place to another (B. K. Sorensen & others, 2002). This is not an easy task because of the complexity and extent of the interconnections. Much of the progress in charting these neural networks has come about through the use of stains, or dyes, that are selectively absorbed by neurons. One commonly used stain is horseradish peroxidase. A stain will coat only a small portion of neurons so that neuroscientists, using high-powered microscopes, can see which neurons absorb the stains and determine how they are connected.

Electrical Recording Also widely used is the *electroencephalograph (EEG),* which records the electrical activity of the brain. Electrodes placed on the scalp detect brainwave activity, which is recorded on a chart known as an electroencephalogram (see figure 3.8). This device has been used to assess brain damage, epilepsy, and other problems (Meador, 2002; Wallace & others, 2001).

An EEG measures the pooled activity of the millions of neurons beneath each electrode. In contrast, in single-unit recording—a measure of a single neuron's electrical activity—a thin wire or *microelectrode* is inserted in or near an individual neuron (Seidemann and others, 1996). The neuron's activity is transmitted to an amplifier, which allows researchers to display information about the activity (McAllen, Trevaks, & Allen, 2001).

Brain Imaging For years x-rays have been used to reveal damage inside or outside our bodies, both in the brain and in other locations. But a single x-ray of the brain is hard to interpret because it shows a two-dimensional image of the three-dimensional interior of the brain (Goel, 1995). A newer technique called *computerized tomography (CT scan)* produces a three-dimensional image obtained from x-rays of the head that are assembled into a composite image by a computer. The CT scan provides valuable information about the location and extent of damage involving stroke, language disorder, or loss of memory.

Positron-emission tomography (PET scan) measures the amount of glucose in various areas of the brain, then sends this information to a computer for analysis. Because

EEGs are also used to study normal brains. (Around the Globe)

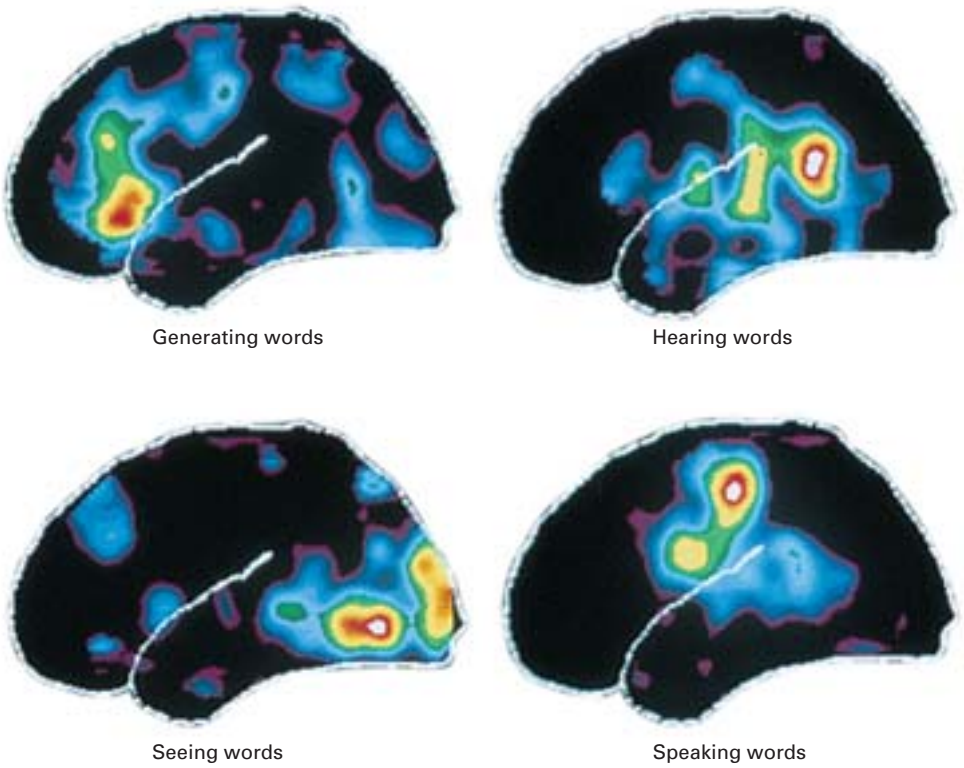


FIGURE 3.9 PET Scan This PET scan of the left half of the brain contrasts the different areas used in aspects of language activity: generating words, hearing words, seeing words, and speaking words.

glucose levels vary with the levels of activity throughout the brain, tracing the amounts of glucose generates a picture of activity levels throughout the brain (Goel & others, 1997; Siebner & others, 2002). Figure 3.9 shows PET scans of people's brain activity while they are hearing, seeing, speaking, and thinking.

Another technique, *magnetic resonance imaging (MRI)*, involves creating a magnetic field around a person's body and using radio waves to construct images of the person's tissues. An extension of the MRI technique, fMRI (functional MRI), can even provide images of biochemical activities (or functions) in the brain. MRI provides very clear pictures of the brain's interior, does not require injecting the brain with a substance, and, unlike x-rays, does not pose a problem of radiation overexposure (Petersen, 2001; Toga and Mazziota, 1999).

In one recent study, Brian Levine and his colleagues from the Rotman Research Institute at the University of Toronto conducted MRI brain scans of a patient who had suffered retrograde amnesia after a severe brain injury. The researchers were able to establish a link between the patient's memory deficiency and damage to his right ventral frontal cortex (Levine and others, 1998). Another study determined the effects of alcoholism on the brain (Tapert & others, 2001). A comparison was made of fMRI scans of two groups of young women, one with a history of heavy drinking, the other with no history of alcohol problems. As they tried to remember the location of an object on a screen, the participants underwent fMRI brain scans. The heavy drinkers did more poorly on the memory task and the fMRI scans revealed more sluggish brain activity.

Levels of Organization in the Brain

As a human embryo develops inside its mother's womb, the nervous system begins forming as a long, hollow tube on the embryo's back. At three weeks or so after conception, cells making up the tube differentiate into a mass of neurons, most of which then develop into three major regions of the brain: the hindbrain, which is adjacent to the top part of the spinal cord; the midbrain, which rises above the hindbrain; and the forebrain, which is the uppermost region of the brain (see figure 3.10).

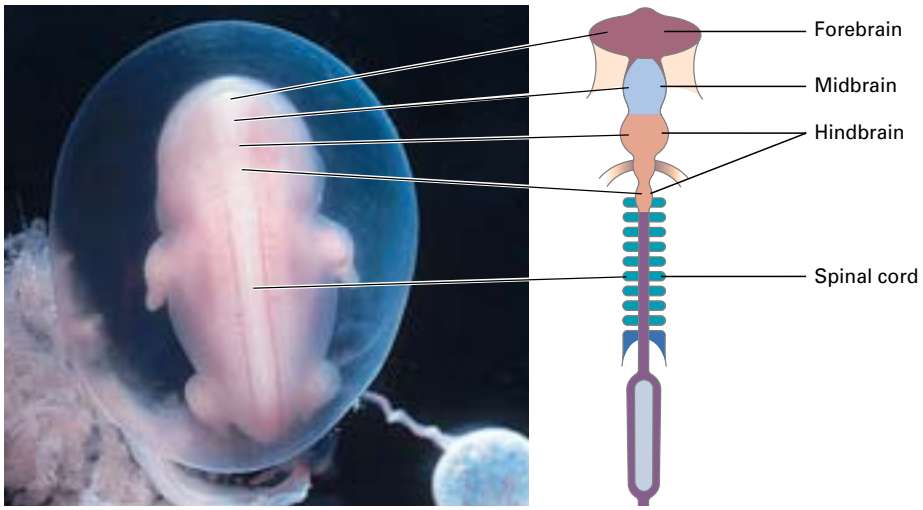


FIGURE 3.10 Embryological Development of the Nervous System
The photograph shows the primitive, tubular appearance of the nervous system at 6 weeks in the human embryo. The drawing shows the major brain regions and spinal cord as they appear early in the development of a human embryo.

Hindbrain The **hindbrain,** located at the skull's rear, is the lowest, and evolutionarily oldest, portion of the brain. The three main parts of the hindbrain are the medulla, cerebellum, and pons. Figure 3.11 shows the location of these brain structures.

The *medulla* begins where the spinal cord enters the skull. It helps to control our breathing and regulates reflexes that allow us to maintain an upright posture.

The *cerebellum* extends from the rear of the hindbrain, just above the medulla. It consists of two rounded structures thought to play important roles in motor coordination (Middleton & Strick, 2001). Leg and arm movements are coordinated by the cerebellum, for example. When we play golf, practise the piano, or learn a new dance, the cerebellum is hard at work. If a higher portion of the brain commands us to write the number 7, it is the cerebellum that integrates the muscular activities required to do so. Damage to the cerebellum impairs the performance of coordinated movements. When this damage occurs, people's movements become uncoordinated and jerky. Extensive damage to the cerebellum even makes it impossible to stand up.

The *pons* is a bridge in the hindbrain. It contains several clusters of fibres involved in sleep and arousal.

Midbrain The **midbrain,** located between the hindbrain and forebrain, is an area in which many nerve-fibre systems ascend and descend to connect the higher and lower portions of the brain. In particular, the midbrain relays information between the brain and the eyes and ears. Visual attention, for example, is linked to one midbrain **nucleus** (*group of specialized nerve cells in the brain or spinal cord*), the *superior colliculus*. Parkinson's disease, a deterioration of movement that produces rigidity and tremors, damages the *substantia nigra*, a small group of cells near the bottom of the midbrain.

Two systems in the midbrain are of special interest. One is the **reticular formation** (see figure 3.11), a diffuse collection of neurons involved in stereotyped patterns of behaviour such as walking, sleeping, or turning to attend to a sudden noise (Soja & others, 2001). The other system consists of small groups of neurons that use the neurotransmitters serotonin, dopamine, and norepinephrine. Although these groups contain relatively few cells, they send their axons to a remarkable variety of brain regions, perhaps explaining their involvement in high-level, integrative functions (Shier, Butler, & Lewis, 1999).

A region called the **brain stem** includes much of the hindbrain (it does not include the cerebellum) and midbrain and is so-called because it looks like a stem. Embedded deep within the brain, the brain stem connects with the spinal cord at its lower end and then extends upward to encase the reticular formation in the midbrain. The most ancient part of the brain, the brain stem evolved more than 500 million years ago (Carter, 1998). It is much like the entire brain of present-day reptiles and thus is often referred to as the "reptilian brain." Nuclei (the plural of nucleus) in the brain stem determine alertness and regulate basic survival functions such as breathing, heartbeat, and blood pressure.

hindbrain The lowest level of the brain, consisting of the medulla, cerebellum, and pons.

midbrain Located between the hindbrain and forebrain, a region in which many nerve-fibre systems ascend and descend to connect the higher and lower portions of the brain.

nucleus (pl. nuclei) A group of specialized nerve cells in the brain or spinal cord.

reticular formation A midbrain system that consists of a diffuse collection of neurons involved in stereotypical behaviours such as walking, sleeping, or turning to attend to a sudden noise.

brain stem The region of the brain that includes most of the hindbrain (excluding the cerebellum) and the midbrain.

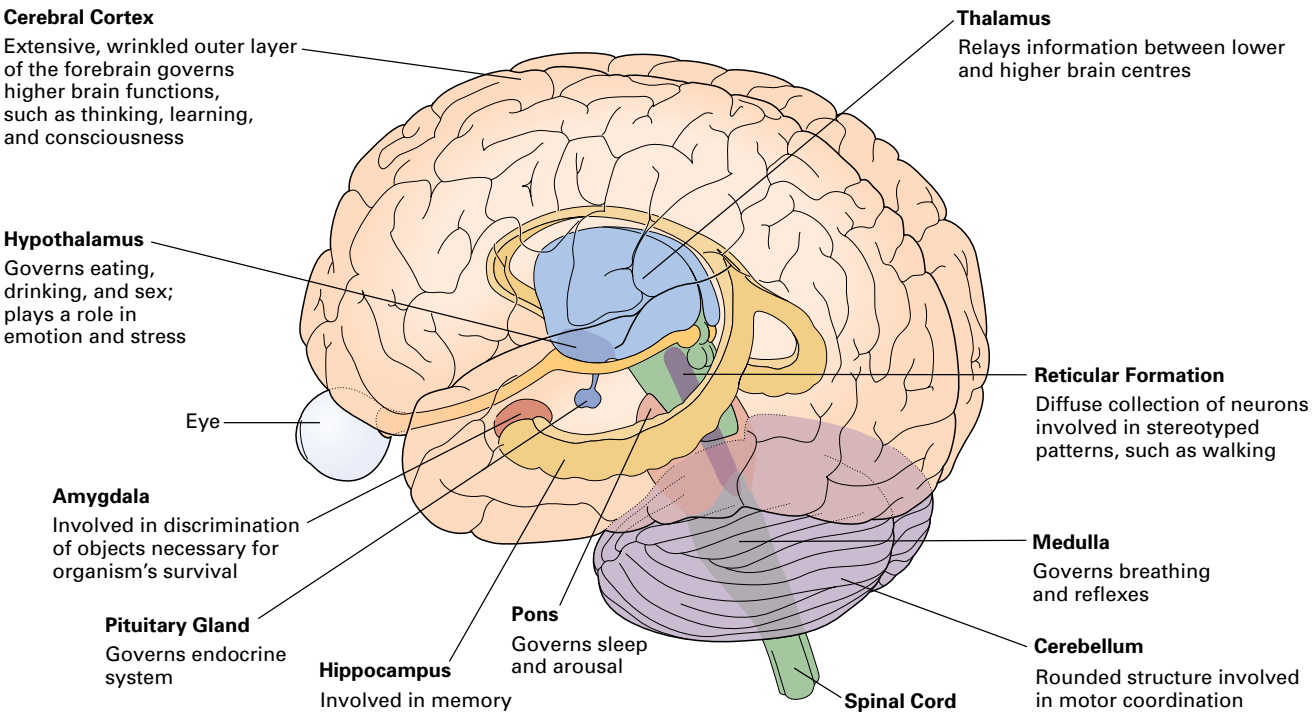


FIGURE 3.11 Structure and Regions in the Human Brain

Forebrain You try to understand what all of these terms and parts of the brain mean. You talk with friends and plan a party for this weekend. You remember that it has been six months since you went to the dentist. You are confident you will do well on the next exam in this course. All of these experiences and millions more would not be possible without the **forebrain,** the highest, and evolutionarily newest, level of the human brain.

Before we explore the structures and function of the forebrain, though, let's stop for a moment and examine how the brain evolved. The brains of the earliest vertebrates were smaller and simpler than those of later animals (Shettleworth, 1998). Genetic changes during the evolutionary process were responsible for the development of more complex brains with more parts and more interconnections (Carlson, 2001). Figure 3.12 compares the brains of a rat, cat, chimpanzee, and human. In the chimpanzee's brain, and especially the human's brain, the hindbrain and midbrain structures are covered by a forebrain structure called the cerebral cortex (Goldsmith & Zimmerman, 2001). The human hindbrain and midbrain are similar to those of other animals, so it is the forebrain structures that mainly differentiate the human brain from the brains of animals such as rats, cats, and monkeys. The human forebrain's most important structures are the limbic system, thalamus, basal ganglia, hypothalamus, and cerebral cortex.

forebrain The highest level of the brain. Key structures in the forebrain are the limbic system, thalamus, basal ganglia, hypothalamus, and cerebral cortex.

limbic system Loosely connected network of structures—including the amygdala and hippocampus—that play important roles in memory and emotion.

Limbic System The **limbic system,** a loosely connected network of structures under the cerebral cortex, is important in both memory and emotion. Its two principal structures are the amygdala and hippocampus (see figure 3.11).

The *amygdala* (from the Latin for "almond" shape) is located within the base of the temporal lobe. It is involved in the discrimination of objects that are necessary for the organism's survival, such as appropriate food, mates, and social rivals. Neurons in the amygdala often fire selectively at the sight of such stimuli, and lesions in or stimulation of the amygdala can cause animals to attempt to eat, fight, or mate with inappropriate objects such as chairs. The amygdala also is involved in emotional awareness and expression through its many connections with higher and lower regions of the brain (Davidson, 2000).

The *hippocampus* has a special role in the storage of memories (Bannerman & others, 2002). Individuals who suffer extensive hippocampal damage cannot retain any new

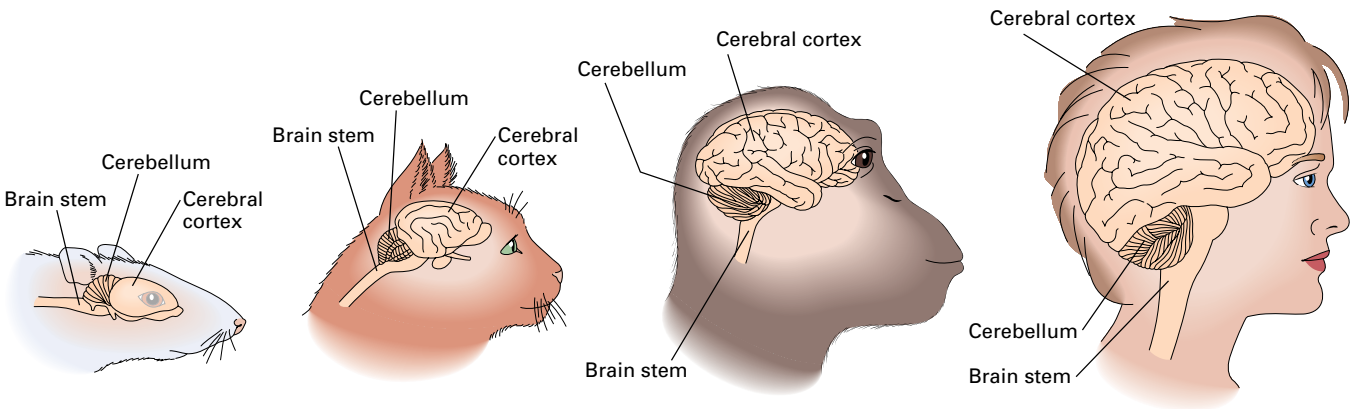


FIGURE 3.12 The Brain in Different Species Note how much larger the cerebral cortex becomes as we go from the brain of a rat to the brain of a human.

conscious memories after the damage. It is fairly certain, though, that memories are not stored "in" the limbic system. Instead, the limbic system seems to determine what parts of the information passing through the cortex should be "printed" into durable, lasting neural traces in the cortex.

Thalamus The **thalamus** is a forebrain structure that sits at the top of the brain stem in the central core of the brain (see figure 3.11). It serves as a very important relay station, functioning much like a server in a computer network. That is, an important function of the thalamus is to sort information and send it to the appropriate places in the forebrain for further integration and interpretation (Castro-Alamancos & Calcagnotto, 2001). For example, one area of the thalamus receives information from the cerebellum and projects it to the motor area of the cerebral cortex. Indeed, most neural input to the cerebral cortex goes through the thalamus. While one area of the thalamus works to orient information from the sense receptors (hearing, seeing, and so on), another region seems to be involved in sleep and wakefulness, having ties with the reticular formation.

Basal Ganglia Above the thalamus and under the cerebral cortex lie large clusters, or *ganglia,* of neurons called basal ganglia. The **basal ganglia** work with the cerebellum and the cerebral cortex to control and coordinate voluntary movements. Basal ganglia enable people to engage in habitual behaviours such as riding a bicycle. Individuals with damage to basal ganglia suffer from either unwanted movement, such as constant writhing or jerking of limbs, or too little movement, as in the slow and deliberate movements of those with Parkinson's disease (Boraud & others, 2002).

Hypothalamus The **hypothalamus,** a small forebrain structure located just below the thalamus, monitors three pleasurable activities—eating, drinking, and sex—as well as emotion, stress, and reward (see figure 3.11 for the location of the hypothalamus). As is discussed later, the hypothalamus also helps direct the endocrine system. Perhaps the best way to describe the function of the hypothalamus is as a regulator of the body's internal state. It is sensitive to changes in the blood and neural input, and it responds by influencing the secretion of hormones and neural outputs. For example, if the temperature of circulating blood near the hypothalamus is increased by just one or two degrees, certain cells in the hypothalamus start increasing their rate of firing. As a result, a chain of events is set in motion. Increased circulation through the skin and sweat glands occurs immediately to release this heat from the body. The cooled blood circulating to the hypothalamus slows down the activity of some of the neurons there, stopping the process when the temperature is just right—37.1° Celsius. These temperature-sensitive neurons function like a finely tuned thermostat in maintaining the body in a balanced state.

The hypothalamus also is involved in emotional states, playing an important role as an integrative location for handling stress. Much of this integration is accomplished through the hypothalamus's action on the pituitary gland, an important endocrine gland located just below it.

thalamus Forebrain structure that functions as a relay station to sort input and direct it to different areas of the cerebral cortex. It also has ties to the reticular formation.

basal ganglia Located above the thalamus and under the cerebral cortex, these large clusters of neurons work with the cerebellum and the cerebral cortex to control and coordinate voluntary movements.

hypothalamus Forebrain structure involved in regulating eating, drinking, and sex; directing the endocrine system through the pituitary gland; and monitoring emotion, stress, and reward.

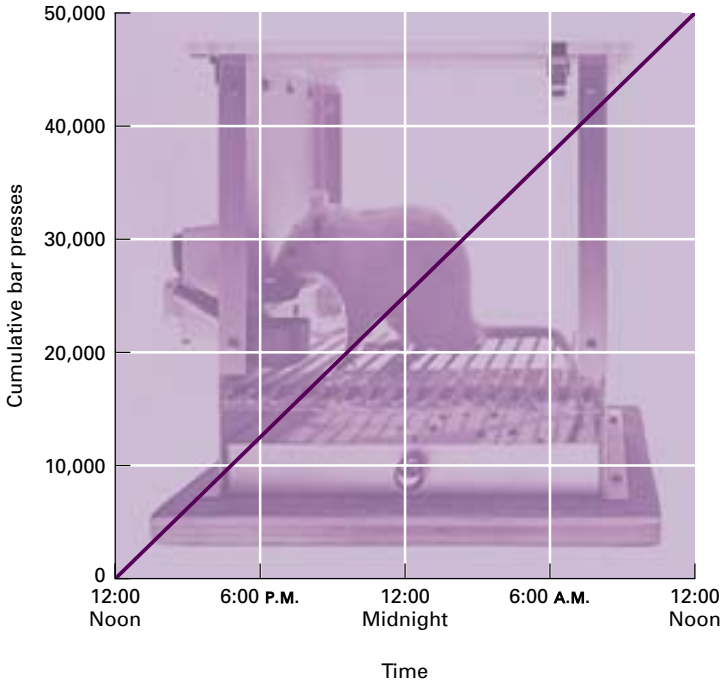


FIGURE 3.13 Results of the Experiment by Olds (1958) on the Role of the Hypothalamus in Pleasure
The graphed results for one rat show that it pressed the bar more than 2000 times an hour for a period of 24 hours to receive stimulation to its hypothalamus. One of the rats in Olds and Milner's experiments is shown pressing the bar.

If certain areas of the hypothalamus are electrically stimulated, a feeling of pleasure results. In a classic experiment, McGill researchers James Olds and Peter Milner (1954) implanted an electrode in the hypothalamus of a rat's brain. When the rat ran to a corner of an enclosed area, a mild electric current was delivered to its hypothalamus. The researchers thought the electric current would cause the rat to avoid the corner. Much to their surprise, the rat kept returning to the corner. Olds and Milner believed they had discovered a pleasure centre in the hypothalamus. Olds (1958) conducted further experiments and found that rats would press bars until they dropped over from exhaustion just to continue to receive a mild electric shock to their hypothalamus. One rat pressed a bar more than 2000 times an hour for a period of 24 hours to receive the stimulation to its hypothalamus (see figure 3.13). Today researchers agree that the hypothalamus is involved in pleasurable feelings but that other areas of the brain, such as the limbic system and a bundle of fibres in the forebrain, are also important in the link between the brain and pleasure (Milner, 1991).

The Olds studies have implications for drug addiction. In the Olds studies, the rat pressed the bar mainly because it produced a positive, rewarding effect (pleasure), not because it wanted to avoid or escape a negative effect (pain). Cocaine users talk about the drug's ability to heighten pleasure in food, in sex, and in a variety of activities, highlighting the reward aspects of the drug (Restak, 1988).

The Cerebral Cortex

The **cerebral cortex** is the highest region of the forebrain and is the most recently developed part of the brain in the evolution scheme. It is in the cerebral cortex that the highest mental functions, such as thinking and planning, take place. The neural tissue that makes up the cerebral cortex is the largest part of the brain in volume (about 80 percent) and covers the lower portions of the brain like a large cap. In humans, the cerebral cortex is greatly convoluted with lots of grooves and bulges, which considerably enlarge its surface area (compared to a brain with a smooth surface). The cerebral cortex is highly connected with other parts of the brain. Literally millions of axons connect the neurons of the cerebral cortex with those located elsewhere in the brain.

cerebral cortex Highest level of the forebrain, where the highest mental functions, such as thinking and planning, take place.

occipital lobe The part of the cerebral cortex at the back of the head that is involved in vision.

temporal lobe The portion of the cerebral cortex just above the ears that is involved in hearing, language processing, and memory.

frontal lobe The part of the cerebral cortex just behind the forehead that is involved in the control of voluntary muscles, intelligence, and personality.

parietal lobe Area of the cerebral cortex at the top of the head that is involved in registering spatial location, attention, and motor control.

Lobes The wrinkled surface of the cerebral cortex is divided into two halves called *hemispheres* (see figure 3.14). Each hemisphere is subdivided into four regions—the frontal lobe, the parietal lobe, the temporal lobe, and the occipital lobe (see figure 3.15).

The **occipital lobe,** at the back of the head, responds to visual stimuli (Milner & Goodale, 1995). Different areas of the occipital lobes are connected to process information about such aspects of visual stimuli as their colour, shape, and motion. A stroke or wound in the occipital lobe can cause blindness or, at a minimum, wipe out a portion of the person's visual field.

The **temporal lobe,** the portion of the cerebral cortex just above the ears, is involved in hearing, language processing, and memory. The temporal lobes have a number of connections to the limbic system. For this reason, people with damage to the temporal lobes cannot file experiences into long-term memory.

The **frontal lobe,** the portion of the cerebral cortex behind the forehead, is involved in the control of voluntary muscles, intelligence, and personality. One fascinating case study illustrates how damage to the frontal lobe can significantly alter personality. Phineas T. Gage, a 25-year-old foreman who worked for the Rutland and

Burlington Railroad, met with an accident on September 13, 1848. Phineas and several co-workers were using blasting powder to construct a roadbed. The crew drilled holes in the rock and gravel, poured in the blasting powder, and then tamped down the powder with an iron rod. While Phineas was still tamping it down, the powder blew up, driving the iron rod up through the left side of his face and out through the top of his head. Though the wound in his skull healed in a matter of weeks, Phineas became a different person. He had been a mild-mannered, hardworking, emotionally calm individual prior to the accident, well liked by all who knew him. Afterward, he became obstinate, moody, irresponsible, selfish, and incapable of participating in any planned activities. Damage to the frontal lobe of his brain dramatically altered Phineas's personality.

Without intact frontal lobes, humans are emotionally shallow, distractible, listless, and so insensitive to social contexts that they may belch with abandon at dinner parties (Hooper & Teresi, 1992). Individuals with frontal lobe damage become so distracted by irrelevant stimuli that they often cannot carry out some basic directions. In one such case, an individual, when asked to light a candle, struck a match correctly but instead of lighting the candle, he put the candle in his mouth and acted as if he was smoking it (Luria, 1973).

The frontal lobes of humans are especially large when compared with those of other animals. For example, the frontal cortex of rats barely exists; in cats, it occupies a paltry 3.5 percent of the cerebral cortex; in chimpanzees, 17 percent; and in humans, approximately 30 percent. Some neuroscientists maintain that the frontal cortex is an important index of evolutionary advancement (Hooper & Teresi, 1992). Fergus Craik and his colleagues from the Rotman Institute at the University of Toronto (Craik & others, 1999) have even presented evidence that the self and self-concept might be represented in the right frontal lobes.

An important part of the frontal lobes is the *prefrontal cortex,* which is at the front of the motor cortex (see figure 3.15). The prefrontal cortex is believed to be involved in higher cognitive functions, such as planning and reasoning (Manes & others, 2002). Some neuroscientists refer to the prefrontal cortex as an executive control system because of its role in monitoring and organizing thinking (Owen, 1997).

The **parietal lobe,** located at the top and toward the rear of the head, is involved in registering spatial location, attention, and motor control. Thus the parietal lobes are at work when you are judging how far you have to throw a ball to get it to someone else, when you shift your attention from one activity to another (turn your attention

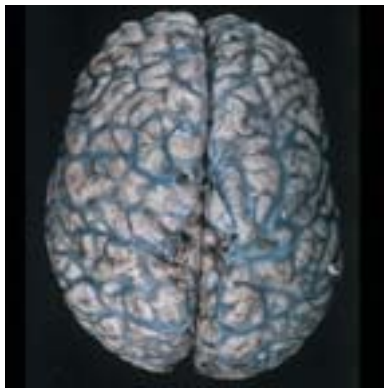


FIGURE 3.14 The Human Brain's Hemispheres The two halves (hemispheres) of the human brain can be seen clearly in this photograph.

This is a computerized reconstruction of Phineas T. Gage's accident, based on measurements taken of his skull.

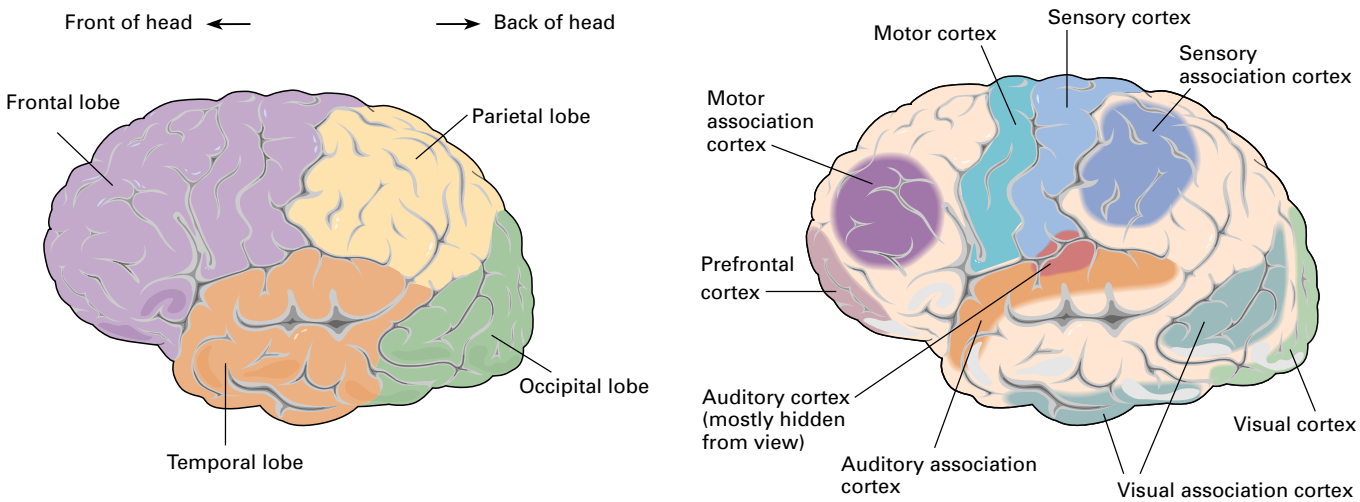


FIGURE 3.15 The Cerebral Cortex's Lobes and Association Areas The cerebral cortex (*left*) is roughly divided into four lobes: occipital, temporal, frontal, and parietal. The cerebral cortex (*right*) also consists of the motor cortex and sensory cortex. Further, the cerebral cortex includes association areas, such as the visual association cortex, auditory association cortex, and sensory association cortex.

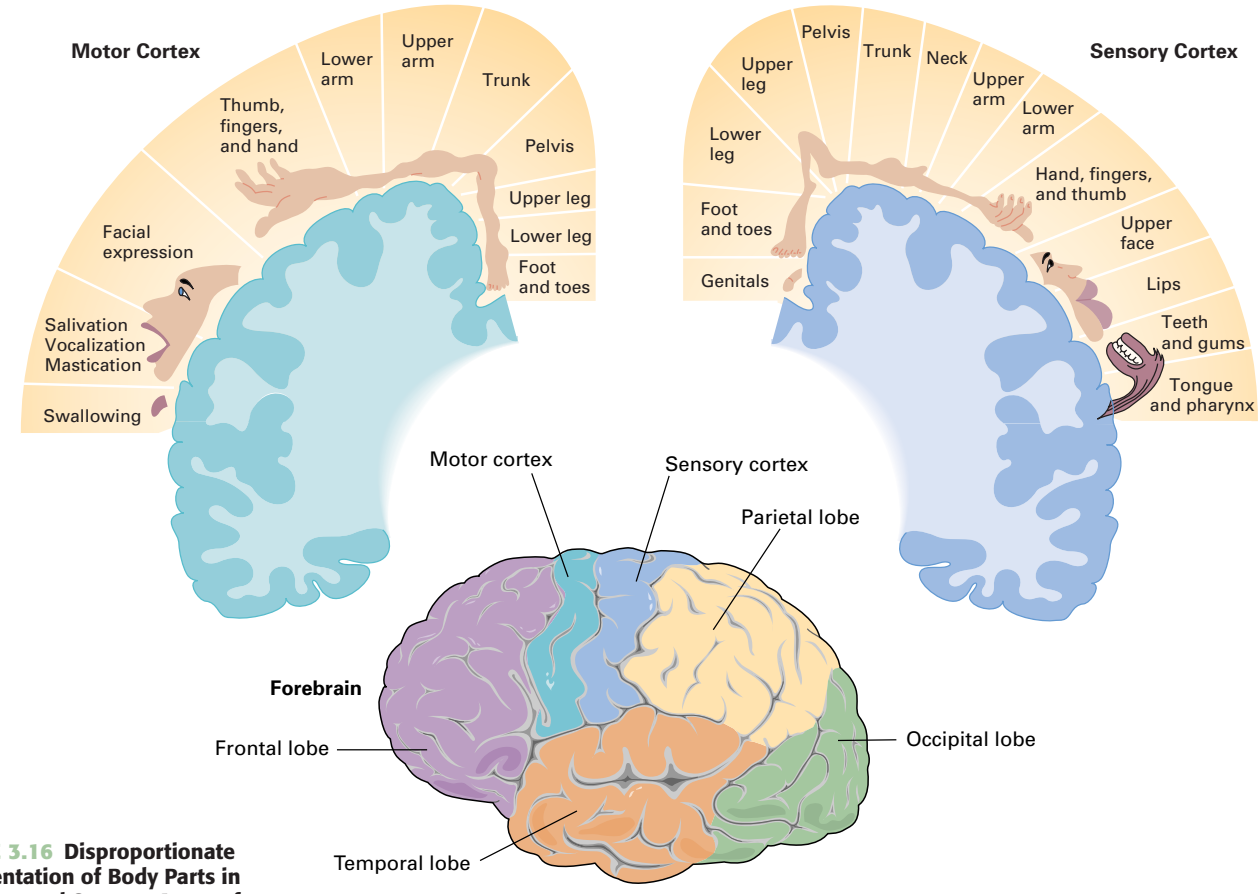


FIGURE 3.16 Disproportionate Representation of Body Parts in the Motor and Sensory Areas of the Cortex The amount of cortex allotted to a body part is not proportionate to the body part's size. Instead, the brain has more space for body parts that require precision and control. Thus the thumb, fingers, and hand require more brain tissue than does the arm.

away from the TV to a noise outside), and when you turn the pages of this book. The brilliant physicist Albert Einstein said that his reasoning often was best when he imagined objects in space. It turns out that his parietal lobes were 15 percent larger than average (Witelson, Kigar, & Harvey, 1999).

In closing this discussion of the cerebral cortex's lobes, a word of caution is in order about going too far in localizing function within a particular lobe. Although we have attributed specific functions to a particular lobe (such as vision in the occipital lobe), there is considerable integration and connection between any two or more lobes and between lobes and other parts of the brain.

Sensory Cortex and Motor Cortex Two other important regions of the cerebral cortex are the sensory cortex and the motor cortex (see figure 3.15). The **sensory cortex** processes information about body sensations. It is located at the front of the parietal lobes. The **motor cortex,** just behind the frontal lobes, processes information about voluntary movement.

The map in figure 3.16 shows which parts of the sensory and motor cortex are associated with different parts of the body. It is based on research done by Wilder Penfield (1947), a neurosurgeon at the Montreal Neurological Institute. He worked with patients who had severe epilepsy and often performed surgery to remove portions of the epileptic patients' brains. However, he was concerned that removing a portion of the brain might impair some of the individuals' functions. Penfield's solution was to map the cortex during surgery by stimulating different cortical areas and observing the responses of the patients, who were given a local anesthetic so they would remain awake during the operation. He found that, when he stimulated certain sensory and motor areas of the brain, different parts of a patient's body moved. For both sensory and motor areas, there is a point-to-point relation between a part

sensory cortex Area of the cerebral cortex that processes information about body sensations.

motor cortex Area of the cerebral cortex that processes information about voluntary movement.

of the body and a location on the cerebral cortex. In figure 3.16, the face and hands are given proportionately more space than other body parts because the face and hands are capable of finer perceptions and movements than are other body areas and, therefore, need more cerebral cortex representation (Penfield & Rasmussen, 1950).

The point-to-point mapping of sensory fields onto the cortex's surface is the basis of our orderly and accurate perception of the world (Cheyne & others, 1998; Fox, 1996). When something touches your lip, for example, your brain knows what body part has been touched because the nerve pathways from your lip are the only pathways that project to the lip region of the sensory cortex.

One familiar example of what happens when these neural pathways get connected the wrong way is seen in Siamese cats. Many Siamese cats have a genetic defect that causes the pathways from the eyes to connect to the wrong parts of the visual cortex during development. The result is that these cats spend their lives looking at things cross-eyed in an effort to "straighten out" the visual image of their visual cortex.

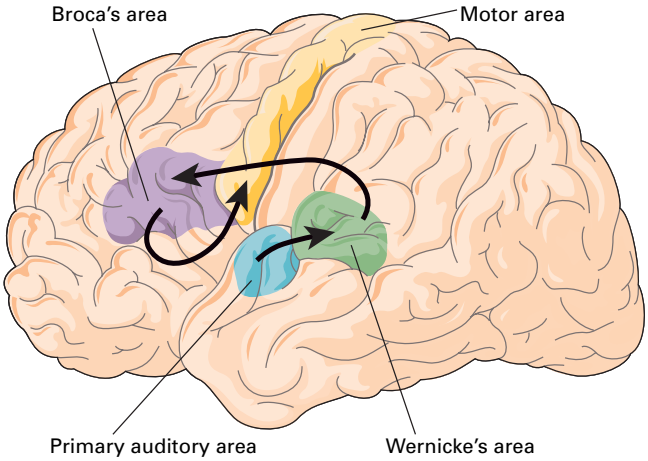


FIGURE 3.17 The Wernicke-Geschwind Model When a word is heard and repeated aloud, the ear sends action potentials to the primary auditory area where the sound is first analyzed. It then goes to Wernicke's area where a sound-based code is retrieved and the word is understood. Next, it goes to Broca's area where the instructions to speak the word are assembled. Finally, these instructions are sent to the motor cortex, which activates the appropriate parts of the speech system.

The Association Cortex Embedded in the brain's lobes, the association cortex makes up 75 percent of the cerebral cortex (see figure 3.15). Processing information about sensory input and motor output is not all that is taking place in the cerebral cortex. The **association cortex** (sometimes called *association areas*) is the region of the cerebral cortex that integrates this information. The highest intellectual functions, such as thinking and problem solving, occur in the association cortex.

Interestingly, damage to a specific part of the association cortex often does not result in a specific loss of function. With the exception of language areas (which are localized), loss of function seems to depend more on the extent of damage to the association cortex than on the specific location of the damage. By observing brain-damaged individuals and using a mapping technique, scientists have found that the association cortex is involved in linguistic and perceptual functioning.

The largest portion of the association cortex is located in the frontal lobe, directly under the forehead. Damage to this area does not lead to sensory or motor loss. Indeed, it is this area that may be most directly related to thinking and problem solving. Early studies even referred to the frontal lobe as the centre of intelligence, but research suggests that frontal lobe damage may not result in a lowering of intelligence. Planning and judgment are often associated with the frontal lobe. Personality also may be linked to the frontal lobe. Recall the misfortune of Phineas Gage, whose personality radically changed after he experienced frontal lobe damage.

The Cerebral Hemispheres and Split-Brain Research

At the beginning of the discussion of the cerebral cortex, we indicated that it is divided into two halves—left and right (see figure 3.14). Do these hemispheres have different functions? In 1861, French surgeon Paul Broca saw a patient who had received an injury to the left side of his brain about 30 years earlier. The patient became known as Tan, because *Tan* was the only word he could speak. Tan suffered from *aphasia*, a language disorder associated with brain damage. Tan died several days after Broca evaluated him, and an autopsy revealed that the injury was to a precise area of the left hemisphere. Today we refer to this area of the brain as *Broca's area*, and we know that it plays an important role in the production of speech. Another area of the brain's left hemisphere that has an important role in language is *Wernicke's area*, which, if damaged, causes problems in comprehending language. More recently, the Wernicke-Geschwind model (see figure 3.17) has been proposed to explain how these two areas collaborate with others when a spoken word is presented and the individual repeats the word out loud (Geschwind & Galaburda, 1987).

association cortex Region of the cerebral cortex in which the highest intellectual functions, including thinking and problem solving, occur (also called association areas).

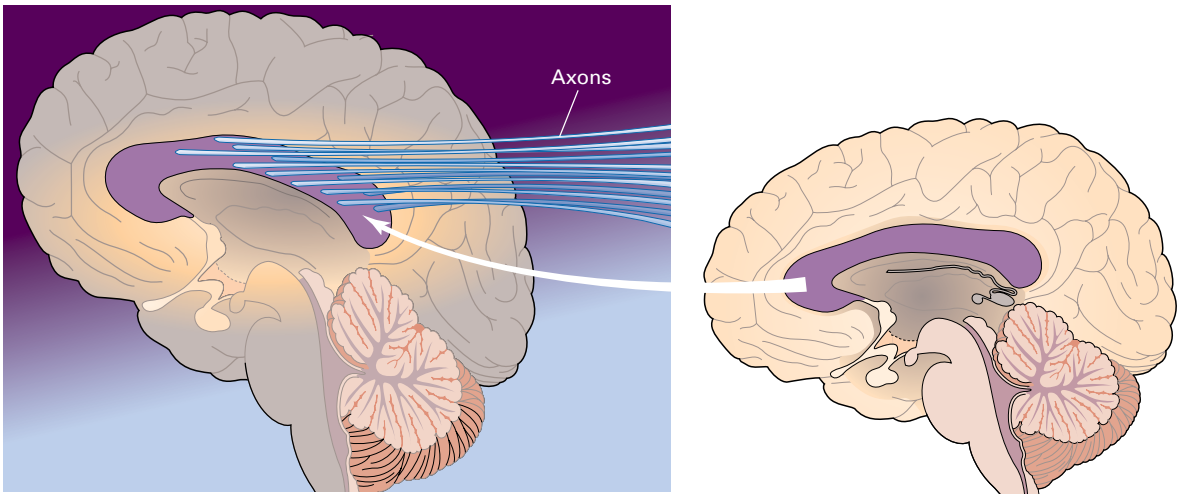


FIGURE 3.18 The Corpus Callosum The corpus callosum is a thick band of about 80 million axons that connect the brain cells in one hemisphere to those in the other. In healthy brains, the two sides engage in a continuous flow of information via this neural bridge.

Today, there continues to be considerable interest in the degree to which the brain's left hemisphere or right hemisphere is involved in various aspects of thinking, feeling, and behaviour (Corballis, Funnell, & Gazzaniga, 2002; Spence & others, 2002). For many years scientists speculated that the **corpus callosum,** the large bundle of axons that connects the brain's two hemispheres, had something to do with relaying information between the two sides (see figure 3.18). Roger Sperry (1974) confirmed this in an experiment in which he cut the corpus callosum in cats. He also severed certain nerves leading from the eyes to the brain. After the operation, Sperry trained the cats to solve a series of visual problems with one eye blindfolded. After the cat learned the task, say with only its left eye uncovered, its other eye was blindfolded and the animal was tested again. The "split-brain" cat behaved as if it had never learned the task. It seems that the memory was stored only in the left hemisphere, which could no longer directly communicate with the right hemisphere.

Further evidence of the corpus callosum's function has come from studies of patients who, like Brandi Binder before surgery, have severe, even life-threatening, forms of epilepsy. Epilepsy is caused by electrical "brainstorms" that flash uncontrollably across the corpus callosum. In one famous case, neurosurgeons severed the corpus callosum of an epileptic patient now known as W. J. in a final attempt to reduce his unbearable seizures. Sperry (1968) examined W. J. and found that the corpus callosum functions the same in humans as in animals—cutting the corpus callosum seemed to leave the patient with "two separate minds" that learned and operated independently.

The right hemisphere, it turns out, receives information only from the left side of the body, and the left hemisphere receives information only from the right side of the body. When you hold an object in your left hand, for example, only the right hemisphere of your brain detects the object. When you hold an object in your right hand, only the left hemisphere of the brain detects the object (see figure 3.19). If you have a normal corpus callosum, both hemispheres receive this information.

In people with intact brains, specialization of function occurs in some areas. Following are the main areas in which the brain tends to divide its functioning into one hemisphere or the other (Gazzaniga, Ivry, & Mangun, 2001; Springer & Deutsch, 1998):

- *Verbal processing.* The most extensive research on the brain's two hemispheres has focused on language. Speech and grammar are localized to the left hemisphere. A common misconception, though, is that *all* language processing is carried out in the brain's left hemisphere. However, such aspects of language as appropriate use of language in different contexts, metaphor, and much of our sense of humour reside in the right hemisphere.

corpus callosum A large bundle of axons that connect the brain's two hemispheres.

- *Nonverbal processing.* The right hemisphere is more dominant in processing nonverbal information, such as spatial perception, visual recognition, and emotion (Corballis, Funnell, & Gazzaniga, 2002). For example, the right hemisphere is mainly at work when we are processing information about people's faces (Kanwisher & Moscovitch, 2000; O'Toole, 2002). The right hemisphere also may be more involved in processing information about emotions, as when we express emotions ourselves and when we recognize others' emotions (Heller, Etienne, & Miller, 1997).

Because differences in the functioning of the brain's two hemispheres are known to exist, people commonly use the phrases *left-brained* and *right-brained* as a way of categorizing themselves and others. Such generalizations have little scientific basis. The most common myth about hemispheric specialization is that the left brain is logical and the right brain is creative. To most scientists, the concept of the brain as split into two tidy halves—one being the source of creativity, the other the source of logical thinking—is simplistic. Sandra Witelson, a neuroscientist at McMaster University, points out that no complex function—music, art, reading, or whatever—can be assigned to one single hemisphere or the other. Complex thinking in normal people involves communication between both sides of the brain. The real issue is the degree to which bihemispheric representation of functions may vary in left-handers versus right-handers (Witelson, 1985), women versus men (Witelson & Kigar, 1992), geniuses versus normal people (Witelson, Kigar, & Harvey, 1999), and even homosexual versus heterosexual people (McCormick & Witelson, 1994).

Roger Sperry did discover that the left hemisphere is superior in the logic used to prove geometric theorems. But in everyday life, our problems involve integrating information and drawing conclusions. In these instances, the right hemisphere is crucial. In virtually all activities, there is an interplay between the brain's two hemispheres (Hoptman & Davidson, 1994). Phil Bryden described this interplay as *complementary specialization* (Bryden, 1986). For example, in reading, the left hemisphere comprehends syntax and grammar, which the right does not. However, the right brain is better at understanding a story's intonation and emotion. The same is true for music and art. In some musical skills, such as recognizing chords, the right hemisphere is better. In others, such as distinguishing which of two sounds came first, the left hemisphere takes over.

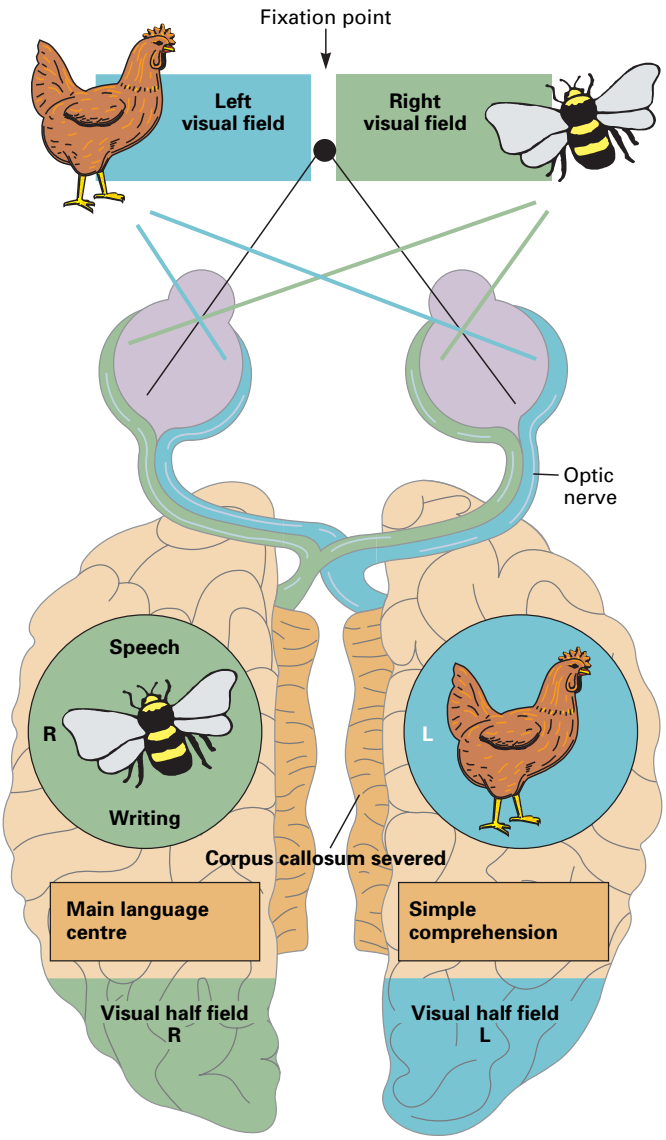


FIGURE 3.19 Visual Information in the Split Brain In a split-brain patient, information from the visual field's left side projects only to the right hemisphere. Information from the visual field's right side projects only to the left hemisphere. Because of these projections, stimuli can be presented to only one of a split-brain patient's hemispheres.

One positive result of the left-brain–right-brain myth is a perception that more right-brain activities and exercises should be incorporated into school programs (Edwards, 1979). In schools that rely heavily on rote learning to instruct students, children probably would benefit from exercises in intuitive thought and holistic thinking. But a deficiency in school curricula has nothing at all to do with left-brain, right-brain specialization (Segalowitz, 1983).

In sum, some specialization of functions exists in both the left hemisphere (processing of certain verbal information) and the right hemisphere (processing of certain nonverbal information) of the brain. However, in many complex tasks in which humans engage in their everyday lives, integration across the hemispheres is common.

To think further about the functioning of the left and right hemispheres, see the Critical Controversy box, which explores similarities and differences in men's and women's brains.

Critical Controversy

Are There "His" and "Hers" Brains?

Does gender matter when it comes to brain structure and function (Kimura, 1987)? Human brains are much alike, whether the brain belongs to a man or a woman. However, researchers have found some differences between the male brain and the female brain (Blum, 1998; Goldstein & others, 2001; Kimura, 2000; Raz & others, 2001). Among differences discovered so far are:

- One part of the hypothalamus responsible for sexual behaviour is larger in men than in women (Swaab & others, 2001).
- Portions of the corpus callosum—the band of tissues through which the brain's two hemispheres communicate—are larger in women than in men (de Lacoste-Utamsing & Holloway, 1982; Le Vay, 1994). Might this difference mean that men and women process information differently? In one study, women were likelier to use both brain hemispheres to process language, whereas men were likelier to use only the left hemisphere (Shaywitz & others, 1995). Despite this difference, the two sexes performed equally well on the task, which involved sounding out words. The researchers concluded that nature has given the brain different routes to the same ability.
- It has been reported that men lose brain tissue earlier in the aging process than women do and that overall they lose more of it (Carter, 1998). Further reports suggest that men are especially prone to tissue loss in the frontal (thinking, reasoning) and temporal (hearing) lobes, but women are prone to tissue loss in the parietal lobe (spatial location) and hippocampus (memory; Nystrand, 1996). Such results, as well as many others in the effort to chart sex differences and similarities in human brains, require further research before being fully accepted as reliable and valid by the scientific community.

Differences in the ways in which men's and women's brains function likely evolved over time. Some of the differences appear to be the result of a division of labour dating to early hunter-gatherer civilizations. For example, men are better than women at spatial-navigational skills, such as map reading, judging distances, and dart throwing (Kimura, 2000; Majeres, 1999). However, some psychologists point out that in many cases such differences are small and that the differences do not mean that all men are better than all women at such tasks (Hyde & Mezulis, 2002). Debate continues to flourish about whether there are gender differences and about how big or small the differences are for many human skills.

In one recent neuroimaging study, an area of the parietal lobe that functions in visuospatial skills was larger in men than in women (Frederikse & others, 2000). Women, on the other hand, have a better memory for words and objects and are better at fine motor skills (Halpern, 1997, 2001). These abilities may have evolved through making clothes and preparing food.

Are these brain differences truly innate, driven by "nature" through evolution, genetic programming, and hormones in the womb? University of Western Ontario neuroscientist Doreen Kimura (1999) has explored how hormones actually "reorganize" the brain early in life. Drawing upon behavioural, neurological, and endocrinological studies, she theorizes how the sexes end up with distinct problem-solving abilities. Or might brain differences be more a consequence of environment, the result of societal influences that stereotypically define sex-specific roles and characteristics, in effect shaping our brains in accordance with these roles? Some psychologists argue that the latter explanation accounts for male/female differences in math and verbal achievement (Eagly, 2001). However, many questions regarding men's and women's brains are exceedingly complex and likely cannot be answered by strictly biological or environmental arguments.

Also, according to psychologist Diane Halpern (2000, 2001), the fact that there are differences between the brains of women and men does not mean that one sex's brain is better, any more than one sex's genitals are better. Different does not mean deficient. People can be different without being unequal in ability.

What do you think?

- Could sex differences in the brain be the result rather than the cause of behavioural differences? Explain.
- Have differences in women's and men's brains likely been exaggerated in light of the substantial similarities in their brains? Might the media be involved in any exaggerations? Explain.
- Because of differences in the brains of males and females, should males and females be educated differently? Explain.

Integration of Function in the Brain

How do all of the regions of the brain cooperate to produce the wondrous complexity of thought and behaviour that characterizes humans? Neuroscience still doesn't have answers to such questions as how the brain solves a murder mystery or writes a poem or essay. But we can get a sense of integrative brain function by considering something like the act of escaping from a burning building.

Imagine you are sitting at your desk writing letters when fire breaks out behind you. The sound of crackling flames is relayed from your ear, through the thalamus, to the auditory cortex, and on to the auditory association cortex. At each stage, the stim-

ulus is processed to extract information, and, at some stage, probably at the association cortex level, the sounds are finally matched with something like a neural memory representing sounds of fires you have heard previously. The association "fire" sets new machinery in motion. Your attention (guided in part by the reticular formation) shifts to the auditory signal being held in your association cortex, and on to your auditory association cortex, and simultaneously (again guided by reticular systems) your head turns toward the noise. Now your visual association cortex reports in: "Objects matching flames are present." In other regions of the association cortex, the visual and auditory reports are synthesized ("We have things that look and sound like fire"), and neural associations representing potential actions ("flee") are activated. However, firing the neurons that code the plan to flee will not get you out of the chair. The basal ganglia must become engaged, and from there the commands will arise to set the brain stem, motor cortex, and cerebellum to the task of actually transporting you out of the room.

Which part of your brain did you use to escape? Virtually all systems had a role; each was quite specific, and together they generated the behaviour. By the way, you would probably remember this event because your limbic circuitry would likely have started the memory formation process when the significant association "fire" was first triggered. The next time the sounds of crackling flames reach your auditory association cortex, the associations triggered would include those of this most recent escape. In sum, considerable integration of function takes place in the brain (Gevins, 1999; Miller & Cohen, 2001).

Review and Sharpen Your Thinking

3 ***Identify the brain's levels and structures, and summarize the functions of its structures.***

- Specify four techniques that are used to study the brain and the nervous system.
- Outline the levels of organization in the human brain.
- Discuss the areas of the cerebral cortex and their functions.
- Explain how split-brain research has increased our understanding of the way the cerebral hemispheres function.
- Describe the integration of function in the brain.

In your experience, does human behaviour differ in important ways from the behaviour of other animals? What tasks are human brains able to accomplish that other animals may not be able to?

Online LearningCentre with PowerWeb

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

THE ENDOCRINE SYSTEM 4

What is the endocrine system and how does it affect behaviour?

The **endocrine system** is a set of glands that regulate the activities of certain organs by releasing their chemical products into the bloodstream. In the past, the endocrine system was considered separate from the nervous system. However, today neuroscientists know that these two systems are often interconnected.

Hormones are the chemical messengers that are manufactured by the endocrine glands. Hormones travel more slowly than nerve impulses. The bloodstream conveys hormones to all parts of the body, and the membrane of every cell has receptors for one or more hormones.

The endocrine glands consist of the pituitary gland, the thyroid and parathyroid glands, the adrenal glands, the pancreas, and the ovaries in women and the testes in men (see figure 3.20). In much the same way that the brain's control of muscular activity is constantly monitored and altered to suit the information received by the brain, the action of the endocrine glands is continuously monitored and changed by nervous, hormonal, and chemical signals (Mader, 2003). Recall from earlier in the chapter that the

endocrine system A set of glands that regulate the activities of certain organs by releasing hormones into the bloodstream.

hormones Chemical messengers manufactured by the endocrine glands.

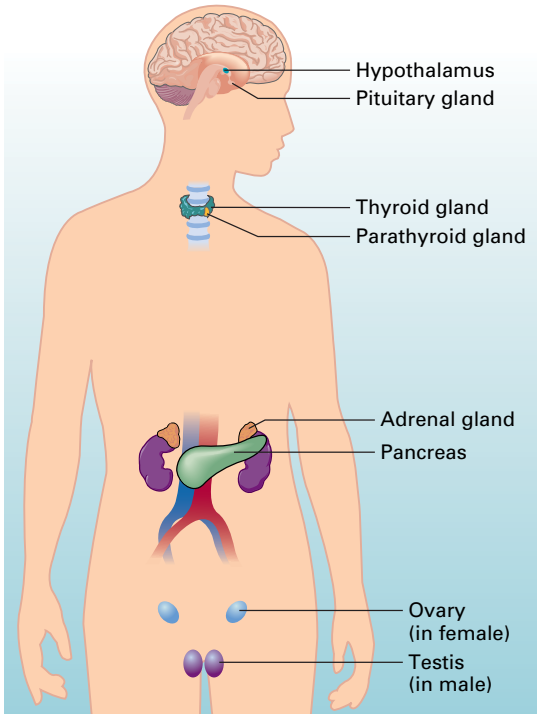


FIGURE 3.20
The Major Endocrine Glands The pituitary gland releases hormones that regulate the hormone secretions of the other glands. The pituitary gland is itself regulated by the hypothalamus.

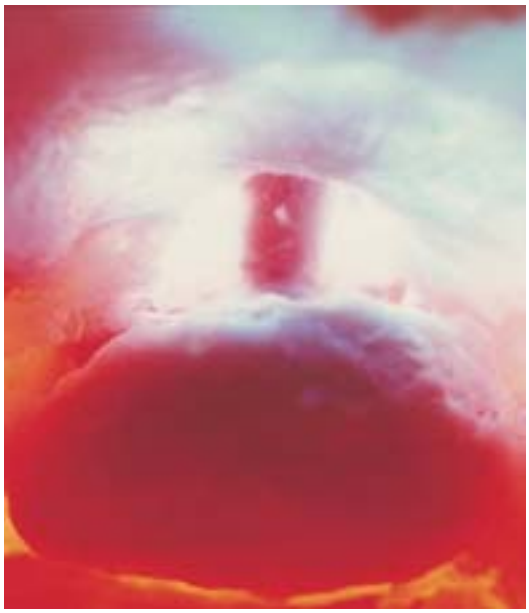


FIGURE 3.21 The Pituitary Gland The pituitary gland, which hangs by a short stalk from the hypothalamus, regulates the hormone production of many of the body's endocrine glands. Here it is enlarged 30 times.

autonomic nervous system regulates processes such as respiration, heart rate, and digestion. The autonomic nervous system acts on the endocrine glands to produce a number of important physiological reactions to strong emotions such as rage and fear.

The **pituitary gland,** a pea-sized gland that sits at the base of the skull, controls growth and regulates other glands (see figure 3.21). The anterior (front) part of the pituitary is known as the master gland, because almost all of its hormones direct the activity of target glands elsewhere in the body. In turn, the anterior pituitary gland is controlled by the hypothalamus.

The **adrenal glands** are instrumental in regulating moods, energy level, and the ability to cope with stress. Each adrenal gland secretes epinephrine (also called adrenaline) and norepinephrine (also called noradrenaline). Unlike most hormones, epinephrine and norepinephrine act quickly. Epinephrine helps a person get ready for an emergency by acting on smooth muscles, the heart, stomach, intestines, and sweat glands. In addition, epinephrine stimulates the reticular formation, which in turn arouses the sympathetic nervous system, and this system subsequently excites the adrenal glands to produce more epinephrine. Norepinephrine also alerts the individual to emergency situations by interacting with the pituitary and the liver. You may remember that norepinephrine functions as a neurotransmitter when it is released by neurons. In the adrenal glands, norepinephrine is released as a hormone. In both instances, norepinephrine conveys information—in the first instance to neurons, in the second to glands (Raven & Johnson, 2002).

Online LearningCentre with PowerWeb

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

pituitary gland An important endocrine gland at the base of the skull that controls growth and regulates other glands.

adrenal glands Important endocrine glands that are instrumental in regulating moods, energy level, and the ability to cope with stress.

Review and Sharpen Your Thinking

4 ***State what the endocrine system is and how it affects behaviour.***

- Describe the endocrine system, its glands, and their functions.

Is the behaviour of animals such as rats, rabbits, and bulls more likely to be strongly controlled by hormones than that of humans? In answering this question, think about the differences in the structures of the brains of humans and those animals that were described earlier in the chapter.

BRAIN DAMAGE, PLASTICITY, AND REPAIR 5

The Brain's Plasticity and Capacity for Repair

Brain Tissue Implants

If the brain is damaged through injury or illness, does it have the capacity to repair itself, or can its functions be restored surgically?

Recall from the discussion of the brain's important characteristics earlier in the chapter that plasticity is an example of the brain's remarkable adaptability. Neuroscientists have studied plasticity especially following brain damage, charting the brain's ability to repair itself. Brain damage can produce horrific effects, including paralysis, sensory loss, memory loss, and personality deterioration. When such damage occurs, can the brain recover some or all of its functions? Recovery from brain damage varies considerably from one case to another depending on the age of the individual and the extent of the damage (Garraghty, 1996; Sofroniew & Mobley, 2001). In the case of Brandi Binder, described at the beginning of the chapter, considerable plasticity was present, and the left hemisphere of her cerebral cortex took over many typically right-hemisphere functions after the right hemisphere was surgically removed because of epilepsy. Other people are less fortunate. There is hope that one day surgeons will be able to implant healthy tissue and restore function lost as a result of illness or injury. We discuss this area of research shortly.

The Brain's Plasticity and Capacity for Repair

The human brain shows the most plasticity in young children before the functions of the cortical regions become entirely fixed (Kolb, 1989). For example, if the speech areas in an infant's left hemisphere are damaged, the right hemisphere assumes much of this language function. However, after age five, damage to the left hemisphere can permanently disrupt language ability (Kolb & others, 1998). The brain's plasticity is further discussed in chapter 4 on development throughout the life span.

A key factor in recovery is whether some or all of the neurons in an affected area are just damaged or completely destroyed (Black, 1998; Carlson, 2001). If the neurons have not been destroyed, brain function often becomes restored over time.

There are three ways in which repair of the damaged brain might take place:

- *Collateral sprouting,* in which the axons of some healthy neurons adjacent to damaged cells grow new branches (Chung & Chung, 2001).
- *Substitution of function,* in which the damaged region's function is taken over by another area or areas of the brain. This is what happened to Brandi Binder.
- *Neurogenesis.* This is the term given to the generation of new neurons. One of the long-standing beliefs in neuroscience regarding plasticity was that all of the neurons an individual will ever have are present soon after birth. However, neuroscientists have recently found that human adults can generate new neurons (Kempermann & Gage, 1999). Researchers also discovered that adult monkeys' brains can create thousands of new neurons each day (Gould & others, 1999). Some researchers believe there is good evidence that neurogenesis is much more pervasive than previously thought (Hsu & others, 2001). However, other neuroscientists argue that the evidence is weak (Rakic, 2002). If researchers can discover how new neurons are generated, possibly the information can be used to fight degenerative diseases of the brain, such as Alzheimer's disease and Parkinson's disease (Gage, 2000).

University of Lethbridge neuroscientist Bryan Kolb suffered some loss of vision from a right occipital stroke, which he correctly self-diagnosed. He then wrote about his recovery in the *Canadian Journal of Psychology* (Kolb, 1990). Another Canadian, documentary filmmaker Bonnie Klein, suffered a catastrophic brain stem stroke. She described her remarkable recovery in *Slow Dance: A Story of Love, Stroke, and Disability* (Klein, 1997).

Brain Tissue Implants

The brain naturally recovers some functions lost following damage, but not all. In recent years, considerable excitement has been generated about *brain grafts,* implants of healthy tissue into damaged brains (Rossi, Saggiorato, & Strata, 2002). The potential success of brain grafts is much better when brain tissue from the fetal stage (an early stage in prenatal development) is used. The neurons of the fetus are still growing and have a much higher probability of making connections with other neurons than do the

neurons of adults. In a number of studies, researchers have damaged part of an adult rat's (or some other animal's) brain, waited until the animal recovered as much as possible by itself, and assessed its behavioural deficits. Then they took the corresponding area of a fetal rat's brain and transplanted it into the damaged brain of the adult rat. In these studies, the rats that received the brain transplants demonstrated considerable behavioural recovery (Dunnett, 1989).

Might such brain grafts be successful with humans suffering from brain damage? Research suggests that they might, but finding donors is a problem (Lindvall, 2001). Aborted fetuses are a possibility, but using them as a source of graft tissue raises ethical issues. Another type of treatment has been attempted with individuals who have Parkinson's disease, a neurological disorder that affects about 200,000 people in Canada. Parkinson's disease impairs coordinated movement to the point that just walking across a room can be a major ordeal. In one recent study, brain grafts of embryonic dopamine neurons from aborted fetuses into individuals with Parkinson's disease resulted in a decrease of negative symptoms in individuals under 60 years of age but not in patients over 60 (Freed & others, 2001).

In another study, neuronal cells were transplanted into stroke victims (Kondziolka & others, 2000). The motor and cognitive skills of 12 patients who had experienced strokes improved markedly after the healthy neuronal cells were implanted in the midbrain.

The potential for brain grafts also exists for individuals with Alzheimer's disease, which is characterized by progressive decline in intellectual functioning resulting from the degeneration of neurons that function in memory. Such degenerative changes can be reversed in rats (Gage & Bjorklund, 1986). As yet, though, no successful brain grafts have been reported for Alzheimer's patients.

Online LearningCentre with PowerWeb

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

Review and Sharpen Your Thinking

5 ***Discuss the brain's capacity for recovery and repair.***

- State the factors that favour recovery of function in damaged brains and list three ways in which the brain may recover.
- Discuss the possibility of repairing damaged brains with tissue grafts.

Suppose someone has suffered a mild form of brain damage. What questions might you ask to determine whether the person's brain will likely be able to either compensate or repair itself?

6 GENETIC AND EVOLUTIONARY BLUEPRINTS OF BEHAVIOUR

Chromosomes, Genes, and DNA | The Study of Genetics | Genetics and Evolution

How do genetics and evolutionary psychology increase our understanding of behaviour?

As you saw at the beginning of this chapter, genetic and evolutionary processes favour organisms that have adapted for survival. Successful adaptations can be physical, as in the case of the brain's increasing complexity, or behavioural, as in the choice of a suitable mate for raising a family.

chromosomes Threadlike structures that contain genes and DNA. Humans have 23 chromosome pairs in the nucleus of every cell. Each parent contributes one chromosome to each pair.

Chromosomes, Genes, and DNA

You began life as a single cell, a fertilized human egg, weighing about one 700-thousandth of a gram. From this single cell, you developed into a human being made up of trillions of cells. The nucleus of each human cell contains 46 **chromosomes,** which are threadlike structures that come in 23 pairs, one member of each pair coming from

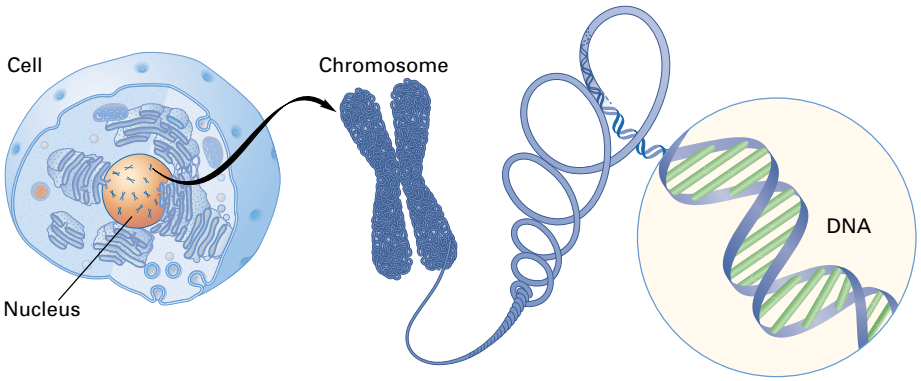


FIGURE 3.22 Cells, Chromosomes, Genes, and DNA (*Left*) The body contains trillions of cells, which are the basic structural units of life. Each cell contains a central structure, the nucleus. (*Middle*) Chromosomes and genes are located in the nucleus of the cell. Chromosomes are made up of threadlike structures composed mainly of DNA molecules. (*Right*) A gene is a segment of DNA that contains the hereditary code. The structure of DNA resembles a spiral ladder.

each parent. Chromosomes contain the remarkable substance **deoxyribonucleic acid,** or **DNA,** a complex molecule that contains genetic information. **Genes,** the units of hereditary information, are short segments of chromosomes, composed of DNA. Genes act like blueprints for cells. They enable cells to reproduce and manufacture the proteins that are necessary for maintaining life. The relationship among chromosomes, genes, and DNA is illustrated in figure 3.22.

When the approximately 30,000 genes from one parent combine at conception with the same number of genes from the other parent, the number of possibilities is staggering. Although scientists are still a long way from unravelling all the mysteries about the way genes work, some aspects of the process are well understood, starting with the fact that every person has two genes for each characteristic governed by principles of heredity (Lewis, 2003; Lewis & others, 2002).

In some gene pairs, one gene is dominant over the other. If one gene of a pair is dominant and one is recessive, according to the **dominant-recessive genes principle,** the dominant gene overrides the recessive gene. A recessive gene exerts its influence only if both genes of a pair are recessive. If you inherit a recessive gene from only one parent, you may never know you carry the gene. In the world of dominant-recessive genes, brown eyes, farsightedness, and dimples rule over blue eyes, nearsightedness, and freckles. If you inherit a recessive gene for a trait from both of your parents, you will show the trait. That's why two brown-eyed parents can have a blue-eyed child: Each parent would have a dominant gene for brown eyes and a recessive gene for blue eyes. Because dominant genes override recessive genes, the parents have brown eyes. However, the child can inherit a recessive gene for blue eyes from each parent. With no dominant gene to override them, the recessive genes make the child's eyes blue.

Unlike eye colour, complex human characteristics such as personality and intelligence are likely influenced by many different genes. The term *polygenic inheritance* is used to describe the influences of multiple genes on behaviour.

The Study of Genetics

Historically speaking, genetics is a relatively young science. Its origins go back to the mid-nineteenth century, when an Austrian monk named Gregor Mendel studied heredity in generations of pea plants. By cross-breeding plants with different characteristics and noting the characteristics of the offspring, Mendel discovered predictable patterns of heredity and laid the foundation for modern genetics. Today researchers continue to apply Mendel's methods, as well as modern technology, in their quest to expand our knowledge of genetics. This section discusses three ways to study genetics: molecular genetics, selective breeding, and behavioural genetics.

Molecular Genetics The field of *molecular genetics* involves actual manipulation of genes using technology to determine their effect on behaviour. There is currently a great deal of enthusiasm about the use of molecular genetics to discover the specific locations on genes that determine an individual's susceptibility to many diseases and other aspects of health and well-being (Dolfin, 2002; Mader, 2003).

deoxyribonucleic acid (DNA) A complex molecule that contains genetic information; makes up chromosomes.

genes The units of hereditary information. They are short segments of chromosomes, composed of DNA.

dominant-recessive genes principle If one gene of a pair governing a given characteristic (such as eye colour) is dominant and one is recessive, the dominant gene overrides the recessive gene. A recessive gene exerts its influence only if both genes in a pair are recessive.

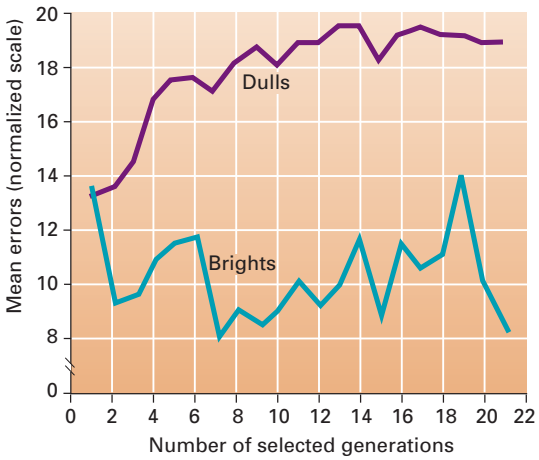


FIGURE 3.23 Results of Tryon's Selective Breeding Experiment with Maze-Bright and Maze-Dull Rats

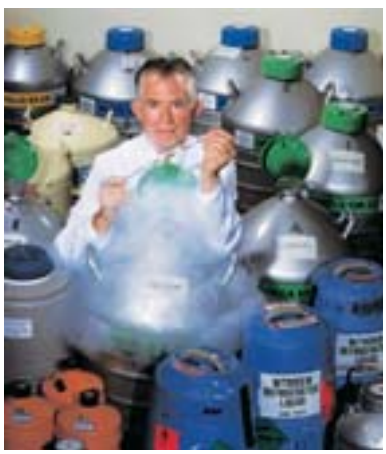
The term *genome* is used to describe the complete set of instructions for making an organism. It contains the master blueprint for all cellular structures and activities for the life span of the organism. To read about the Human Genome Project and its possible applications, see the Psychology and Life box.

Selective Breeding *Selective breeding* is a genetic method in which organisms are chosen for reproduction based on how much of a particular trait they display. Mendel developed this technique in his studies of pea plants. A more recent example involving behaviour is the classic selective breeding study conducted by Robert Tryon (1940). He chose to study maze-running ability in rats. After he trained a large number of rats to run a complex maze, he then mated the rats that were the best at maze running ("maze bright") with each other and the ones that were the worst ("maze dull") with each other. He continued this process with 21 generations of rats. As can be seen in figure 3.23, after several generations, the maze-bright rats significantly outperformed the maze-dull rats.

Selective breeding studies have demonstrated that genes are an important influence on behaviour, but that does not mean that experience is unimportant (Pinel, 2003). For example, in another study, maze-bright and maze-dull rats were reared in one of two environments: (1) an impoverished environment that consisted of a barren wire-mesh group cage, or (2) an enriched environment that contained tunnels, ramps, visual displays, and other stimulating objects (Cooper & Zubeck, 1958). When they reached maturity, only the maze-dull rats that had been reared in an impoverished environment made more maze-learning errors than the maze-bright rats.

Selective breeding is practised at the Repository for Germinal Choice in Escondido, California, which was founded by Dr. Robert Graham as a sperm bank for Nobel Prize winners and other bright individuals with the intent of producing geniuses. The sperm is available to women whose husbands are infertile. What are the odds that the sperm bank will yield that special combination of factors required to produce a creative genius? Twentieth-century Irish-born playwright George Bernard Shaw once told a story about a beautiful woman who wrote to him, saying that, with her body and his mind, they could produce wonderful offspring. Shaw responded by saying that, unfortunately, the offspring might get his body and her mind!

What do you think about the Nobel Prize winners' sperm bank? Is it right to breed for intelligence? Does it raise visions of the German genetics program of the 1930s and 1940s, based on the Nazis' belief that certain traits were superior? The Nazis tried to produce children with such traits and killed people without them. Or does the sperm bank merely provide a social service for couples who cannot conceive a child, couples who want to maximize the probability that their offspring will have good genes?



Dr. Graham with the frozen sperm of a Nobel Prize–winning donor.

Behaviour Genetics *Behaviour genetics* is the study of the degree and nature of heredity's influence on behaviour. Behaviour genetics is less invasive than molecular genetics and selective breeding. Using methods such as the *twin study,* behaviour geneticists examine the extent to which individuals are shaped by their heredity and their environmental experiences (Wahlsten, 2000).

In the most common type of twin study, the behavioural similarity of identical twins is compared with the behavioural similarity of fraternal twins. *Identical twins* develop from a single fertilized egg that splits into two genetically identical embryos, each of which becomes a person. *Fraternal twins* develop from separate eggs and separate sperm, making them genetically no more similar than nontwin siblings. They may even be of different sexes.

By comparing groups of identical and fraternal twins, behaviour geneticists capitalize on the fact that identical twins are more similar genetically than are fraternal twins. In one twin study, 7000 pairs of Finnish identical and fraternal twins were compared on the personality traits of extroversion (being outgoing) and neuroticism (being psychologically unstable; Rose & others, 1988). The identical twins were much more alike than the fraternal twins on both of these personality traits, suggesting that genes influence both traits.

The Human Genome Project and Your Genetic Future

The Human Genome Project, begun in the 1970s, has made stunning progress in mapping the human genome. Goals for 2003 are to identify all of the genes in human DNA and determine the sequence of 3 billion chemical base pairs that make up human DNA (U.S. Department of Energy, 2001). Among the surprise discoveries of the Human Genome Project is that humans have only about 30,000 genes—it was previously thought that we had 50,000 to 100,000. The project also has revealed that human DNA is about 98 percent identical to chimpanzee DNA (U.S. Department of Energy, 2001).

The Human Genome Project has already linked specific DNA variations with increased risk of a number of diseases and conditions, including Huntington's disease (in which the central nervous system deteriorates), some forms of cancer, asthma, diabetes, hypertension, and Alzheimer's disease (Davies, 2001). Other documented DNA variations affect the way people react to certain drugs.

A positive result from the Human Genome Project. Shortly after Andrew Gobea was born, his cells were genetically altered to prevent his immune system from failing.

Every individual carries a number of DNA variations that might predispose that person to a serious physical disease or mental disorder. Identifying these flaws could enable doctors to estimate an individual's disease risks, recommend healthy lifestyle regimens, and prescribe the safest and most effective drugs. A decade or two from now, parents of a newborn baby may be able to leave the hospital with a full genome analysis of their offspring that reveals various disease risks.

However, mining DNA variations to discover health risks might increasingly threaten an individual's ability to obtain and hold jobs, obtain insurance, and keep genetic profiles private. For example, should an airline pilot or neurosurgeon who one day may develop a disorder that makes the hands shake be required to leave that job early?

Answering the following questions should encourage you to think further about some of the issues involved in our genetic future (NOVA, 2001):

1. Would you want yourself or a loved one to be tested for a gene that increases your risk for a disease but does not determine whether you will actually develop the disease?
2. Would you want yourself and your mate tested before having offspring to determine your risk for having a child who is likely to contract various diseases?
3. Should testing of fetuses be restricted to traits that are commonly considered to have negative outcomes, such as Huntington's disease?
4. Should altering a newly conceived embryo's genes to improve qualities such as intelligence, appearance, and strength be allowed?
5. Should employers be permitted access to your genetic information?
6. Should life insurance companies have access to your genetic information?

One problem with twin studies is that adults might stress the similarities of identical twin children more than those of fraternal twins, and identical twins might perceive themselves as a "set" and play together more than fraternal twins do. If so, observed similarities in identical twins might be more strongly influenced by environmental factors than usually thought.

In another type of twin study, researchers evaluate identical twins who have been reared in separate environments. If their behaviour is similar, the assumption is that heredity has played an important role in shaping their behaviour. This strategy is the basis for the Minnesota Study of Twins Reared Apart, directed by Thomas Bouchard and his colleagues (1996). They bring together identical twins from all over the world who have been reared apart to study their behaviour. They ask thousands of questions about their family and childhood environment, personal

What is the nature of the twin-study method?

The Jim twins: how coincidental? Springer (*right*) and Lewis were unaware of each other for 39 years.

interests, vocational orientation, and values. Detailed medical histories are obtained, including information about their diet, smoking, and exercise habits.

One pair of twins in the Minnesota study, Jim Springer and Jim Lewis, were separated at four weeks of age and did not see each other again until they were 39 years old. They had an uncanny number of similarities, even though they had lived apart. For example, they both worked as part-time deputy sheriffs, had vacationed in Florida, had owned Chevrolets, had dogs named Toy, and had married and divorced women named Betty. Both liked math but not spelling. Both were good at mechanical drawing. Both put on 10 pounds at about the same time in their lives, and both started suffering headaches at 18 years of age. They did have a few differences. For example, one expressed himself better orally, and the other was more proficient at writing. One parted his hair over his forehead, the other wore his hair slicked back with sideburns.

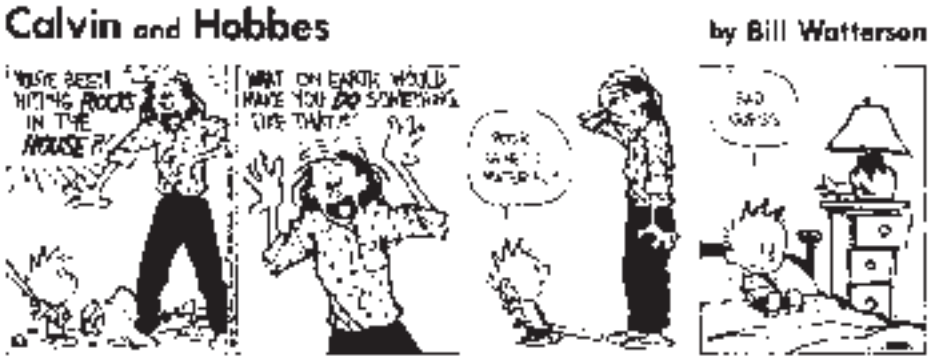
Critics argue that some of the separated twins in the Minnesota study had been together several months prior to their adoption, that some had been reunited prior to their testing (in some cases for a number of years), that adoption agencies often put identical twins in similar homes, and that even strangers who spend several hours together are likely to come up with some coincidental similarities (Adler, 1991). Still, even in the face of such criticism, it seems unlikely that all of the similarities in the identical twins reared apart could be due to experience alone.

Behaviour geneticists also use *adoption studies* to try to determine whether the behaviour of adopted children is more like that of their biological parents or their adoptive parents. Another type of adoption study compares biological and adopted siblings. In one study, the educational levels attained by biological parents were better predictors of the adopted children's IQ scores than were the IQs of the children's adoptive parents (Scarr & Weinberg, 1983). Because of the stronger genetic link between the adopted children and their biological parents, the implication is that heredity plays an important role in intelligence. However, there are numerous studies that document the critical role of environment in intelligence, as well (Sternberg, 1997).

Genetics and behaviour, especially the way heredity and environment interact, are discussed further in chapter 4.

Genetics and Evolution

Often we can see the effects of genetics by observing family resemblances. For example, you might have your mother's dark hair and your father's long legs. Evolutionary influences are not as easy to see, because we share physical and psychological characteristics with every other human, such as a cerebral cortex in our brain that allows us to think and plan. We also share certain problems that we have to solve and adapt to, such as how to protect ourselves from harm, how to nourish our bodies, how to find a compatible mate, and how to rear our children. In the evolutionary scheme, some individ-



uals were more successful at solving these problems and adapting effectively than others (Cummings, 2003; Goldsmith & Zimmerman, 2001). Those who were successful passed on their genes to the next generation. Those who were less successful did not.

In the evolutionary psychology view, psychological functions evolved to become specialized. Thus, just as the cerebellum became functionally specialized in coordinating movement, so it might be that specialized psychological functions evolved (Buss, 2000). Among the specialized psychological functions that evolutionary psychologists study are

- Development of a fear of strangers between 3 and 24 months of age, as well as fears of snakes, spiders, heights, open spaces, and darkness (Marks, 1987)
- Perceptual adaptations for tracking motion (Ashida, Seiffert, & Osaka, 2001)
- Children's imitation of high-status rather than low-status models (Bandura, 1977)
- The worldwide preference for mates who are kind, intelligent, and dependable (Buss & others, 1990)

Evolutionary psychologists believe that these specialized functions developed because they helped humans adapt and solve problems in past evolutionary environments (Cosmides & others, 2003). According to Martin Daly, Margo Wilson, and Denys deCatanzaro, of McMaster University, these problems include parenthood (Daly & Wilson, 1998), homicide (Daly & Wilson, 1988), and motivation and emotion (deCatanzaro, 1999). In later chapters, we examine what evolutionary psychologists have to say about other psychological topics.

Before leaving the topic of evolutionary psychology, it is important to mention that some critics believe it places too much emphasis on biological foundations of behaviour. For example, Albert Bandura (1998), whose social cognitive theory was described in chapter 1, acknowledges the importance of human adaptation and change. However, he rejects what he calls "one-sided evolutionism," in which social behaviour is the product of evolved biology. Bandura recommends a bidirectional view. In this view, evolutionary pressures created changes in biological structures for the use of tools, which enabled organisms to manipulate, alter, and construct new environmental conditions. Environmental innovations of increasing complexity, in turn, produced new selection pressures for the evolution of specialized biological systems for consciousness, thought, and language.

Human evolution gave us body structures and biological potentialities, not behavioural dictates, according to scientists such as Steven Jay Gould (1981). Having evolved, advanced biological capacities can be instrumental in producing diverse cultures—aggressive or peaceful, for example (Janicki & Krebs, 1998). And Russian-American scientist Theodore Dobzhansky (1977) reminds us that the human species has selected for learnability and plasticity, which allows us to adapt to diverse contexts. Most, if not all, psychologists would agree that the interaction of biology and environment is the basis for our own development as human beings. McGill psychologist Donald Hebb used to offer a useful analogy: what is the relevant contribution of height and width to the area of a rectangle? Of course both dimensions are absolutely essential; if either is reduced to zero, there is no rectangle any more. Similarly, if an attractive, popular, intelligent girl is elected president of her senior high school class, her success is due to both heredity and the environment. Chapter 4 further explores the influence of biology and environment on human development.

Review and Sharpen Your Thinking

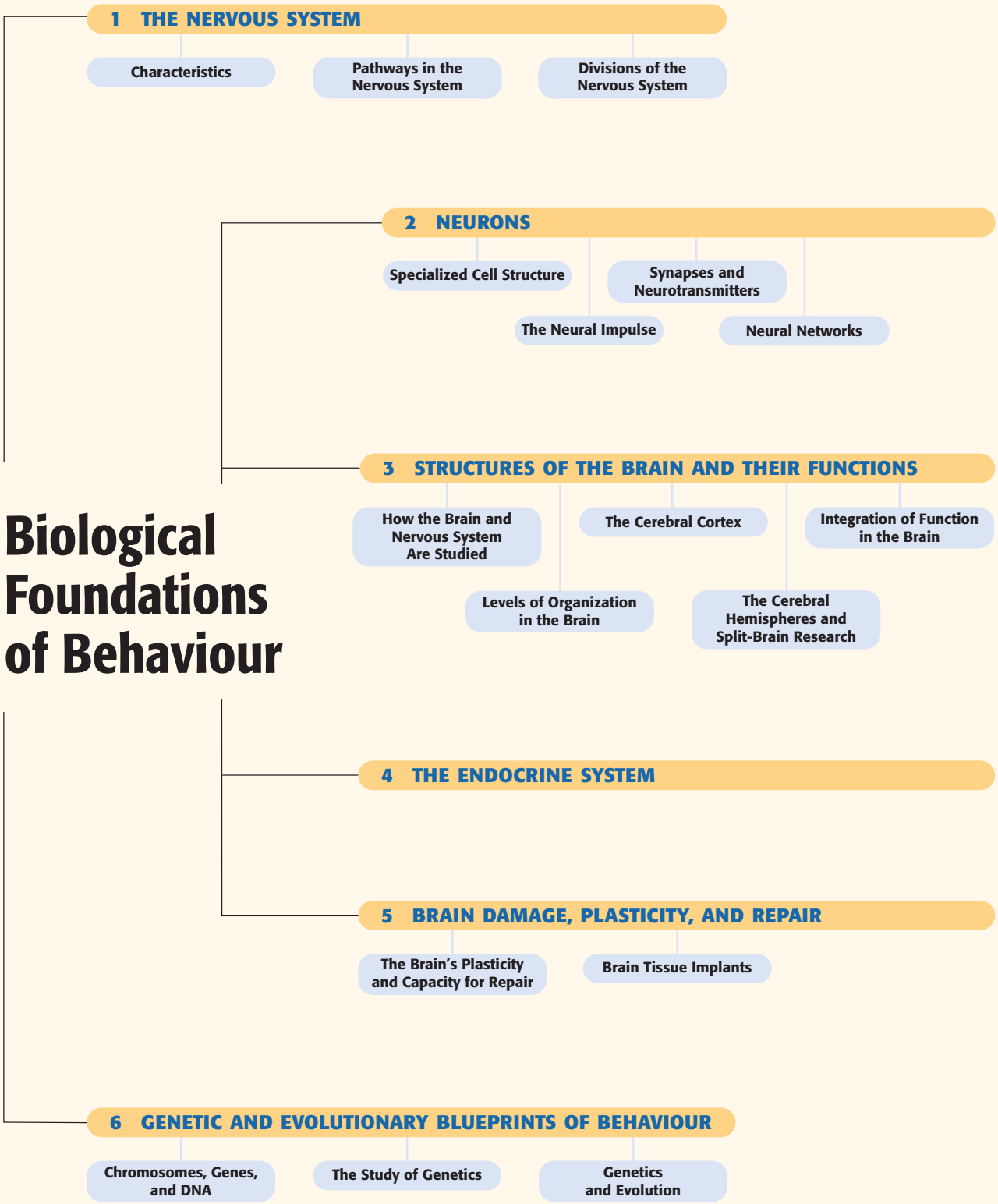
6 ***Explain how genetics and evolutionary psychology increase our understanding of behaviour.***

- Discuss the structures and functions of chromosomes, genes, and DNA.
- Describe three methods for studying genetics.
- Explain how evolution might direct human behaviour.

What ethical issues regarding genetics and behaviour might arise in the future?

For study tools related to this learning goal, see the Study Guide and the Online Learning Centre.

Reach Your Learning Goals



1 *Discuss the nature and basic functions of the nervous system.*

- The nervous system is the body's electrochemical communication circuitry. Four important characteristics of the brain and nervous system are complexity, integration, adaptability, and electrochemical transmission. The brain's special ability to adapt and change is called plasticity.
- The flow of information in the nervous system occurs in specialized pathways of nerve cells. Three of these pathways involve sensory input, motor output, and neural networks.
- The nervous system is divided into two main parts: central (CNS) and peripheral (PNS). The CNS consists of the brain and spinal cord. The PNS has two major divisions: somatic and autonomic. The autonomic nervous system consists of two main divisions: sympathetic and parasympathetic.

2 *Explain what neurons are and describe how they process information.*

- Neurons are cells that specialize in processing information. They make up the communication network of the nervous system. Glial cells perform supportive and nutritive functions for neurons. The three main parts of the neuron are the cell body, dendrite (receiving part), and axon (sending part). A myelin sheath encases and insulates most axons and speeds up transmission of neural impulses.
- A neuron sends information along its axon in the form of brief electric impulses, or waves. Resting potential is the term given to the stable, slightly negative charge of an inactive neuron. When the electrical signals exceed a certain activation threshold, positively charged sodium ions rush into the neuron. The brief wave of electrical charge that sweeps down the axon is called the action potential. The neuron returns to a resting potential as positively charged potassium ions move out of it, returning the neuron to a negative charge. The action potential abides by the all-or-none principle: Its strength does not change during transmission.
- To go from one neuron to another, information must be converted from an electrical impulse to a chemical messenger called a neurotransmitter. At the synapse where neurons meet, neurotransmitters are released into the narrow gap that separates them. There some neurotransmitter molecules attach to receptor sites on the receiving neuron, where they stimulate another electrical impulse. Neurotransmitters can be excitatory or inhibitory depending on the nature of the neural impulse. Neurotransmitters include acetylcholine, GABA, norepinephrine, dopamine, serotonin, and endorphins. Most drugs that influence behaviour do so mainly by mimicking neurotransmitters or interfering with their activity.
- Neural networks are clusters of neurons that are interconnected to process information.

3 *Identify the brain's levels and structures and the functions of its structures.*

- The main techniques used to study the brain are brain lesioning, staining, electrical recording, and brain imaging.
- The three major levels of the brain are the hindbrain, midbrain, and forebrain. The hindbrain is the lowest portion of the brain. The three main parts of the hindbrain are the medulla (involved in controlling breathing and posture), cerebellum (involved in motor coordination), and pons (involved in sleep and arousal).
- From the midbrain many nerve-fibre systems ascend and descend to connect to higher and lower levels of the brain. The midbrain contains the reticular formation, which is involved in stereotypical patterns of behaviour (such as walking, sleeping, or turning to a sudden noise), and small groups of neurons that communicate with many areas in the brain. The brain stem consists of much of the hindbrain (excluding the cerebellum) and the midbrain.
- The forebrain is the highest level of the brain. The key forebrain structures are the limbic system, thalamus, basal ganglia, hypothalamus, and cerebral cortex. The limbic system is involved in memory and emotion through its two structures, the amygdala (which plays roles in survival and emotion) and the hippocampus (which functions in the storage of memories). The thalamus is a forebrain structure that serves as an important relay station for processing information. The basal ganglia are forebrain structures that help to control and coordinate voluntary movements. The hypothalamus is a forebrain structure that monitors eating, drinking, and sex; directs the endocrine system through the pituitary gland; and is involved in emotion, stress, and reward.
- The cerebral cortex makes up most of the outer layer of the brain. Higher mental functions, such as thinking and planning, take place in the cerebral cortex. The wrinkled surface of the cerebral cortex is divided into hemispheres. Each hemisphere is divided into four lobes: occipital, temporal, frontal, and parietal. There is considerable integration and connection between the brain's lobes. The sensory cortex processes information about body sensations. The motor cortex processes information about voluntary movement. Penfield (1947) pinpointed specific areas in the brain that correspond to specific parts of the body and also mapped sensory fields onto the cortex's surface. The association cortex, which makes up 75 percent of the cerebral cortex, is instrumental in integrating information, especially about the highest intellectual functions.

- A controversial topic is the extent to which the left and right hemispheres of the brain are involved in different functions. Two areas in the left hemisphere that involve specific language functions are Broca's area (speech) and Wernicke's area (comprehending language). The corpus callosum is a large bundle of fibres that connects the two hemispheres. Researchers have studied what happens when the corpus callosum has to be severed, as in some cases of severe epilepsy. Research suggests that the left brain is more dominant in processing verbal information (such as language), and the right brain in processing nonverbal information (such as spatial perception, visual recognition, and emotion). Nonetheless, in a normal individual whose corpus callosum is intact, both hemispheres of the cerebral cortex are involved in most complex human functioning.
- It is extremely important to remember that generally brain function is integrated and involves connections between different parts of the brain. Pathways of neurons involved in a particular function, such as memory, are integrated across different parts and levels of the brain.

4 *State what the endocrine system is and how it affects behaviour.*

- The endocrine glands release hormones directly into the bloodstream for distribution throughout the body. The pituitary gland is the master endocrine gland. The adrenal glands play important roles in moods, energy level, and ability to cope with stress.

5 *Describe the brain's capacity for recovery and repair.*

- The human brain has considerable plasticity, although this plasticity is greater in young children than later in development. Three ways in which a damaged brain might repair itself are collateral sprouting, substitution of function, and neurogenesis.
- Brain grafts are implants of healthy tissue into damaged brains. Brain grafts are more successful when fetal tissue is used.

6 *Explain how genetics and evolutionary psychology increase our understanding of behaviour.*

- Chromosomes are threadlike structures that come in 23 pairs, one member of each pair coming from each parent. Chromosomes contain the genetic substance deoxyribonucleic acid (DNA). Genes, the units of hereditary information, are short segments of chromosomes composed of DNA. The dominant-recessive genes principle states that if one gene of a pair is dominant and one is recessive, the dominant gene overrides the recessive gene.
- Three methods that are used to study heredity's influence are molecular genetics, selective breeding, and behaviour genetics. Two methods used by behaviour geneticists are twin studies and adoption studies.
- Several key points in evolutionary psychology centre on the idea that nature selects behaviours that increase an organism's reproductive success, the importance of adaptive behaviour, and specialization of functions. Evolutionary psychologists believe that just as parts of the brain have become specialized in function through the process of evolution, so have mental processes and behaviour. Critics stress that it is important to recognize how evolutionary advances allow humans to choose and select their environments, rather than being completely under the control of their evolutionary past.

Key Terms

nervous system, p. 74
plasticity, p. 75
afferent nerves, p. 76
efferent nerves, p. 76
neural network, p. 76
central nervous system (CNS), p. 76
peripheral nervous system (PNS), p. 76
somatic nervous system, p. 76
autonomic nervous system, p. 77
sympathetic nervous system, p. 77
parasympathetic nervous system, p. 77
neuron, p. 78
glial cells, p. 78
cell body, p. 78
dendrite, p. 78
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occipital lobe, p. 90
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frontal lobe, p. 90
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sensory cortex, p. 92
motor cortex, p. 92
association cortex, p. 93
corpus callosum, p. 94
endocrine system, p. 97
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pituitary gland, p. 98
adrenal glands, p. 98
chromosomes, p. 100
deoxyribonucleic acid (DNA), p. 101
genes, p. 101
dominant-recessive genes principle, p. 101

Apply Your Knowledge

1. Consider the four characteristics of the nervous system. Suppose you had to do without one of them. Which would you choose, and what would be the consequences for your behaviour?
2. Do a search on the World Wide Web for "nutrition" and "the brain." Examine the claims made by one or more of the websites. Based on what you learned in the chapter about how the nervous system works, how could nutrition affect brain function? Based on what you know about being a scientist, how believable are the claims on the website?
3. Imagine that you could make one part of your brain twice as big as it is right now. Which part would it be, and how do you think your behaviour would change as a result? What if you had to make another part of your brain half its current size? Which part would you choose to shrink, and what would the effects be?
4. Ephedra is a drug contained in a number of formulas marketed to enhance athletic performance. Among the actions of ephedra is stimulation of areas that normally respond to epinephrine and norepinephrine. Think about the two different kinds of actions (neurotransmitter and hormone) these chemicals normally have in the nervous system, and describe the kinds of side effects you might expect from taking ephedra. In particular, why might taking ephedra be very dangerous?
5. It's not unusual to read headlines announcing that genes are responsible for a desirable behaviour (for example, "Born to run . . . or dance or jump or walk," *National Post*, March 14, 2002), or a troublesome behaviour (for example, "Next time you pig out, blame it on the genes," *Los Angeles Times*, October 19, 2000, or "Men are born fighters," *The Times* (London), October 19, 2001). How would you interpret statements like these in light of the material discussed in the text?

Connections

For extra help in mastering the material in the chapter, see the review questions and practice quizzes in the Student Study Guide and the Online Learning Centre.