2 Biology and Behaviour

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Lori and Reba Schappell are middle-aged sisters who are intimately aware of every aspect of each other's lives. They have never spent a day, or even a moment apart—they are conjoined twins (also known as Siamese twins). Not only are they conjoined, they happen to fall into the rare 2 percent of conjoined twins who are attached at the head. Lori and Reba are attached at the left temple just above the eye—each one facing the other. The true extent of their attachment became evident only recently when MRI technology indicated that the twins shared a significant portion of their frontal lobes—the part of the brain associated with personality, emotion, and higher intellectual functions. Given such a strong fusion of brain and nerve tissue, it might have been expected that these two sisters would share the same personality, likes and dislikes, and feelings about things ("Conjoined twins," 2000). Exactly how similar these twins are is not yet known; however, we do know that the sisters do not share thoughts—even emotional ones—or dreams, and they do not share all interests. For example, Reba is pursuing a country and western singing career but Lori prefers just to listen to her sister perform (Sunday Times, 2000). Information gathered from conjoined twins is challenging our beliefs and knowledge about how the brain works.

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In a more recent case, the decision of how to handle shared brain tissue and the circulatory systems that support the brain and body became a more critical issue. Among the triplet sisters Faryal, Nida, and Hira, two—Hira and Nida—were joined at the head and shared some brain matter and cerebral circulation. Doctors recommended that the conjoined sisters be separated, but the medical expertise required for this type of surgery just wasn't available in their homeland, Pakistan ("Separate lives," 2000, p. 1). The future looked grim until Dr. Hoffman, at Toronto's Hospital for Sick Children, and his team of neurosurgeons, neuroradiologists, plastic surgeons, anesthetists, urologists, cardiologists, and surgical nurses agreed to try the surgery.

The twins were just two years old when they underwent surgery to separate them for the first time in their lives. The shared brain matter was in the parietal region and it was thought to be nonfunctional, so it was divided among the two sisters. A special clip was used to block part of the cerebral circulation shared by the twins. Excessive bleeding from this area during surgery would spell disaster. The 17-hour surgery ended in both success and failure. Within a month Nida died of a heart attack. Hira flourished. In 1997, she received the last treatment for her scalp, after which she would return home to continue her normal life as an independent, healthy five-year-old (Murray, 1999). (Story adapted from "Conjoined twins," 2000; Duce, 2000; Murray, 1999; "Separate lives," 2000.)

In Chapter 1 we defined psychology as the scientific study of behaviour and mental processes. Before we can understand and appreciate our behaviour and mental processes, we must first explore the all-important biological connection. Every thought we think, every emotion we feel, every sensation we experience, every decision we reach, every move we make—in short, all human behaviour—is rooted in a biological event. Therefore, we launch our exploration of psychology with the study of biology and behaviour. Our story begins where the action begins, in the smallest functional unit of the brain—the nerve cell, or neuron.

LINK IT!

Conjoined Twins
www.bbc.co.uk/science/horizon/conjoined_twins_transcript.shtml

www.med.harvard.edu/AANLIB/home.html
The Whole Brain Atlas

www.bic.mni.mcgill.ca/brainweb/
BrainWeb: Simulated Brain Database

The Neurons and the Neurotransmitters

The Neurons: Billions of Brain Cells

What is a neuron, and what are its three parts?

All our thoughts, feelings, and behaviour can ultimately be traced to the activity of specialized cells called **neurons.** Most experts estimate that there are as many as 100 billion neurons in the brain (Swanson, 1995). This means that you have about 17 times as many neurons as there are people living on this planet right now.

Neurons perform several important tasks: (1) Afferent (sensory) neurons relay messages from the sense organs and receptors—eyes, ears, nose, mouth, and skin—to the brain or spinal cord. (2) Efferent (motor) neurons convey signals from the brain and spinal cord to the glands and muscles, enabling us to move. (3) Interneurons, thousands of times more numerous than motor or sensory neurons, carry information between neurons in the brain and between neurons in the spinal cord.

Anatomy of a Neuron: Looking at Its Parts

Neurons transmit signals through the nervous system. Although no two neurons are exactly alike, nearly all are made up of three important parts: cell body (soma), dendrites, and axon. Figure 2.1 shows the structure of a neuron. The **cell body** contains the nucleus and carries out the metabolic, or life-sustaining, functions of the neuron. Branching out from the cell body are the **dendrites**, which look much like the leafless branches of a tree. The dendrites are the primary receivers of signals from other neurons, but the cell body can also receive the signals directly. Dendrites do not merely receive signals from other neurons and relay them to the cell body. Dendrites relay messages backward—from the cell body to their own branches (a process called back propagating). These backward messages may shape the dendrites responses to future signals they receive (Magee & Johnston, 1997; Sejnowski, 1997).

The **axon** is the slender, tail-like extension of the neuron that sprouts into many branches, each ending in a rounded axon terminal. The axon terminals transmit signals to the dendrites, to the cell bodies of other neurons, and to muscles, glands, and other parts of the body. In humans, some axons are short—only

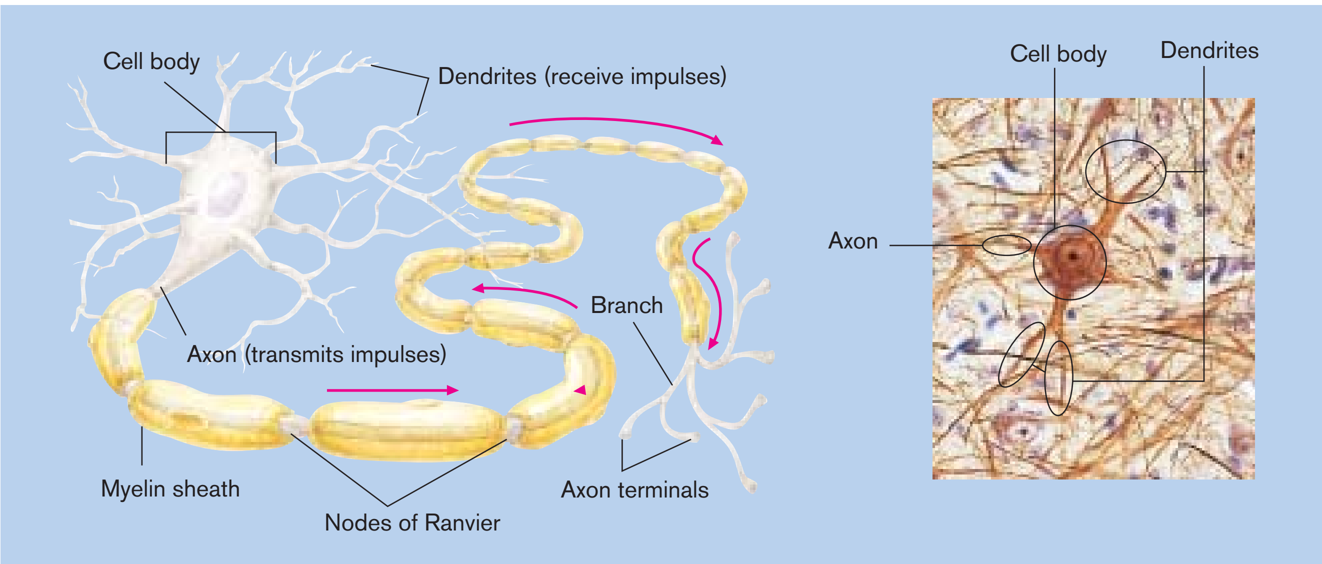


FIGURE 2.1

The Structure of a Neuron **Neurons have three important parts: (1) a cell body, which carries out the metabolic functions of the neuron; (2) branched fibres called dendrites, which are the primary receivers of the impulses from other neurons; and (3) a slender, tail-like extension called an axon, the transmitting end of the neuron, which sprouts into many branches, each ending in an axon terminal. The photograph shows human neurons greatly magnified.**

neuron (NEW-ron): A specialized cell that conducts impulses through the nervous system and contains three major parts–a cell body, dendrites, and an axon.

cell body: The part of the neuron, containing the nucleus, that carries out the metabolic functions of the neuron.

dendrites (DEN-drytes): The branch-like extensions of a neuron that receive signals from other neurons.

axon (AK-sahn): The slender, tail-like extension of the neuron that transmits signals to the dendrites or cell body of other neurons or to the muscles or glands.

thousandths of a centimetre. Others can be up to a metre long—long enough to reach from the brain to the tip of the spinal cord, or from the spinal cord to remote parts of the body.

The Synapse

What is a synapse?

Remarkably, the billions of neurons that send and relay signals are not physically connected. The axon terminals are separated from the receiving neurons by tiny, fluid-filled gaps called *synaptic clefts*. The **synapse** is the junction where the axon terminal of a sending neuron communicates with a receiving neuron across the synaptic cleft. There may be as many as 100 trillion synapses in the human nervous system (Swanson, 1995), with each neuron potentially connecting with thousands of other neurons (Kelner, 1997).

How big is one trillion? Numbers in the trillions are hard for us to comprehend. You know how short a time one second is. It takes almost 32 000 years for one trillion seconds to pass. Now try to imagine how incredibly complex your brain must be if there are between 10 trillion and 100 trillion synapses across which your neurons are passing and receiving messages.

If neurons are not physically connected, how do they communicate? How do they send and receive their messages?

The Neural Impulse: The Beginning of Thought and Action

What is the action potential?

Cells in the brain, the spinal cord, and the muscles generate electrical potentials. Every time we move a muscle, experience a sensation, or have a thought or a feeling, a small but measurable electrical impulse is present.

How does this biological electricity work? Even though the impulse that travels down the axon is electrical, the axon does not transmit it the way a wire conducts an electrical current. Rather, bodily fluids contain certain types of chemical molecules known as ions, some with a positive charge and others with a negative charge. What actually moves through the axon is a change in the permeability of the cell membrane. When this process occurs, ions move through the membrane, into and out of the neuron. Every neuron (like every other living cell) has a membrane. Inside this membrane there are normally more negative than positive ions. When at rest (not firing), a neuron carries a negative electrical potential relative to the environment outside the cell. This slight negative charge is referred to as the neuron's **resting potential**.

When a neuron is sufficiently stimulated, its resting potential becomes disturbed. As a result, the cell membrane of the neuron changes its permeability. This causes more positive ions to flow into the cell

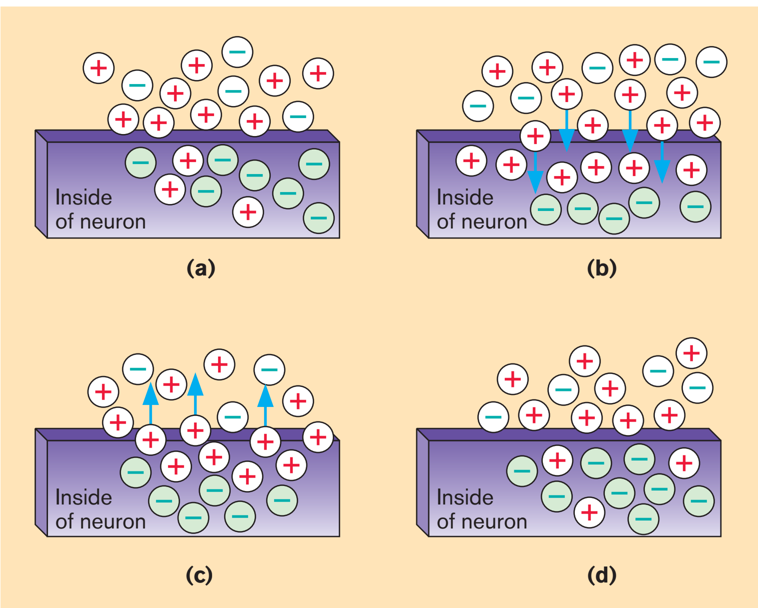


FIGURE 2.2

The Action Potential **(a) When a neuron is at rest (not firing), the inside of the neuron has a slight negative electrical charge compared to the outside; this is referred to as the neuron's "resting potential." (b) When a neuron is stimulated, more positively charged particles flow into the cell, making the inside suddenly positive compared to the outside of the cell. This sudden reversal is the action potential. (c) Immediately after the neuron fires, some positive particles are actively pumped out of the cell. (d) The neuron returns to its resting potential and is ready to fire again if stimulated.**

and other ions to flow out. If the disturbance reaches a minimum intensity known as the threshold, the neuron's resting membrane potential is suddenly reversed—it becomes positive. This sudden reversal of the resting potential is the **action potential**. The action potential operates according to the "all or none" law—the neuron either fires completely or does not fire at all. Immediately after the neuron reaches its action potential and fires, it returns to its resting potential until stimulated again. But its rest may be very short, because neurons can fire up to 1 000 times per second. Figure 2.2 illustrates the movement of positive ions across the cell membrane, which stimulates the neuron to its action potential.

Consider this important question: If a neuron only fires or does not fire, how can we tell the difference between a very strong and a very weak stimulus? a jarring blow and a soft touch? a blinding light and a dim one? a shout and a whisper? The answer lies in the number of neurons firing at the same time and their rate of firing (the number of times per second). A weak stimulus may cause relatively few neurons to fire; a strong stimulus may cause thousands of neurons to fire at the same time. Furthermore, a weak stimulus may cause neurons to fire very slowly; a strong stimulus may cause neurons to fire hundreds of times per second (normally the firing rate is much slower).

Nerve impulses travel at speeds between about 1 metre per second and about 100 metres per second (about 360 kilometres per hour). The speed of the impulse is related to the size of the axon. Neurons with larger, longer axons—those that reach from the brain through the spinal cord, and from the spinal cord to remote parts of the body—send impulses at a faster speed than those with smaller, shorter axons. How can they do this?

The most important factor in the speed of the impulse is the **myelin sheath**—a white, fatty coating wrapped around some axons that acts as insulation. If you look again at Figure 2.1, you will see that this coating has numerous gaps called *nodes of Ranvier*. These nodes cause the myelin sheath to look like links of sausage strung together. The electrical impulse is retriggered or regenerated at each node (or naked gap) along the axon. Thus impulses travel up to 100 times faster along axons with myelin sheaths.

Neurotransmitters: The Chemical Messengers of the Brain

What are neurotransmitters, and what role do they play in the transmission of signals from one neuron to another?

Once a neuron fires, how does it get its message to other neurons? Messages are transmitted between neurons by one or more of a large group of chemical substances known as **neurotransmitters** (Hokfelt et al., 1984).

Where are the neurotransmitters located? Inside the axon terminal are many small, sphere-shaped containers with thin membranes, called *synaptic vesicles*, which hold the neurotransmitters. When an action potential arrives at the axon terminal, synaptic vesicles move toward the cell membrane, fuse with it, and release their neurotransmitter molecules. This process is shown in Figure 2.3.

The Receptor Sites: Locks for Neurotransmitter Keys

Once released, neurotransmitters do not simply flow into the synaptic cleft and stimulate all the adjacent neurons. Each neurotransmitter has a distinctive molecular shape. Numerous **receptor sites** on the surfaces of dendrites and cell bodies also have distinctive shapes. Neurotransmitters can affect only those neurons that contain receptor sites designed to receive molecules matching their particular shape. In

synapse (SIN-aps): The junction where the axon of a sending neuron communicates with a receiving neuron across the synaptic cleft.

resting potential: The membrane potential of a neuron at rest, about –70 millivolts.

action potential: The firing of a neuron that results when the charge within the neuron becomes more positive than the charge outside the cell's membrane.

myelin sheath (MY-uh-lin): The white, fatty coating wrapped around some axons that acts as insulation and enables impulses to travel much faster.

neurotransmitter (NEW-ro-TRANS-miter): A chemical that is released into the synaptic cleft from the axon terminal of the sending neuron, crosses the synapse, and binds to appropriate receptor sites on the dendrites or cell body of the receiving neuron, influencing the cell either to fire or not to fire.

receptor site: A site on the dendrite or cell body of a neuron that will receive only specific neurotransmitters.

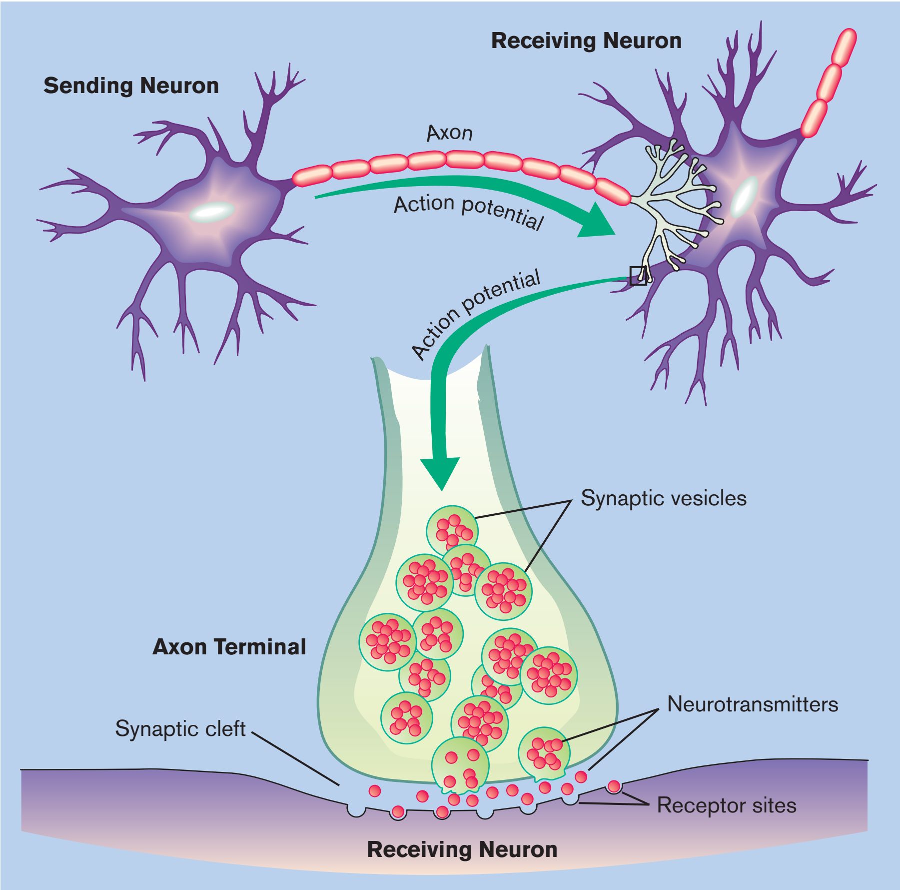


FIGURE 2.3

Synaptic Transmission **Sending neurons transmit their messages to receiving neurons by electrochemical action. When a neuron fires, the action potential arrives at the axon terminal and triggers the release of neurotransmitters from the synaptic vesicles. Neurotransmitters flow into the synaptic cleft and move toward the receiving neuron, which has numerous receptor sites. The receptor sites will receive only neurotransmitters with distinctive molecular shapes that match them. Neurotransmitters influence the receiving neuron only to fire or not to fire.**

other words, each receptor site is like a locked door that only certain neurotransmitter "keys" can unlock.

However, the process by which neurotransmitters bind with receptor sites is not as fixed and rigid as keys fitting locks or jigsaw puzzle pieces interlocking. Receptor sites in the brain are living matter; they can expand and contract their enclosed volumes. The interaction where the neurotransmitter and the receptor meet is controlled not by the direct influence of one on the other, but by their *mutual influence* on each other. Thus, a certain neurotransmitter may be competing for the same receptor with another neurotransmitter of a slightly different shape. The receptor will admit only one of the competing neurotransmitters—the one that fits it most perfectly. This means that a neurotransmitter may be received by a receptor at one time, but not at other times if another neurotransmitter molecule is present whose "affinity with the receptor is even stronger. As in dating and mating, what is finally settled for is always a function of what is available" (Restak, 1993, p. 28).

The Action of Neurotransmitters

When neurotransmitters enter receptor sites on the dendrites or cell bodies of receiving neurons, their action is either excitatory (influencing the neurons to fire) or inhibitory (influencing them not to fire). Because a single neuron may connect with thousands of other neurons at the same time, there will always be both excitatory and inhibitory influences on receiving neurons. For the neuron to fire, the excitatory influences must exceed the inhibitory influences of neurotransmitter substances by a sufficient amount (the threshold).

For many years researchers believed that each individual neuron responded to only one neurotransmitter. But it is now known that individual neurons may respond to several different neurotransmitters. This suggests a greater flexibility of response, even at the level of a single neuron.

You may wonder how the synaptic vesicles can continue to pour out their neurotransmitters, yet have a ready supply so that the neuron can respond to continuing stimulation. First, the cell body of the neuron is always working to manufacture more of the neurotransmitter substance. Second, after accomplishing its mission, the neurotransmitter may be broken down into its component molecules and reclaimed by the axon terminal to be recycled and used again. Third, by an important process called **reuptake**, the neurotransmitter substance may be taken intact back into the axon terminal, ready for immediate use. This ends the neurotransmitter's excitatory or inhibitory effect on the receiving neuron.

The important point to remember is that signals travel between neurons by way of the neurotransmitters, the chemical messengers of the brain.

LINK IT!

neuroscience.about.com/science/neuroscience/cs/neurotransmitters/
Neurotransmitters

www.pharmcentral.com/neurotransmitters.htm
Neurotransmitters

The Variety of Neurotransmitters: Some Excite and Some Inhibit

What are some of the ways in which neurotransmitters affect our behaviour, and what are some of the major neurotransmitters?

Neurotransmitters are manufactured in the brain, the spinal cord, the glands, and a few other parts of the body. Each kind of neurotransmitter affects the activity of the brain in a different way. Some neurotransmitters regulate the actions of glands and muscles; others affect learning and memory; still others promote sleep or stimulate mental and physical alertness. Some neurotransmitters orchestrate our feelings and emotions, from depression to euphoria. Others (endorphins) provide relief from pain.

To date, researchers have identified some 60 chemical substances manufactured by the body that may act as neurotransmitters (Greden, 1994). It was long believed that an individual neuron could secrete only one neurotransmitter. But more recently it has been demonstrated that some single neurons may secrete several different neurotransmitters (Changeux, 1993). We have already seen that neurotransmitters have two possible general effects on receiving neurons—excitatory and inhibitory. Some neurotransmitters are always excitatory, others are always inhibitory; still others can be either, depending on the receptor with which they bind.

Acetylcholine

The neurotransmitter **acetylcholine** may produce either excitatory or inhibitory effects. Acetylcholine has an excitatory effect on the skeletal muscle fibres, causing them to contract so that we can move. But it has an inhibitory effect on the muscle fibres in the heart.

The acetylcholine receptor, the first neurotransmitter receptor to be isolated, has been studied extensively (Changeux, 1993). Acetylcholine is involved in a variety of functions, including learning and memory, and in rapid eye movement (REM) sleep, the stage of sleep during which dreaming occurs.

The Monoamines

An important class of neurotransmitters known as monoamines includes four neurotransmitters—dopamine, norepinephrine (noradrenalin), epinephrine (adrenalin), and serotonin. Like acetylcholine, **dopamine** (DA) produces both excitatory and inhibitory effects and is involved in several functions, including learning, attention, movement, and reinforcement. A deficiency in dopamine is related to Parkinson's disease, a condition characterized by tremors and rigidity in the limbs. To treat Parkinson's disease, then, can doctors simply give dopamine to patients through injections or in pill form? No, because dopamine, like many other substances, cannot cross from the bloodstream directly into the brain. The symptoms of Parkinson's disease can, however, be controlled by a drug called *L-dopa* that can cross the blood–brain barrier and be converted into dopamine.

reuptake: The process by which neurotransmitter molecules are taken from the synaptic cleft back into the axon terminal for later use, thus terminating their excitatory or inhibitory effect on the receiving neuron.

acetylcholine: A neurotransmitter that plays a role in learning, memory, and rapid eye movement (REM) sleep and causes the skeletal muscle fibres to contract.

dopamine (DOE-pah-meen): A neurotransmitter that plays a role in learning, attention, and movement; a deficiency of dopamine is associated with Parkinson's disease, and an oversensitivity is associated with some cases of schizophrenia.

Norepinephrine affects eating habits (it stimulates the intake of carbohydrates) and it plays a major role in alertness and wakefulness. It is also one of two neurotransmitters that are believed to facilitate female sexual behaviour. *Epinephrine* also acts as a neurotransmitter in the brain, but its role is minor compared to that of norepinephrine. Epinephrine affects the metabolism of glucose and causes the nutrient energy stored in muscles to be released during strenuous exercise.

Serotonin produces inhibitory effects at most of the receptors with which it forms synapses. It plays an important role in regulating mood, sleep, impulsivity, aggression, and appetite (Greden, 1994). A deficiency in serotonin has also been associated with such behaviours as suicide and impulsive violence (Sandou et al., 1994). Both serotonin and norepinephrine are related to positive moods and a deficiency in them has been linked to depression. Some antidepressant drugs relieve the symptoms of depression by blocking the uptake of seratonin or norepinephrine, thus increasing the neurotransmitter's availability in the synapses.

Amino Acids

Researchers believe that eight or more amino acids also serve as neurotransmitters. Two of particular importance—they are found more commonly than any others in the central nervous system—are glutamate (glutamic acid) and GABA (gamma-aminobutyric acid). Glutamate is the primary excitatory neurotransmitter in the brain (Riedel, 1996). It may be released by some 40 percent of neurons and is active in higher brain centres that are involved in learning, thought, and emotions (Coyle & Draper, 1996).

GABA is the main inhibitory neurotransmitter in the brain (Miles, 1999) and is widely distributed throughout the brain and spinal cord. It is thought to facilitate the control of anxiety in humans. Researchers believe that an abnormality in the neurons that secrete GABA is one of the causes of epilepsy, a serious neurological disorder in which neural activity can become so heightened that seizures result.

Endorphins

Over 25 years ago, Candace Pert and her colleagues (1974) demonstrated that a localized region of the brain contains neurons with receptors that respond to the opiates—drugs such as opium, morphine, and heroin. It is now known that the brain produces its own opiate-like substances, known as **endorphins.** Endorphins provide relief from pain and produce feelings of pleasure and well-being.

Generally, one single neurotransmitter is not responsible for a given mental function. Memory, for example, is modified by a collection of neurotransmitters, including acetylcholine, epinephrine, norepinephrine, and (probably) serotonin. Review & Reflect 2.1 summarizes the major neurotransmitters and the behaviours with which they seem to be most strongly associated.

Glial Cells: The Neurons' Helper Cells

Glial cells are specialized cells in the brain that form the myelin coating and perform many other important functions. *Glia* means "glue," and these cells hold the neurons together. Glial cells remove waste products such as dead neurons from the brain by engulfing and digesting them; they also handle other manufacturing, nourishing, and clean-up tasks. Glial cells serve another function when the brain is being formed and as it grows and develops: they act as guides, taking the specialized neurons from where

REVIEW & REFLECT 2.1
Major Neurotransmitters and Their Functions

Neurotransmitter	Believed to Affect
Acetylcholine (ACh)	Movement, learning, memory, REM sleep
Dopamine (DA)	Learning, attention, movement
Norepinephrine (NE)	Eating habits, sleep, female sexual behaviour
Epinephrine	Metabolism of glucose, energy release during exercise
Serotonin	Neurobiological functions such as mood, sleep, and appetite
GABA	Neural inhibition in the central nervous system, possibly sleep
Endorphins	Relief from pain; feelings of pleasure and well-being

Remember It!

Neurons and Neurotransmitters

1. The branch-like extensions of neurons that act as the primary receivers of signals from other neurons are the
   a. dendrites.
   b. axons.
   c. glia.
   d. cell bodies.
2. The junction where the axon of a sending neuron communicates with a receiving neuron is called the
   a. reuptake site.
   b. receptor site.
   c. synapse.
   d. axon terminal.
3. When a neuron fires, neurotransmitters are released from the synaptic vesicles in the ______________ terminal into the synaptic cleft.
   a. dendrite
   b. cell body's
   c. receptor
   d. axon
4. The resting potential is the firing of a neuron that results when the charge within the neuron becomes more positive than the charge outside the cell membrane. (true/false)
5. Receptor sites on the receiving neuron
   a. receive any available neurotransmitter molecules.
   b. receive only neurotransmitter molecules of a specific shape.
   c. can be influenced only by neurotransmitters from a single neuron.
   d. are located only on the dendrites.
6. Which of the following substances cross the synaptic cleft and enter receptor sites on the dendrites and cell bodies of receiving neurons?
   a. Sodium ions
   b. Potassium ions
   c. Neurotransmitters
   d. Synapse modulators
7. Endorphins, norepinephrine, dopamine, and serotonin are all examples of
   a. hormones.
   b. neurotransmitters.
   c. neuropeptides.
   d. neuromodulators.

Answers: 1. a 2. c 3. d 4. false 5. b 6. c 7. b

they are formed to where they will finally function (Hoekfelt et al., 2000).

Glial cells are smaller than neurons but outnumber them about nine to one (Travis, 1994). Remarkably, glial cells make up more than half the volume of the human brain. It is now known that they interact with neurons in complex ways and that they play a part in creating a more efficient brain (Abbott & Raff, 1991).

The Central Nervous System

We have discussed how neurons function individually and in groups through electrochemical action. But human functioning involves much more than the actions of individual neurons. Collections of neurons, brain structures, and organ systems must also be explored. The nervous system is divided into two parts: (1) the **central nervous system (CNS)**, which is composed of the brain and the spinal cord, and (2) the peripheral nervous system, which connects the CNS to all other parts of the body (see Figure 2.4, or, for a complete depiction, Figure 2.12).

norepinephrine: A neurotransmitter affecting eating and sleep; a deficiency of norepinephrine is associated with depression.

serotonin: A neurotransmitter that plays an important role in regulating mood, sleep, aggression, and appetite; a serotonin deficiency is associated with anxiety, depression, and suicidal feelings.

endorphins (en-DOOR-fins): Chemicals produced naturally by the brain that reduce pain and affect mood positively.

glial cells (GLEE-ul): Cells that help to make the brain more efficient by holding the neurons together, removing waste products such as dead neurons, making the myelin coating for the axons, and performing other manufacturing, nourishing, and clean-up tasks.

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

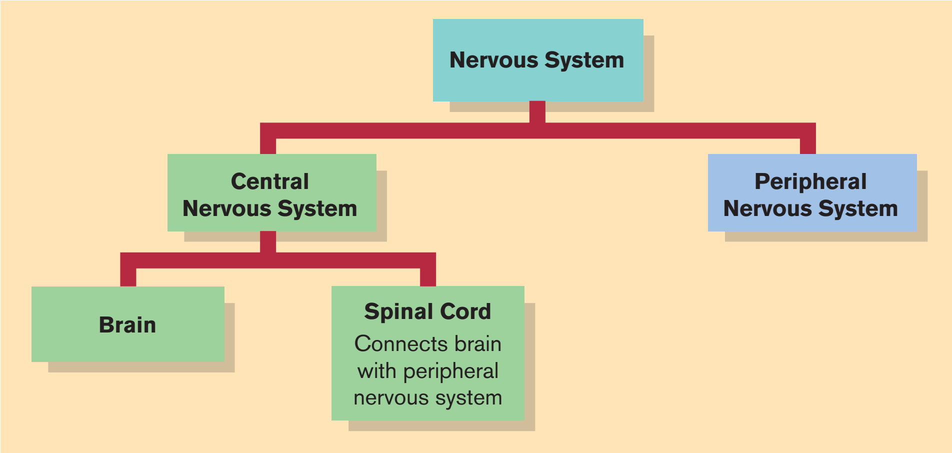


FIGURE 2.4
Divisions of the Human Nervous System The human nervous system is divided into two parts: (1) the central nervous system, consisting of the brain and the spinal cord; and (2) the peripheral nervous system.

The Spinal Cord: An Extension of the Brain

Why is an intact spinal cord important to normal functioning?

The **spinal cord** can best be thought of as an extension of the brain. Like the brain, it has grey matter as well as white matter and is loaded with glial cells. A cylinder of neural tissue about the diameter of your little finger, the spinal cord reaches from the base of the brain, through the neck, and down the hollow centre of the spinal column. The spinal cord is protected by bone and also by spinal fluid, which serves as a shock absorber. The spinal cord literally links the body with the brain. It transmits messages between the brain and the peripheral nervous system. Thus sensory information can reach the brain, and messages from the brain can be sent to the muscles, the glands, and other parts of the body.

Although the spinal cord and the brain usually function together, the spinal cord can act without help from the brain to protect us from injury. For example, the spinal reflex that causes you to withdraw your hand quickly from a hot stove is controlled by the spinal cord without the initial involvement of the brain. The brain, however, quickly becomes aware and involved when the pain signal reaches it. At that point you might plunge your hand into cold water to relieve the pain.

LINK IT!

www.anatomy.uq.edu.au/histology/contents/spinalcord_nerve/grossspinal/text.html
Gross Anatomy of the Spinal Cord and Spinal Nerves

The Brainstem: The Most Primitive Part of the Brain

What are the crucial functions handled by the brainstem?

The **brainstem** begins at the site where the spinal cord enlarges as it enters the skull. The brainstem includes the medulla, the pons, and the reticular formation, as shown in Figure 2.5. The brainstem handles functions that are vital to our physical survival; damage to it is life-threatening. The **medulla** is the part of the brainstem that controls heartbeat, breathing, blood pressure, coughing, and swallowing. Fortunately, the medulla handles these functions automatically, so you do not have to decide consciously to breathe or remember to keep your heart beating.

Extending through the brainstem into the pons is another important structure, the **reticular formation**, sometimes called the *reticular activating system* (RAS). Find it in Figure 2.5. The reticular formation plays a crucial role in arousal and attention. Every day our sense organs are bombarded with stimuli, but we cannot possibly pay attention to everything we see or hear. The reticular formation screens messages entering the brain. It blocks some messages and sends others on to higher brain centres for processing.

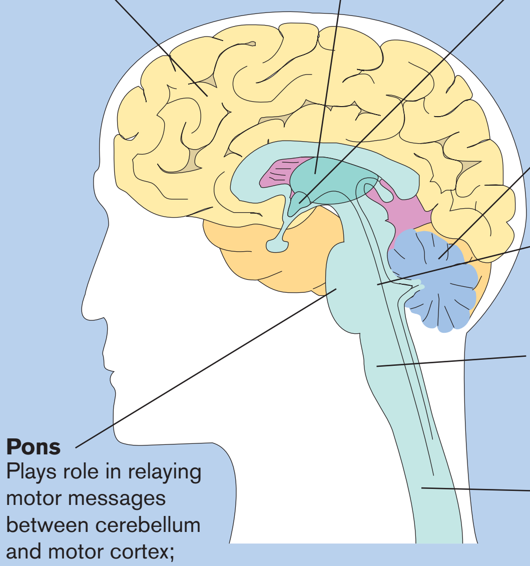


FIGURE 2.5
Major Structures of the Human Brain
Some of the major structures of the brain are shown in the drawing, and a brief description of the function of each is provided. The brain stem contains the medulla, the reticular formation, and the pons.

The reticular formation also determines how alert we are. When it slows down, we doze off or go to sleep. But like an alarm clock, it also can jolt us into consciousness. Thanks to the reticular formation, important messages get through even when we are asleep. That is why parents may be able to sleep through a thunderstorm but will awaken to the slightest cry of their baby. (The next time you sleep through your alarm and are late for class, blame it on your reticular formation.)

Above the medulla and at the top of the brainstem is a bridge-like structure called the *pons* (Latin for "bridge"). The pons extends across the top front of the brainstem and connects to the left and right halves of the cerebellum. The pons plays a role in body movement and exerts an influence on sleep and dreaming. Hobson and McCarley (1977) report that the neurons in the pons begin firing rapidly just as a sleeper begins to dream.

LINK IT!

www.uic.edu/~upaul1/brainstem/index-new.html
University of Illinois at Chicago, Brainstem Tutorial

The Cerebellum: A Must for Graceful Movement

What are the primary functions of the cerebellum?

Cerebellum means "little cerebrum." With its two hemispheres, it resembles the large cerebrum, which rests above it (see Figure 2.5). Its main functions are to execute smooth, skilled movements and to regulate muscle tone and posture (Lalonde & Botez, 1990). It

spinal cord: An extension of the brain, reaching from the base of the brain through the neck and spinal column, that transmits messages between the brain and the peripheral nervous system.

brainstem: The structure that begins at the point where the spinal cord enlarges as it enters the brain–and that includes the medulla, the pons, and the reticular formation.

medulla (muh-DUL-uh): The part of the brainstem that controls heartbeat, blood pressure, breathing, coughing, and swallowing.

reticular formation: A structure in the brainstem that plays a crucial role in arousal and attention that screens sensory messages entering the brain.

cerebellum (sehr-uh-BELL-um): The brain structure that executes smooth, skilled body movements and regulates muscle tone and posture.

The major functions of the cerebellum are to execute smooth, skilled movements and to regulate muscle tone and posture.

has been found to play a role in motor learning and in retaining memories of motor activities. The cerebellum coordinates and orchestrates the movements necessary to perform many everyday activities without studied, conscious effort. It enables you to guide food from the plate to your mouth, walk in a straight line, or touch the tip of your nose. But with a damaged cerebellum, or one that is temporarily impaired by alcohol, such simple acts may be difficult or impossible to perform. Recent studies suggest that the cerebellum is involved in cognitive as well as motor functions (Allen et al., 1997; Fiez, 1996).

The Thalamus: The Relay Station between Lower and Higher Brain Centres

What is the primary role of the thalamus?

Above the brainstem lie two extremely important structures—the thalamus and the hypothalamus (refer to Figure 2.5). The **thalamus,** which looks like two egg-shaped structures, serves as the relay or switching station for virtually all the information that flows into and out of the higher brain centres. This includes sensory information from all the senses except smell. Incoming sensory information from the eyes, ears, skin, and taste buds travels first to parts of the thalamus or hypothalamus and then to the area of the cortex that handles vision, hearing, touch, or taste. Pain signals connect directly with the thalamus, which sends the pain message to the appropriate sensory areas of the cerebral cortex.

The thalamus—at least one small part of it—apparently affects our ability to learn new information, especially if it is verbal. This structure also plays a role in the production of language (Albert & Helm-Estabrooks 1988a; Metter 1991). The thalamus also regulates sleep cycles in cooperation (it is believed) with the pons and the reticular formation. The synchronized firing of networks of neurons in one part of the thalamus has been observed during slow-wave (deep) sleep (Krosigk, 1993).

What a diverse range of activities this single brain structure performs! Now consider a much smaller structure, the hypothalamus.

The Hypothalamus: A Master Regulator

What are some of the processes regulated by the hypothalamus?

Nestled directly below the thalamus and weighing only about 56 grams, the **hypothalamus** is, for its weight, the most influential structure in the brain. It regulates hunger, thirst, sexual behaviour, and a wide variety of emotional behaviours. The hypothalamus also regulates internal body temperature, starting the process that causes us to perspire when we are too hot and to shiver to conserve body heat when we are too cold. It also regulates the biological clock—our body rhythms and the timing of our sleep/wakefulness cycle (Ginty et al., 1993). As small as it is, the hypothalamus maintains nearly all our bodily functions except blood pressure, heart rhythm, and breathing.

The physiological changes in the body that accompany strong emotion are initiated by neurons concentrated mainly in the hypothalamus. You have felt these physical changes—sweaty palms, a pounding heart, a hollow feeling in the pit of your stomach, or a lump in your throat.

Electrical stimulation of parts of the hypothalamus has elicited some unusual reactions in animals. In 1969, José Delgado implanted an electrode in a

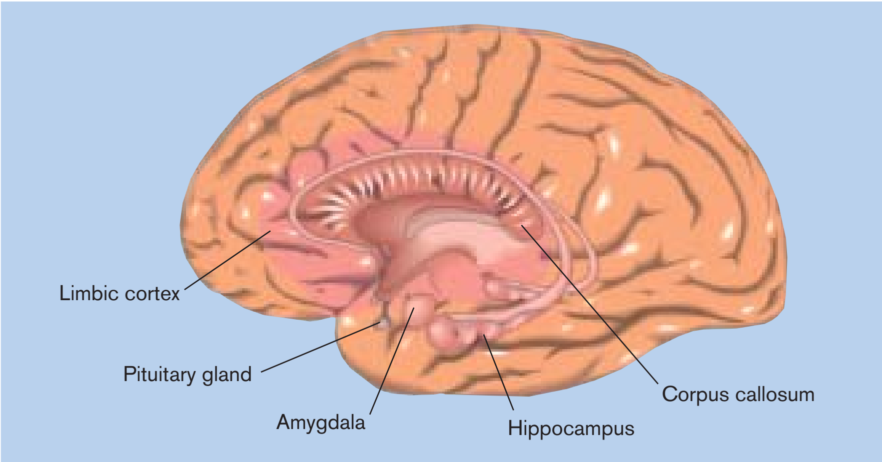


FIGURE 2.6
The Principal Structures in the Limbic System The amygdala plays an important role in emotion; the hippocampus is essential in the formation of conscious memory.

particular spot in the hypothalamus of a bull that had been bred specifically for bullfighting. Delgado stood calmly in the ring as the bull charged him. He then pressed a remote-control box that stimulated an area of the bull's hypothalamus. The bull stopped abruptly in its tracks. (Fortunately for Delgado, the batteries in the remote were working.) Apparently, aggression in animals can be turned on and off by stimulating specific areas of the hypothalamus. Pleasurable sensations can also be produced this way (Olds, 1956).

The Limbic System: Primitive Emotion and Memory

What is the role of the limbic system?

The **limbic system** is a group of brain structures involved in emotional expression, memory, and motivation. The **amygdala** plays an important role in our responses to aversive (i.e., unpleasant) stimuli (LeDoux, 1994). It is also prominently involved in various aspects of learning, such as learned fear responses that help humans and other animals avoid dangerous situations and aversive consequences (LeDoux, 1995). Specifically, the amygdala helps us form associations between external events (including social ones) and the emotions related to those events (Aggleton, 1993). Damage to the amygdala can also impair one's ability to recognize (1) facial expressions showing fear or anger, and (2) tone of voice expressing these emotions (Scott et al., 1997).

The **hippocampus** is another important part of the limbic system, located in the interior temporal lobes (see Figure 2.6). The hippocampus is absolutely essential in the formation of conscious memory (Squire, 1992). If your hippocampus were destroyed, you would not be able to store or recall any new information of a personal or cognitive nature (Eichenbaum, 1977; Gluck & Myers, 1997). Yet memories stored before the hippocampus was destroyed would remain intact. The hippocampus also plays a role in the brain's internal representation of space in the form of neural "maps" that help us learn our way around new environments and remember where we have been (Thompson & Best, 1990; Wilson & McNaughton, 1993).

Researchers at McGill University suggest that the components of the limbic system work together to help us remember emotion-based information (McDonald & White, 1993).

thalamus (THAL-uh-mus): The structure located above the brainstem that acts as a relay station for information flowing into or out of the higher brain centres.

hypothalamus (HY-po-THAL-uh-mus): A small but influential brain structure that controls the pituitary gland and regulates hunger, thirst, sexual behaviour, body temperature, and a wide variety of emotional behaviours.

limbic system: A group of structures in the brain, including the amygdala and hippocampus, that are collectively involved in emotion, memory, and motivation.

amygdala (ah-MIG-da-la): A structure in the limbic system that plays an important role in emotion, particularly in response to aversive stimuli.

hippocampus (hip-po-CAM-pus): A structure in the limbic system that plays a central role in the formation of long-term memories.

Remember It!

The Central Nervous System

1. The brain and the spinal cord make up the peripheral nervous system. (true/false)
2. The hypothalamus regulates all of the following except
   a. internal body temperature.
   b. hunger and thirst.
   c. coordinated movement.
   d. sexual behaviour.
3. Match each function with the appropriate structure.
   ___ 1) Connects the brain with the peripheral nervous system
   ___ 2) Controls heart rate, breathing, and blood pressure
   ___ 3) Consists of the medulla, the pons, and the reticular formation
   ___ 4) Influences attention and arousal
   ___ 5) Coordinates complex body movements
   ___ 6) Serves as a relay station for sensory information flowing into the brain

   a. medulla
   b. spinal cord
   c. reticular formation
   d. thalamus
   e. cerebellum
   f. brainstem

Answers: 1. false 2. c 3. true 4. 1) b 2) a 3) f 4) c 5) e 6) d

The Cerebral Hemispheres

What are the cerebral hemispheres, the cerebral cortex, and the corpus callosum?

The most extraordinary and the most essentially human part of the magnificent human brain is the cerebrum and its cortex. If you could peer into your skull and look into your own brain, you would see a structure that resembles the inside of a huge walnut (see Figure 2.7). Just as a walnut has two matched halves connected to each other, the **cerebrum** is composed of two **cerebral hemispheres**—a left and a right. These are physically connected at the bottom by a thick band of nerve fibres called the **corpus callosum**. This connection makes possible the transfer of information and the coordination of activity between the hemispheres. In general, the right cerebral hemisphere controls the left side of the body (i.e., movement and feeling); the left cerebral hemisphere controls the right side of the body. In over 95 percent of people, the left hemisphere also controls language functions (Hellige, 1990).

The cerebral hemispheres have a thin outer covering about half a centimetre thick called the **cerebral cortex,** which is primarily responsible for the higher mental processes of language, memory, and thinking. The presence of the cell bodies of billions of neurons in the cortex gives it a greyish appearance. Thus, the cortex is often referred to as grey matter. Beneath the cortex are the white myelinated axons (white matter) that connect cortex neurons with those in other brain regions. It is arranged in numerous folds or wrinkles called "convolutions." About two-thirds of the cortex is hidden from view in the folds. The cortex of less intelligent animals is much smaller in proportion to total brain size and, therefore, is much less convoluted.

The cerebral cortex contains three types of areas: (1) sensory input areas, where vision, hearing, touch, pressure, and temperature register; (2) motor areas, which control voluntary movement; and (3) **association areas**, which house our memories and are involved in thought, perception, and language.

The Lobes of the Brain

In each cerebral hemisphere there are four lobes—the frontal lobe, the parietal lobe, the occipital lobe, and the temporal lobe. Find them in Figure 2.8. Each of the lobe's functions are also reviewed in the *Apply It!* box near the end of the chapter.

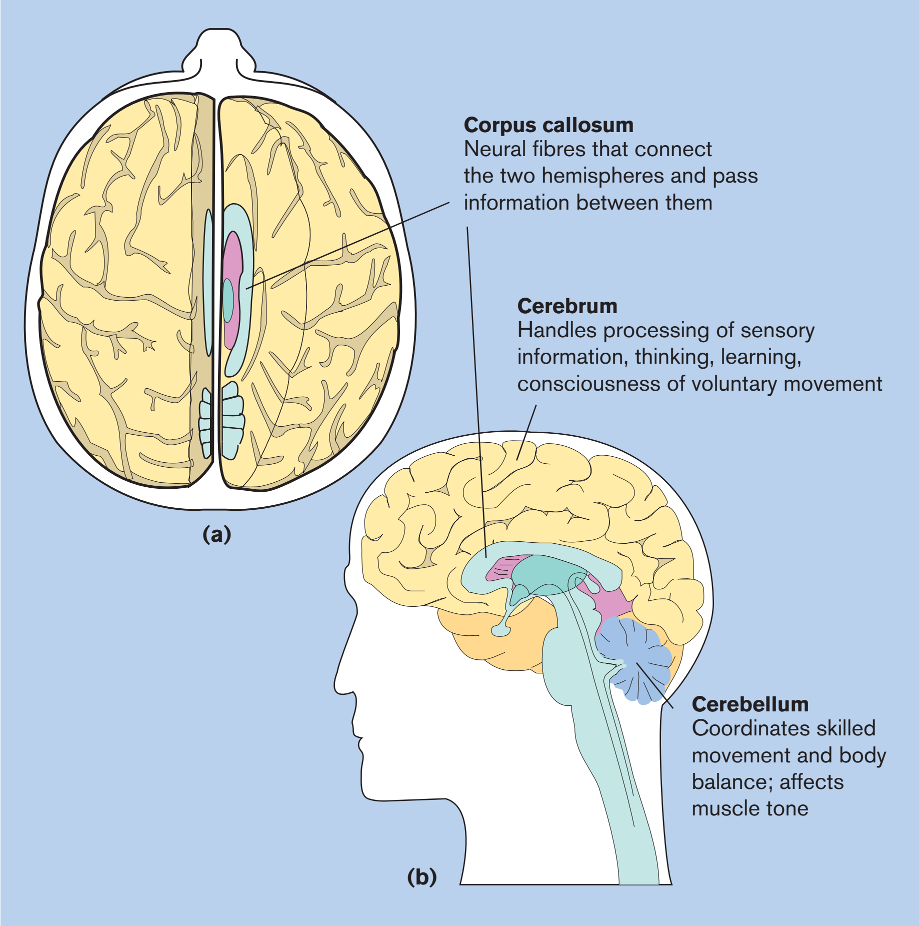
The Frontal Lobes: For Moving, Speaking, and Thinking

What are some of the main areas within the frontal lobes, and what are their functions?

Of the lobes in the brain, the **frontal lobes** are by far the largest. They begin at the front of the brain and extend to the top centre of the skull. They contain the motor cortex, Broca's area, and the frontal association areas.

FIGURE 2.7

Two Views of the Cerebral Hemispheres The two hemispheres rest side by side like two matched halves, physically connected by the corpus callosum, shown in (a). An inside view of the right hemisphere of the cerebrum and cerebellum is shown in (b).



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The two cerebral hemispheres show up clearly in this view looking down on an actual brain.

THE MOTOR CORTEX The **motor cortex** controls voluntary body movement (see Figure 2.8). The right motor cortex controls movement on the left side of the body, and the left motor cortex controls movement on the right side of the body. Research, however, has established that the left motor cortex is involved in the control of voluntary movement on the left side of the body as well (Kim et al., 1993).

Examine Figure 2.9. Notice the motor homunculus, or "little man," drawn next to the cross-section of the motor cortex. The body parts are drawn in proportion to the amount of motor cortex that controls each body part. The parts of the body that are capable of the most finely coordinated movements, such as the fingers, lips, and tongue, have a larger share of the motor cortex. Areas such as the legs and the trunk, which are capable only of gross movement, have a smaller amount of motor cortex. The lower parts of the body are controlled mainly by neurons at the top of the motor cortex; upper-body parts (face, lips, and tongue) are controlled mainly by neurons near the

cerebrum (seh-REE-brum): The largest structure of the human brain, consisting of the two cerebral hemispheres connected by the corpus callosum and covered by the cerebral cortex.

cerebral hemispheres (seh-REE-brul): The right and left halves of the cerebrum, covered by the cerebral cortex and connected by the corpus callosum.

corpus callosum (KOR-pus-kah-LO-sum): The thick band of nerve fibres that connects the two cerebral hemispheres and makes possible the transfer of information and the synchronization of activity between them.

cerebral cortex (seh-REE-brul-KOR-tex): The grey, convoluted covering of the cerebral hemispheres that is responsible for higher mental processes such as language, memory, and thinking.

association areas: Areas of the cerebral cortex that house memories and are involved in thought, perception, learning, and language.

frontal lobes: The lobes that control voluntary body movements, speech production, and such functions as thinking, motivation, planning for the future, impulse control, and emotional responses.

motor cortex: The strip of tissue at the rear of the frontal lobes that controls voluntary body movement.

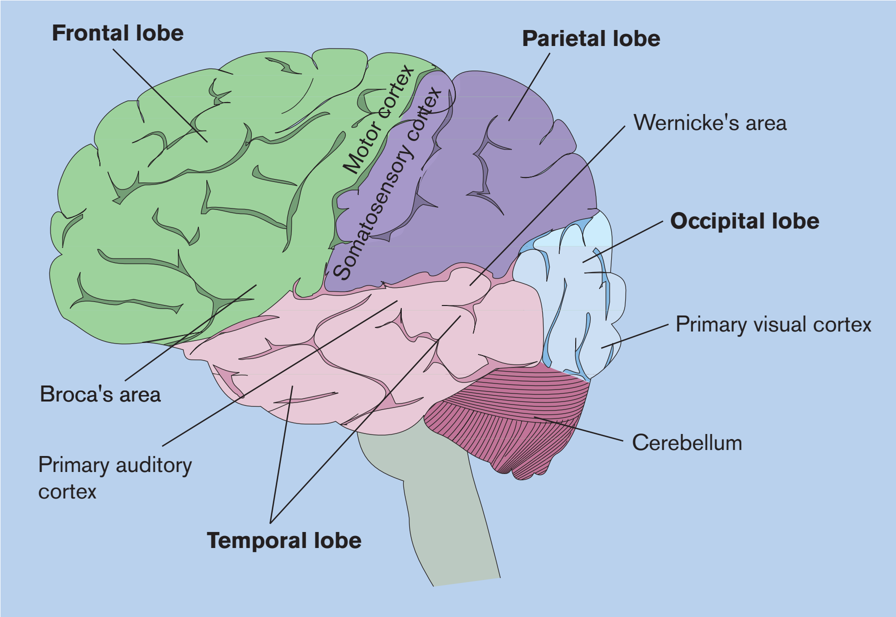


FIGURE 2.8
The Cerebral Cortex of the Left Hemisphere This illustration of the left cerebral hemisphere shows the four lobes: (1) the frontal lobe, including the motor cortex and Broca's area; (2) the parietal lobe, with the somatosensory cortex; (3) the occipital lobe, with the primary visual cortex; and (4) the temporal lobe, with the primary auditory cortex and Wernicke's area.

bottom of the motor cortex. For example, when you wiggle your right big toe a cluster of brain cells firing at the top of the left motor cortex is chiefly responsible for producing the movement. This "map" of the motor cortex is based upon the pioneering work of Canadian neurosurgeon Wilder Penfield, who recorded the responses of patients who received electrical stimulation of this area while under surgery.

Recent research indicates that the clusters of neurons responsible for moving a body part—a finger, for example—are active over a wider area of the cortex than was earlier assumed. This means that there is considerable overlap in the neurons that fire to move a finger (Scheiber & Hibbard, 1993).

What happens when part of the motor cortex is damaged? Depending on the severity of the damage, either paralysis or some impairment of coordination can result. Sometimes damage in the motor cortex causes the seizures of grand mal epilepsy. On the other hand, if an arm or leg is amputated, many of the neurons in the corresponding area of the motor cortex will eventually be dedicated to another function (Murray, 1995).

BROCA'S AREA In 1861, Paul Broca performed autopsies on two bodies—one of a person who had been totally without speech, the other of a person who had been able to say only four words (Jenkins et al., 1975). Broca found that both persons had had damage in the left hemisphere, slightly in front of the part of the motor cortex that controls movement of the jaw, lips, and tongue. Broca was among the first scientists to demonstrate the existence of localized functions in the cerebral cortex (Schiller, 1993). He concluded that the site of damage, now called **Broca's area,** was the part of the brain responsible for speech production (refer to Figure 2.8). Broca's area is involved in directing the muscle movements required to produce speech sounds.

If Broca's area is damaged, **Broca's aphasia** may result. **Aphasia** is a general term for a loss or impairment of the ability to use or understand language, resulting from damage to the brain (Goodglass, 1993). Characteristically, patients with Broca's aphasia know what they want to say but can speak very little or not at all. If they are able to speak, their words are produced very slowly, with great effort, and are poorly articulated.

LINK IT!

www.epub.org.br/cm/n02/historia/broca.htm
Sabbatini, R.M.E.: A Brief Biography of Pierre Paul Broca

FRONTAL ASSOCIATION AREAS Much of the frontal lobes consists of association areas that are involved in thinking, motivation, planning for the future, impulse control, and emotional responses (Stuss et al., 1992).

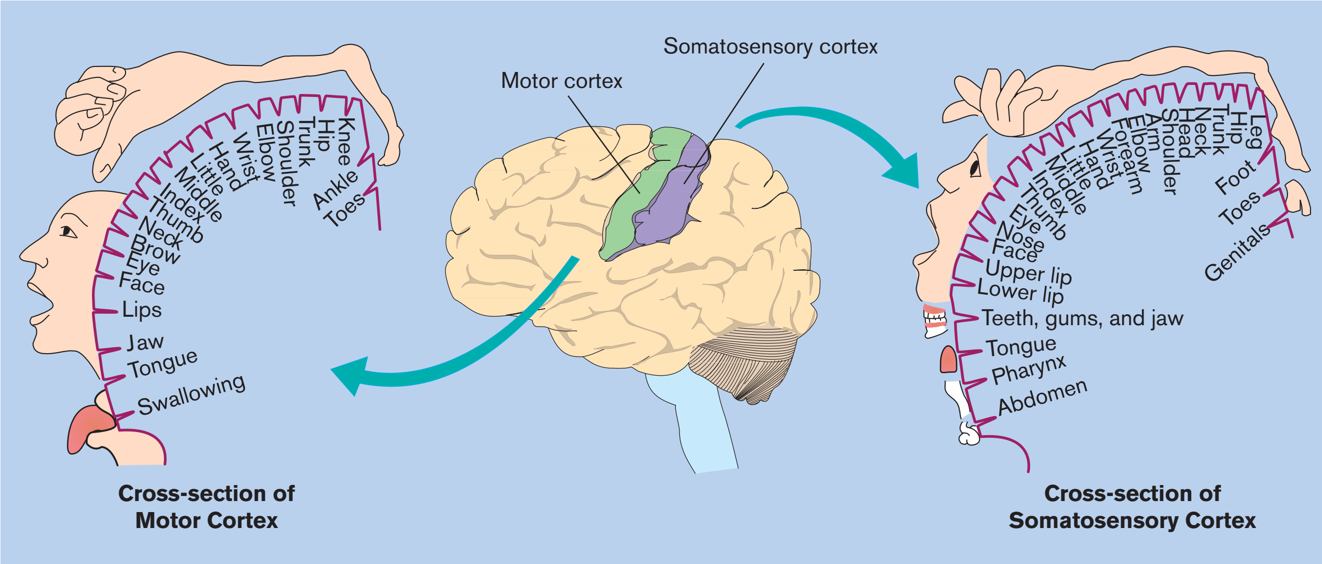


FIGURE 2.9

The Motor Cortex and the Somatosensory Cortex from the Left Hemisphere **The left motor cortex controls voluntary movement in the right side of the body. The left somatosensory cortex is the site where touch, pressure, temperature, and pain sensations from the right side of the body register. The more sensitive the body parts and the more capable they are of finely coordinated movements, the greater the areas of somatosensory cortex and motor cortex dedicated to those body parts. Note what large sections of cortex serve the head, face, hands, and fingers, and what small sections serve such large areas as the trunk, arms, and legs.**

Image omitted due to copyright restrictions.

This computer-generated image shows the likely path of the bar that tore through Phineas Gage's skull.

Sometimes pronounced changes in emotional responses occur when the frontal lobes are damaged. One famous case involved Phineas Gage, a 25-year-old man who had a metal rod driven through the bottom of his left cheekbone and out through the top of his skull. The damage to the frontal lobes drastically altered impulse control and emotional responses. Using measurements from Gage's skull and modern brain-imaging techniques, researchers have been able to identify the probable location of the damage Gage's brain suffered (Damasio et al., 1994). The photo above shows the most likely trajectory of the metal rod that tore through his skull.

LINK IT!

www.mc.maricopa.edu/academic/cult_sci/anthro/origins/phineas.html
Phineas Gage—Into the Mind

Broca's area (BRO-kuz): The area in the frontal lobe, usually in the left hemisphere, that controls production of the speech sounds.

Broca's aphasia (BRO-kuz uh-FAY-zyah): An impairment in the ability to physically produce speech sounds, or in extreme cases an inability to speak at all; caused by damage to Broca's area.

aphasia (uh-FAY-zyah): A loss or impairment of the ability to understand or communicate through the written or spoken word, which results from damage to the brain.

The Parietal Lobes: Vital to Our Sense of Touch

What are the primary functions of the parietal lobes in general and the somatosensory cortex in particular?

The **parietal lobes** lie directly behind the frontal lobes, in the top-middle portion of the brain. The parietal lobes are involved in the reception and processing of touch stimuli. The front strip of brain tissue in the parietal lobes, called the **somatosensory cortex**, is where touch, pressure, temperature, and pain register in the cortex (refer back to Figure 2.8). The somatosensory cortex also makes us aware of our body movements and the positions of our body parts at any given moment.

Dusser de Bareene discovered the function of the somatosensory cortex in 1916, when he applied a small amount of strychnine to a number of points along a monkey's somatosensory cortex. The strychnine stimulated the neurons to fire. As he touched each point, the monkey scratched a different location on its skin. Using this technique, de Bareene was able to map the monkey's somatosensory cortex.

If various points on your own somatosensory cortex were electrically stimulated, you would feel either a tingling sensation or a numbness in a corresponding part of your body. A person with damage to the somatosensory cortex of one hemisphere loses some sensitivity to touch on the opposite side of the body. If the damage is severe enough, the person may not be able to feel the difference between sandpaper and silk. Or the affected part of the body may feel numb.

The two halves of the somatosensory cortex (i.e., in the left and right parietal lobes) are wired to opposite sides of the body. Also, cells at the top of the somatosensory cortex govern feeling in the lower extremities of the body. When you drop a brick on your right foot, the topmost brain cells of the left somatosensory cortex fire and register the pain sensation. (Note: This is not a *Try It!* exercise.) Notice in Figure 2.9 the large somatosensory areas connected to sensitive body parts such as the tongue, lips, face, and hand, particularly the thumb and index finger. Observe the small amount of cortex connected to the trunk of the body, which is a large area.

Under unusual circumstances, the somatosensory cortex may reorganize itself to accommodate unusual demands made upon it (Diamond et al., 1994). For example, among blind people, experienced Braille readers have a larger area of the somatosensory cortex dedicated to the fingertips they use for reading than to their other fingertips (Pascual-Leone & Torres, 1993).

Other parts of the parietal lobes are responsible for spatial orientation and sense of direction. There are association areas in the parietal lobes that house our memory of how objects feel so that we can identify objects by touch. People with damage to these areas could hold a pencil, scissors, or a ball in their hand but not be able to identify it by touch alone.

The Occipital Lobes: The Better to See You With

What are the primary functions of the occipital lobes in general and the primary visual cortex in particular?

Behind the parietal lobes at the rear of the brain lie the **occipital lobes**, which are involved in the reception and interpretation of visual information (refer back to Figure 2.8). At the very back of the occipital lobes is the **primary visual cortex**, the site where vision registers in the cortex.

Each eye is connected to the primary visual cortex in both the right and left occipital lobes. Look straight ahead and draw an imaginary line down the middle of what you see. Everything to the left of the line is referred to as the left visual field and registers in the right visual cortex. Everything to the right of the line is the right visual field and registers in the left visual cortex. A person who sustains damage to one primary visual cortex will still have partial vision in both eyes. This is described by University of Lethbridge researcher Brian Kolb (1990), who reports on the long process of recovering from this type of damage.

The association areas in the occipital lobes are involved in the interpretation of visual stimuli. The association areas hold memories of past visual experiences and enable us to recognize what is familiar among the things we see. When these areas are damaged, people can lose their ability to identify objects visually, although they are still able to identify the same objects by touch or through some other sense.

The Temporal Lobes: Hearing's Here

What are the major areas within the temporal lobes, and what are their functions?

The **temporal lobes**, located slightly above the ears, are involved in the reception and interpretation of auditory stimuli. The site in the cortex where hearing registers is known as the **primary auditory cortex**. When this

Remember It!

The Cerebral Hemispheres

1. What is the thick band of fibres connecting the two cerebral hemispheres?
   a. cortex
   b. cerebrum
   c. corpus callosum
   d. motor cortex
2. The thin outer covering of the cerebrum is the
   a. cerebral cortex.
   b. myelin sheath.
   c. cortex callosum.
   d. white matter.
3. Match the lobes with the brain areas they contain.
   ___ 1) primary auditory cortex, Wernicke's area
   ___ 2) primary visual cortex
   ___ 3) Broca's area, motor cortex
   ___ 4) somatosensory cortex

   a. frontal lobes
   b. parietal lobes
   c. occipital lobes
   d. temporal lobes
4. Match the specialized area with the appropriate description of function.
   ___ 1) site where hearing registers
   ___ 2) site where vision registers
   ___ 3) site where touch, pressure, and temperature register
   ___ 4) speech production
   ___ 5) voluntary movement
   ___ 6) formulation and understanding of the spoken and written word
   ___ 7) thinking, motivation, impulse control

   a. primary visual cortex
   b. motor cortex
   c. frontal association area
   d. primary auditory cortex
   e. somatosensory cortex
   f. Wernicke's area
   g. Broca's area

Answers: 1. c 2. a 3. 1) d 2) c 3) a 4) b 4. 1) d 2) a 3) e 4) g 5) b 6) f 7) c

area is stimulated with an electrical probe, the person hears bursts of sound. The primary auditory cortex in each temporal lobe receives sound inputs from both ears. Injury to one of these areas results in reduced hearing in both ears; the destruction of both areas causes total deafness.

WERNICKE'S AREA Adjacent to the primary auditory cortex in the left temporal lobe is **Wernicke's area,** which is the area involved in comprehending the spoken word and in formulating coherent written and spoken language (refer back to Figure 2.8). In about 95 percent of people, Wernicke's area is in the left hemisphere. When you listen to someone speak, the sound registers first in the primary auditory cortex. The sound is then sent to Wernicke's area, where the speech sounds are unscrambled into meaningful patterns of words. The same areas that are active when we listen to someone speak are also active in deaf individuals when they watch a person using sign language (Nishimura et al., 1999). Wernicke's area is also involved when we select the words to use in speech and written expression.

Wernicke's aphasia is a type of aphasia resulting from damage to Wernicke's area. Although speech

parietal lobes (puh-RY-uh-tul): The lobes that contain the somatosensory cortex (where touch, pressure, temperature, and pain register) and other areas that are responsible for body awareness and spatial orientation.

somatosensory cortex (so-MAT-o-SENS-or-ee): The strip of tissue at the front of the parietal lobes where touch, pressure, temperature, and pain register in the cortex.

occipital lobes (ahk-SIP-uh-tul): The lobes that contain the primary visual cortex, where vision registers, and association areas involved in the interpretation of visual information.

primary visual cortex: The area at the rear of the occipital lobes where vision registers in the cerebral cortex.

temporal lobes: The lobes that contain the primary auditory cortex, Wernicke's area, and association areas for interpreting auditory information.

primary auditory cortex: The part of the temporal lobes where hearing registers in the cerebral cortex.

Wernicke's area: The language area in the temporal lobe involved in comprehension of the spoken word and in formulation of coherent speech and written language.

Wernicke's aphasia: Aphasia resulting from damage to Wernicke's area, in which the patient's spoken language is fluent, but the content is either vague or incomprehensible to the listener.

is fluent and words are clearly articulated, the actual message does not make sense to others (Maratsos & Matheney, 1994). The content may be vague or bizarre; or it may contain inappropriate words and parts of words, or a gibberish of non-existent words. People with Wernicke's aphasia are not aware that anything is wrong with their speech.

Another kind of aphasia is auditory aphasia, or word deafness. It can occur if there is damage to the nerves connecting the primary auditory cortex with Wernicke's area. The person is able to hear normally but may not understand spoken language. As if hearing a foreign language spoken, the person hears the sounds but has no idea what the speaker is saying.

THE TEMPORAL ASSOCIATION AREAS The other parts of the temporal lobes consist of the association areas that house memories and are involved in the interpretation of auditory stimuli. For example, you have an association area where your memories of various sounds are stored, so that you instantly recognize the sounds of running water, fire engine sirens, dogs barking, and so on. There is also a special association area where familiar melodies are stored.

Specialization of the Cerebral Hemispheres

The two cerebral hemispheres make different but complementary contributions to our mental and emotional life. Research has shown that some **lateralization** of the hemispheres exists—that is, each hemisphere is specialized, to some extent, for certain functions. Yet functions are usually not handled exclusively by one hemisphere; the two hemispheres always work together (Bradshaw, 1989; Efron, 1990). Much of what we know about lateralization is derived from pioneering research conducted by Doreen Kimura at the University of Western Ontario (1961, 1973). She studied tasks in which different information could be presented to each of the hemispheres at the same time, thus demonstrating hemispheric specialization.

Functions of the Left Hemisphere: Language First and Foremost

What are the main functions of the left hemisphere?

In 95 percent of right-handers and in about 62 percent of left-handers, the **left hemisphere** handles most of the language functions, including speaking, writing, reading, and understanding the spoken word (Hellige, 1990). American Sign Language (ASL), which is used by deaf persons, is processed by both hemispheres (Neville et al., 1998). The left hemisphere is specialized for mathematical abilities, particularly calculation; it also processes information in an analytical and sequential, or step-by-step, manner (Corballis, 1989). Logic is primarily though not exclusively a left-brain specialty.

The left hemisphere coordinates complex movements by directly controlling the right side of the body and by indirectly controlling the movements of the left side of the body. It accomplishes this by sending orders across the corpus callosum to the right hemisphere so that the proper movements will be coordinated and executed smoothly. (Remember that the cerebellum also plays an important role in coordinating complex movements.)

Functions of the Right Hemisphere: The Leader in Visual-Spatial Tasks

What are the primary functions of the right hemisphere?

The **right hemisphere** is generally considered to be better at visual-spatial relations. Artists, sculptors, architects, and household do-it-yourselfers have strong visual-spatial skills. When you put together a jigsaw

Image omitted due to copyright restrictions.

Because the left hand of a professional string player must rapidly and accurately execute fine movements and slight pressure variations, it is not surprising that these musicians have an unusually large area of the somatosensory cortex dedicated to the fingers of that hand.

puzzle, draw a picture, or assemble a piece of furniture according to instructions, you are calling primarily on your right hemisphere.

The right hemisphere processes information holistically rather than part by part or piece by piece (Corballis, 1989). While auditory, visual, and touch stimuli register in both hemispheres, the right hemisphere appears to be more specialized for complex perceptual tasks. Consequently, the right hemisphere is better at recognizing patterns, whether of familiar voices (Van Lancker et al., 1988), melodies (Springer & Deutsch, 1985), or visual patterns.

Although the left hemisphere is generally considered the language hemisphere, the right hemisphere makes an important contribution to how we "hear" language. According to Howard Gardner, the right hemisphere is involved "in understanding the theme or moral of a story, in grasping metaphor … and even in supplying the punch line for a joke" (1981, p. 74). It is the right hemisphere that is able to understand familiar idiomatic expressions such as "turning over a new leaf." If the right hemisphere is damaged, a person can understand only the literal meaning of such a statement.

To experience an effect of the specialization of the cerebral hemispheres, try your hand at the *Try It!*

Creativity and intuition are typically considered right hemisphere specialties, but the left hemisphere shares these functions. The right hemisphere controls singing and seems to be more specialized for musical ability in untrained musicians (Kinsella et al., 1988). But in trained musicians, both hemispheres play important roles in musical ability. In fact, parts of the left auditory cortex are significantly larger in musicians with perfect pitch (Schlaug et al., 1995)

Patients with right-hemisphere damage may have difficulty with spatial orientation, such as in finding their way around, even in familiar surroundings. They may have attentional deficits and be unaware of objects in the left visual field—a condition called "unilateral neglect" (Bellas et al., 1988; Halligan & Marshall, 1994). Unilateral neglect patients may eat only the food on the right side of their plate, read only the words on the right half of a page, and even groom only the right half of their body (Bisiach, 1996). And remarkably, some patients may even deny that their arm on the side opposite the brain damage belongs to them (Posner, 1996).

The Right Hemisphere's Role in Emotion: Recognizing and Expressing Emotion

According to Phil Bryden and his colleagues at the University of Waterloo, the right hemisphere is also more active in recognizing and expressing emotion (Bryden & MacRae, 1988). Reading and interpreting non-verbal behaviour, such as gestures and facial expressions, is primarily a right-hemisphere task (Hauser, 1993). Look at the two faces in the next *Try It!* (Jaynes, 1976).

Try It!

Testing the Hemispheres

Get a metre stick or yardstick. Try balancing it across your left hand and then across your right hand. Most people are better with their dominant hand. Is this true for you?

Now try this: Begin reciting the alphabet out loud as fast as you can while balancing the stick with your *left* hand. Do you have less trouble this time? Why? The right hemisphere controls the act of balancing with the left hand. However, your left hemisphere, though poor at controlling the left hand, still tries to coordinate your balancing efforts. When you distract the left hemisphere with a steady stream of talk, the right hemisphere can orchestrate more efficient balancing with your left hand, without interference.

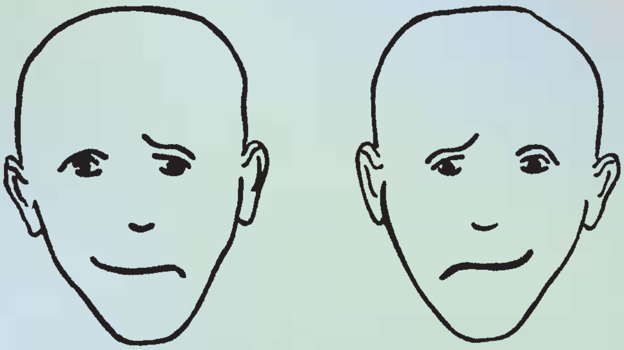
lateralization: The specialization of one of the cerebral hemispheres to handle a particular function.

left hemisphere: The hemisphere that controls the right side of the body, coordinates complex movements, and (in 95 percent of people), controls the production of speech and written language.

right hemisphere: The hemisphere that controls the left side of the body and that, in most people, is specialized for visual-spatial perception and for understanding of non-verbal behaviour.

Try It!

Handedness and Perception



Pick out the happy face and the sad face.

Even though the faces in the drawings are mirror images, right-handed people tend to see the face on the left as the happier face. If you are right-handed, you are likely to perceive the emotional tone revealed by the part of the face to your left as you view it (McGee & Skinner, 1987). The right hemisphere processes information from the left visual field, so right-handed people tend to be more emotionally affected by the left side of the faces they view.

It is also the right hemisphere that responds to the emotional messages conveyed by another's tone of voice (Heilman et al., 1975). For example, say a professor sarcastically tells a student who enters the class late, "Well, I'm so glad you could come today." A student with right-hemisphere damage might respond only to the actual meaning of the words rather than to the sarcastic tone.

The right hemisphere is involved in our tone of voice and particularly in our facial expressions. The left side of the face, controlled by the right hemisphere, usually conveys stronger emotion than the right side of the face (Sackeim et al., 1978). Lawrence Miller (1988) describes the facial expressions and the voice inflections of people with right-hemisphere damage as "often strangely blank—almost robotic" (p. 39).

Evidence is accumulating that brain mechanisms responsible for negative emotions reside in the right hemisphere, while those responsible for positive emotions are found in the left hemisphere (Hellige, 1993). Recent research shows that patients suffering from major depression experience decreased activity in the left prefrontal cortex, where positive emotions are produced (Drevets et al., 1997).

The Split Brain: Separate Halves or Two Separate Brains?

What is the significance of the split-brain operation?

The fact that parts of the human brain are specialized for some functions does not mean that some people are left-brained while others are right-brained. Unless the hemispheres have been surgically separated, they do not operate in isolation and cannot be educated separately. Although each has important specialized functions, the cerebral hemispheres are always in intimate and immediate contact, thanks to the corpus callosum.

In very rare cases, people have been born with no corpus callosum or have had their corpus callosum severed in a drastic surgical procedure called the **split-brain operation**. Neurosurgeons Joseph Bogen and Philip Vogel (1963) found that patients with severe epilepsy, suffering frequent grand mal seizures, could be helped by surgery that severed the corpus callosum. In this way, the pulsing waves of neural activity that occur during a seizure could be confined to one brain hemisphere. For more information about epilepsy, read *On the Cutting Edge in Canada*.

The split-brain operation surgically separates the hemispheres, making the transfer of information between them impossible. The patient is left with two independently functioning hemispheres. In some cases the operation has been quite successful, completely eliminating seizures. And it causes no major changes in personality, intelligence, or behaviour.

Research with split-brain patients by Roger Sperry (1964, 1966) and colleagues Michael Gazzaniga (1967, 1970, 1989) and Jerre Levy (1985) has expanded our knowledge of the unique capabilities of the individual hemispheres. Sperry (1968) found that when surgically separated, each hemisphere continued to have individual and private experiences, sensations, thoughts, and perceptions. However, most sensory experiences were shared almost simultaneously, because each ear and eye has direct sensory connections to both hemispheres. For his work, Sperry won the Nobel Prize in Medicine in 1981.

on the cutting edge in canada

Image omitted due to copyright restrictions.

Epilepsy

Epilepsy is a disorder in which the normal electrical activity of the brain is disrupted. When a disruption occurs, the person may experience strange sensations, feelings, and behaviour, and sometimes the person has muscle spasms, convulsions, or loses consciousness (National Institute of Neurological Disorders and Stroke, 2000). There are several types of epileptic seizures, and they reflect the different parts of the brain that are involved in the disruption. *Generalized seizures* (also called grand mal) occur when the whole brain is involved. Grand mal seizures usually involve a loss of consciousness accompanied by convulsions. *Absence seizures* involve a sudden but fleeting loss of consciousness such that the person may not even be aware that a seizure has occurred (Encarta, 2000). Although the grand mal seizure is the one most often depicted in movies, it is the partial seizure that is most common.

Partial seizures involve only one area of the brain and are classified as simple, complex, and absence/petit mal seizures. *Simple partial seizures* may produce jerky body motions, some impairment in vision or hearing, nausea, and fear, but there is no loss of awareness. *Complex partial seizures,* also called temporal lobe epilepsy, interrupt normal behaviour and involve loss of awareness. Individuals may continue to be active but may appear to be in a trance. They have no control over body movements; therefore, their behaviour may appear random and inappropriate relative to the setting they are in or the activity in which they were engaged prior to the seizure. Often auras precede the seizure. Auras vary and can include unusual sensations or smells, dizziness, or fearfulness (Encarta, 2000).

People with epilepsy may develop behavioural and emotional problems as a result of the unpredictability, embarrassment, or frustration of having seizures or as a result of the ridicule or stigma associated with the disorder (National Institute of Neurological Disorders and Stroke, 2000). Epileptics often experience physical and social restrictions imposed by themselves or others.

Drugs and surgery are the most common treatments. Historically, evaluation of treatment effectiveness involved measuring seizure frequency (Wiebe & Derry, 2000). More recently, Dr. Paul Derry, a psychologist at the London Health Sciences Centre in London, Ontario, and his colleagues, have begun to assess the quality of life of individuals undergoing treatments for epilepsy. In a series of recent studies, Dr. Derry has examined psychological outcomes in patients who have undergone surgery for temporal lobe epilepsy (Derry et al., 1997; Derry & Wiebe, 2000; Wiebe & Derry, 2000). Brain surgery is performed to relieve seizures so as to optimize the patient's quality of life. The best results occur when brain surgery results in a 90 percent reduction of seizures or a seizure-free patient.

Surgical reduction of seizures by itself does not predict good outcomes. Pre-existing personality and social variables can also predict quality of life. Individuals who take an active role in their own health and believe they have some personal control, who have less overall anxiety and emotional distress, and who have had previous success in coping under stress and adequate social support report the best outcomes (Derry & Wiebe, 2000). Timing in assessment is also critical because adjustment occurs over time—sometimes one or two years are required for adjustment to occur (Wiebe & Derry, 2000). Derry and colleagues are continuing their study of psychological factors that predict adjustment both when surgical procedures are perceived to be successful or not.

Image omitted due to copyright restrictions.

Paul Derry

LINK IT!

psych.butler.edu/bwoodruf/courses/splitbrain/splitbrainvisanat.html
Anatomical Basis of Split Brain Phenomenon

split-brain operation: An operation, performed in severe cases of epilepsy, in which the corpus callosum is cut, separating the cerebral hemispheres and usually lessening the severity and frequency of grand mal seizures.

www.macalester.edu/~psych/whathap/UBNRP/Split_Brain/Split_Brain_Consciousness.html
Split Brain Consciousness

www.tbidoc.com
Brain Injury and Neuropsychology

www.epub.org.br/cm/n02/historia/psicocirg_i.htm
R.M.E. Sabbatini. (1997, June/August), The history of psychosurgery, Brain & Mind Magazine, 1(2)

Testing the Split-Brain Person

Sperry's research revealed some fascinating findings. In Figure 2.10, a split-brain patient sits in front of a screen that separates the right and left fields of vision. If an orange is flashed to the right field of vision, it will register in the left (verbal) hemisphere. If asked what he saw, the patient will readily reply, "I saw an orange." But suppose that an apple is flashed to the left visual field and is relayed to the right (non-verbal) hemisphere. If asked what he saw, the patient will reply, "I saw nothing."

How could the patient report that he saw the orange but not the apple? Sperry maintains that in split-brain patients, only the verbal left hemisphere can report what it sees. In these experiments, the left hemisphere does not see what is flashed to the right hemisphere, and the right hemisphere is unable to report verbally what it has viewed. But did the right hemisphere actually see the apple that was flashed in the left visual field? Yes, because with his left hand (which is controlled by the right hemisphere), the patient can pick out from behind a screen the apple or any other object shown to the right hemisphere. The right hemisphere knows and remembers what it sees just as well as the left; but unlike the left hemisphere, the right cannot name what it has seen. (In these experiments, images must be flashed for no more than one or two tenths of a second so that the participants do not have time to refixate their eyes and send the information to the opposite hemisphere.)

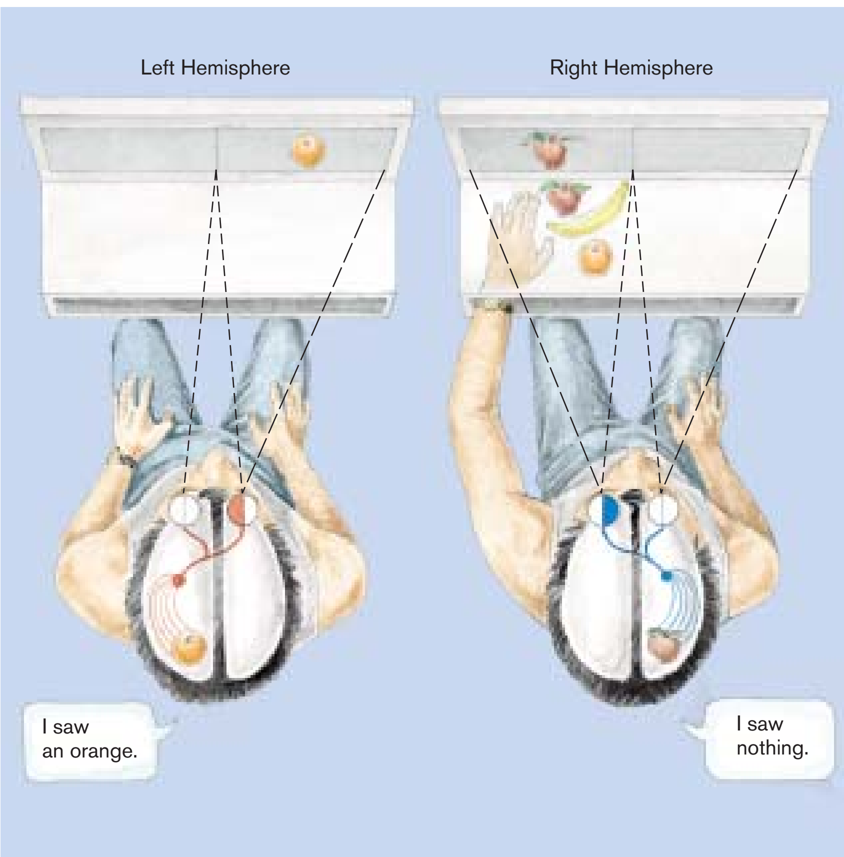


FIGURE 2.10
Testing a Split-Brain Person **Using special equipment, researchers are able to study the independent functioning of the hemispheres in split-brain persons. In this experiment, when a visual image (an orange) is flashed on the right side of the screen, it is transmitted to the left (talking) hemisphere. When asked what he saw, the split-brain patient replies, "I saw an orange." When an image (an apple) is flashed on the left side of the screen, it is transmitted only to the right (non-verbal) hemisphere. Because the split-brain patient's left (language) hemisphere did not receive the image, he replies, "I saw nothing." But he can pick out the apple by touch if he used his left hand, proving that the right hemisphere "saw" the apple. (Based on Gazzaniga, 1983.)**

Remember It!

Specialization in the Cerebral Hemispheres

1. Match the hemisphere with the specialized abilities usually associated with it.

___ 1) visual-spatial skills
___ 2) speech
___ 3) recognition and expression of emotion
___ 4) singing
___ 5) mathematics

a. right hemisphere
b. left hemisphere

2. Which of these statements is *not* true of the split-brain operation?
   a. It is used for people suffering from severe epilepsy.
   b. It provides a means of studying the functions of the individual hemispheres.
   c. It causes major changes in intelligence, personality, and behaviour.
   d. It makes transfer of information between the hemispheres impossible.

Answers: 1. 1) a 2) b 3) a 4) a 5) b 2. c

Discovering the Brain's Mysteries

What are some methods that researchers have used to learn about brain function?

Today, researchers are unlocking the mysteries of the human brain using electrical stimulation, the electroencephalograph (EEG), and the microelectrode, as well as modern scanning devices such as computerized axial tomography (CT scan), magnetic resonance imaging (MRI), positron-emission tomography (PET scan), functional MRI, and others.

The EEG and the Microelectrode

What is the electroencephalogram (EEG), and what are three of the brain-wave patterns it reveals?

In 1924, Austrian psychiatrist Hans Berger invented the electroencephalograph, a machine that amplifies a million times the electrical activity occurring in the brain. This electrical activity, detected by electrodes placed at various points on the scalp, produces a record of brain-wave activity called an **electroencephalogram (EEG)**. The EEG measures three types of waves. **Beta waves** are associated with mental or physical activity. **Alpha waves** are associated with deep relaxation, and **delta waves** with deep sleep. Figure 2.11 shows the various brain-wave patterns and their associated psychological states.

The most recent application of EEG studies employs a computerized imaging technique in which various colours are generated to represent the different levels of electrical activity occurring every millisecond on the surface of the brain.

While the EEG is able to detect electrical activity in different areas of the brain, it cannot reveal what is happening in individual neurons. Microelectrodes can. A **microelectrode** is a wire so small it can be inserted into a single neuron without damaging it. Microelectrodes can be used to monitor the electrical activity of a single neuron or to stimulate activity within it. Researchers have used microelectrodes to

electroencephalogram (EEG) (ee-lek-tro-en-SEFF-uh-lo-gram): The record of an individual's brainwave activity made by the electroencephalograph.

beta wave (BAY-tuh): The brain wave of 13 or more cycles per second that occurs when an individual is alert and mentally or physically active.

alpha wave: The brain wave of 8–12 cycles per second that occurs when an individual is awake but deeply relaxed, usually with the eyes closed.

delta wave: The slowest brain wave, having a frequency of 1–3 cycles per second and associated with slow-wave (deep) sleep.

microelectrode: An electrical wire so small that it can be used either to monitor the electrical activity of a single neuron or to stimulate activity within it.

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The electroencephalograph (EEG) uses electrodes placed on the scalp to amplify and record electrical activity in the brain.

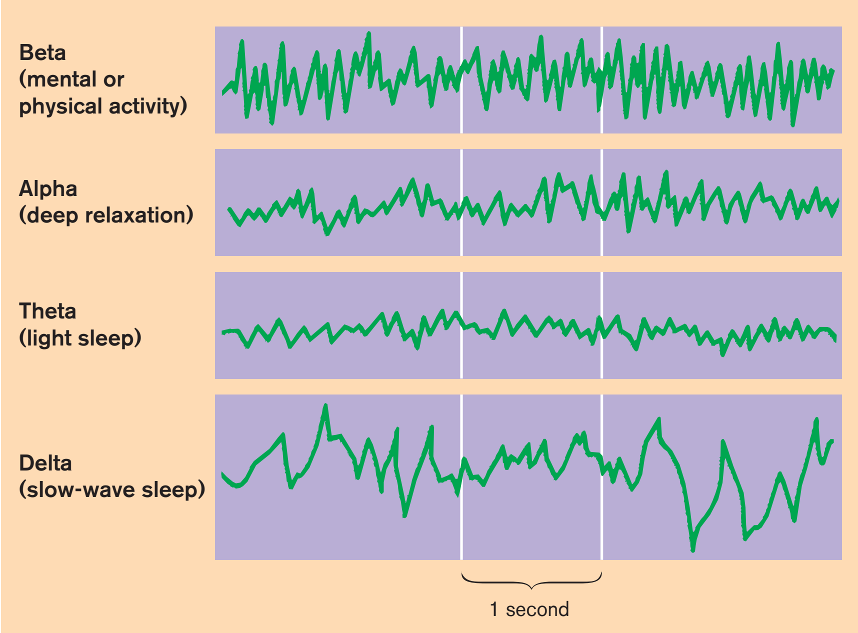

FIGURE 2.11

EEG Patterns Associated with Various Waking and Sleeping States

EEG patterns vary according to the level of brain activity monitored. Beta waves occur when a person is mentally or physically active.

discover the exact functions of single cells within the primary visual cortex and the primary auditory cortex.

The CT Scan and MRI

The patient undergoing a **CT scan (computerized axial tomography)** is placed inside a large, doughnut-shaped structure. An X-ray tube then circles the patient's entire head and shoots pencil-thin X-rays through the brain. A series of computerized cross-sectional images results; these images reveal the structures within the brain (or other parts of the body) as well as abnormalities and injuries, including tumours and old or recent strokes.

Another technique, **MRI (magnetic resonance imaging)**, produces clearer and more detailed images without exposing patients to the hazards of X-ray photography (Potts et al., 1993). MRI is a powerful diagnostic tool that can be used to find abnormalities in the central nervous system and in other systems of the body.

Although the CT scan and MRI do a remarkable job of showing what the brain looks like both inside and out, they cannot reveal what the brain is doing. But other technological marvels can.

The PET Scan, the Functional MRI, and Other Imaging Techniques

The **PET scan (positron-emission tomography)** is a powerful instrument for identifying malfunctions that cause physical and psychological disorders and also for studying normal brain activity (Volkow & Tancredi, 1991). The PET scan can map the patterns of blood flow, oxygen use, and consumption of glucose (the food of the brain). It can also show the action of drugs and other biochemical substances in the brain and other bodily organs (Farde, 1996).

The patient undergoing a PET scan either is injected with radioactive glucose or inhales oxygen laced with low-level radioactivity. The more active any part of the brain is, the more oxygen and glucose it consumes. The PET scan produces a computerized image in colours that vary with the amount of radioactive substance left behind as the brain uses different levels of oxygen or glucose.

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MRI (left) is a powerful tool for revealing what the brain looks like. Unlike PET scans, however, it cannot show us what the brain is doing. PET scans (right) show activity in specific areas of the brain.

The PET scan can detect only *changes* in blood flow and in oxygen and glucose consumption as they occur in the various brain areas. Many parts of the brain are always active, even when a person is doing nothing observable. How do researchers separate the activities of specific brain locations from those of other, unrelated brain locations? Thanks to sophisticated computers and creative mathematical techniques, researchers can "subtract" all other brain activities from the activities involved in the specific mental tasks the participants are performing at a given time (Raichle, 1994b).

One new application, functional MRI (fMRI), can image both brain structure and brain activity. It has several advantages over other imaging techniques: it requires nothing (radioactive or otherwise) to be injected into participants. Its ability to image precise locations of activity clearly is better than PET's and it can detect changes that take place in less than a second compared to around a minute for PET ("Brain Imaging," 1997). The major limitation of fMRI is that the participant's entire body must be confined within a long, narrow tube—a claustrophobic person's worst nightmare—during the entire imaging period.

For more information about these discoveries, read *On the Cutting Edge in Canada.*

Brain Damage: Causes and Consequences

What must occur in the brain for there to be some recovery from brain damage?

How can a person survive such massive brain damage as in the case of Phineas Gage, while a small bullet fired into the brain in particular places can result in instant death? The precise location of a brain injury is the most important factor determining whether a person lives or dies. Had the metal rod torn through Gage's brainstem, that would have been the end of him. Brain damage has many causes. Stroke, head injuries, diseases, tumours, and the abuse of drugs can leave people with a variety of disabilities.

CT scan (computerized axial tomography): A brain-scanning technique involving a rotating X-ray scanner and a high-speed computer analysis that produces slice-by-slice, cross-sectional images of the structure of the brain.

magnetic resonance imaging (MRI): A diagnostic scanning technique that produces high-resolution images of the structures of the brain.

PET scan (positron-emission tomography): A brain-imaging technique that reveals activity in various parts of the brain on the basis of the amount of oxygen and glucose consumed.

on the cutting edge in canada

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o copyright restrictions.

fMRI

One of the most exciting developments in the new field of cognitive neuroscience (an area of science that examines the neural bases of perception, cognition, and motor control) is *functional magnetic resonance imaging* (fMRI). How does it work? It has been known for some time that more active brain areas require more oxygen and, consequently, more blood is distributed to those regions. For example, suppose a given part of the brain is involved in reading. Whenever you read (this passage for example!), the neurons in that part of your brain will require more oxygen.

In Canada, at the Robarts Research Institute affiliated with the University of Western Ontario, research is being conducted with a "4 Tesla" MR system (one of six in the world). Dr. Ravi Menon, a Canadian physicist, and a research team composed of psychologists and physiologists, including Philip Servos from Wilfrid Laurier University, have been making important discoveries about the neural bases of visual and touch perception and visually guided action such as eye and arm movements.

Using the fMRI technology, Servos was able to map out the brain regions responsible for sensory information about the face. He demonstrated that there are errors in Penfield's original map. The face portion of the homunculus that Penfield mapped out was found to be upside down. Servos continues to map out the details of the sensory homunculus using fMRI. Such studies make possible the identification of brain regions that are as small as one cubic millimetre (the size of the head of a pin)! Although most fMRI work done in the world today can only monitor changes in the brain that occur over several seconds, recent groundbreaking work by Dr. Menon and his colleagues has made it possible to monitor changes in the brain that occur in the subsecond range.

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Dr. Ravi Menon

Recovering from Brain Damage

It was formerly thought that once neurons are destroyed, they were gone forever. However, research indicates that the hippocampus can regenerate neurons (Jones, 1999), damaged neurons can sprout new dendrites and re-establish connections with other neurons to assume some of the functions of the brain cells that were lost, and axons are able to regenerate and grow (Fawcett, 1992).

Some abilities lost through brain damage can be regained if areas near the damaged site take over the lost function. The brain's ability to reorganize and to compensate for brain damage is termed **plasticity**. Plasticity is greatest in young children, whose hemispheres haven't yet been completely lateralized (Bach-y-Rita & Bach-y-Rita, 1990). Some individuals who have had an entire hemisphere removed early in life because of uncontrollable epilepsy have been able to lead near-normal intellectual lives (Bower, 1988).

The Peripheral Nervous System

What is the peripheral nervous system?

The **peripheral nervous system (PNS)** is made up of all the nerves that connect the central nervous system to the rest of the body. Without the peripheral nervous system, the brain and spinal cord, encased in their bone coverings, would be isolated and unable to send information to or receive information from other parts of the body. The peripheral nervous system has two subdivisions—the somatic nervous system and the autonomic nervous system. Figure 2.12 shows the subdivisions within the peripheral nervous system.

The Somatic Nervous System

The somatic nervous system consists of all the *sensory* nerves, which transmit information from the sense receptors—eyes, ears, nose, tongue, and skin—to the central nervous system; and all the *motor* nerves, which relay messages from the central nerv-

Remember It!

Studying the Brain

1. The CT scan and MRI are used to
   a. show the amount of activity in various parts of the brain.
   b. produce images of the structures within the brain.
   c. measure electrical activity in the brain.
   d. observe neural communication at synapses.
2. Which of the following reveals the electrical activity of the brain by producing a record of brain waves?
   a. electroencephalograph
   b. CT scan
   c. PET scan
   d. MRI
3. Which of the following reveals brain activity and function, rather than the structure of the brain?
   a. CT scan b. EEG
   c. PET scan d. MRI
4. Match the brain-wave pattern with the state associated with it.
   ___ 1) Slow-wave (deep) sleep a. beta wave
   ___ 2) Deep relaxation while awake b. delta wave
   ___ 3) Physical or mental activity c. alpha wave
5. Plasticity of the brain increases with age. (true/false)

Answers: 1. b 2. a 3. c 4. 1) b 2) c 3) a 5. false

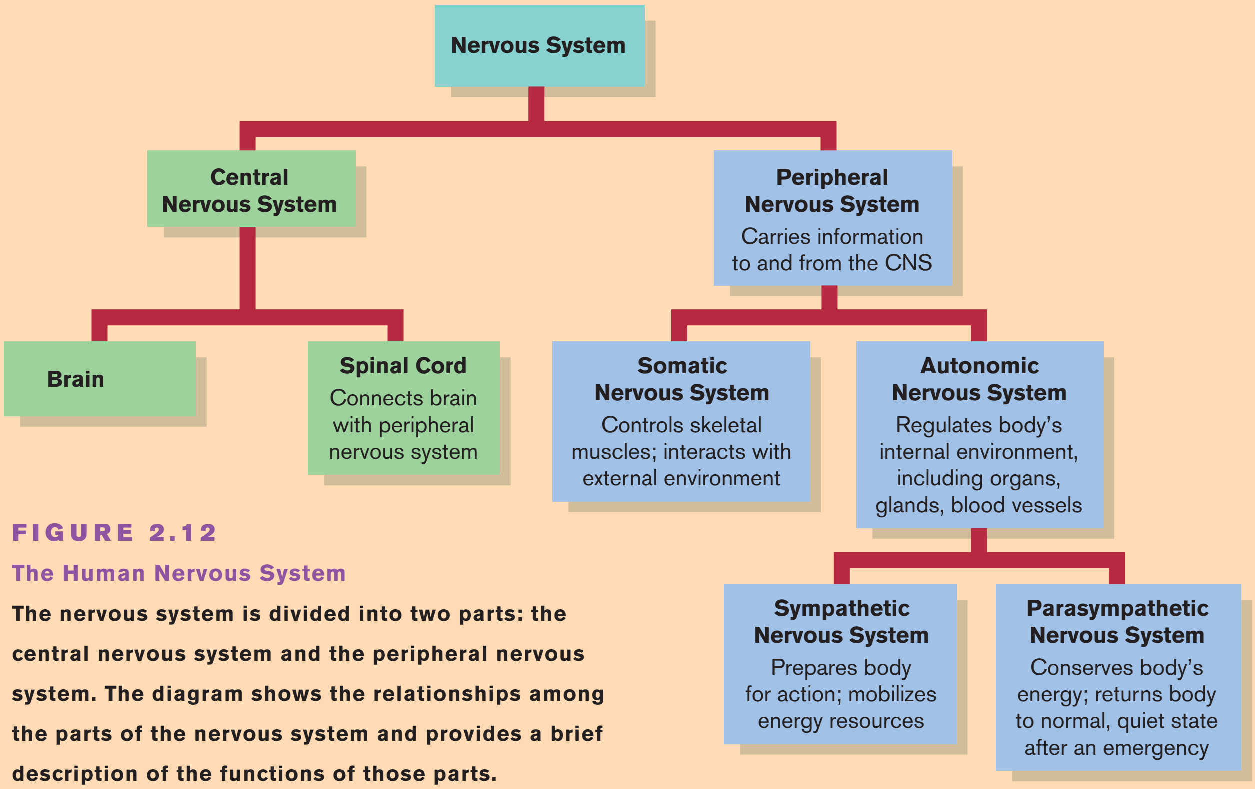

FIGURE 2.12
The Human Nervous System
The nervous system is divided into two parts: the central nervous system and the peripheral nervous system. The diagram shows the relationships among the parts of the nervous system and provides a brief description of the functions of those parts.

ous system to all the skeletal muscles of the body. In short, the nerves of the somatic nervous system make it possible for us to sense our environment and to move, and they are primarily under our conscious control.

plasticity: The ability of the brain to reorganize and compensate for brain damage.

peripheral nervous system (PNS) (peh-RIF-er-ul): The nerves connecting the central nervous system to the rest of the body; has two subdivisions—the autonomic and the somatic nervous systems.

The Autonomic Nervous System

What are the roles of the sympathetic and parasympathetic nervous systems?

The word *autonomic* is sometimes misread by students as *automatic.* That is not a bad synonym, because the autonomic nervous system operates quite well automatically, without our being conscious of it. It transmits messages between the central nervous system and the glands, the cardiac (heart) muscle, and the smooth muscles (such as those in the large arteries, the gastrointestinal system, and the small blood vessels), which are not normally under voluntary control.

The autonomic nervous system is further divided into two parts—the sympathetic and the parasympathetic nervous systems. Any time you are under stress or faced with an emergency, the **sympathetic nervous system** automatically mobilizes the body's resources, preparing you for action. This physiological arousal produced by the sympathetic nervous system is called the "fight or flight" response. If an ominous-looking stranger started following you and quickened his pace as you turned down a dark, deserted street, your sympathetic nervous system would automatically set to work. Your heart would begin to pound, your pulse rate would increase rapidly, your breathing would quicken, and your digestive system would nearly shut down. The blood flow to your skeletal muscles would be enhanced, and all of your bodily resources would be made ready to handle the emergency—RUN!

But once the emergency is over, something must happen to bring these heightened bodily functions back to normal. The **parasympathetic nervous system** is responsible for this. As a result of its action, your heart stops pounding and slows to normal, your pulse rate and breathing slow down, and the digestive system resumes its normal functioning. As you can see in Figure 2.13, the sympathetic and parasympathetic branches act as opposing but complementary forces in the autonomic nervous system. Their balanced functioning is essential for our health and survival.

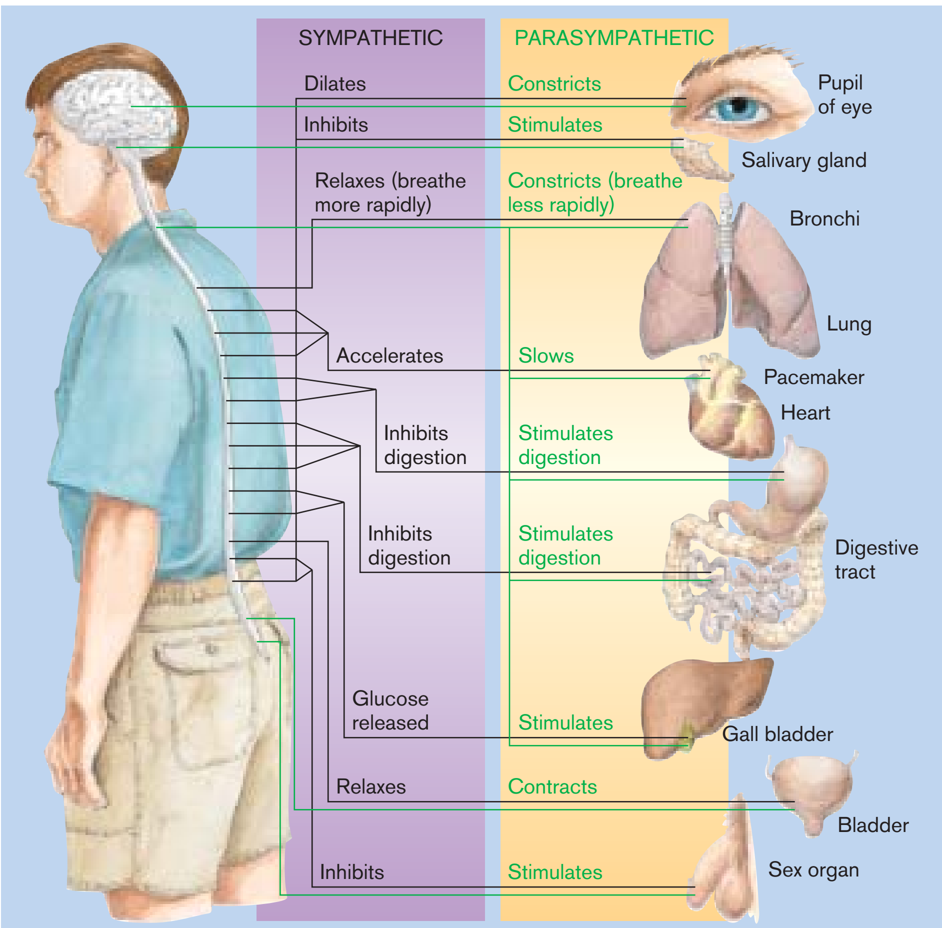

FIGURE 2.13
The Autonomic Nervous System The autonomic nervous system consists of (1) the sympathetic nervous system, which mobilizes the body's resources during emergencies or during stress, and (2) the parasympathetic nervous system, which is associated with relaxation and which brings the heightened bodily responses back to normal after an emergency. This diagram shows the opposite effects of the sympathetic and parasympathetic nervous systems on various parts of the body.

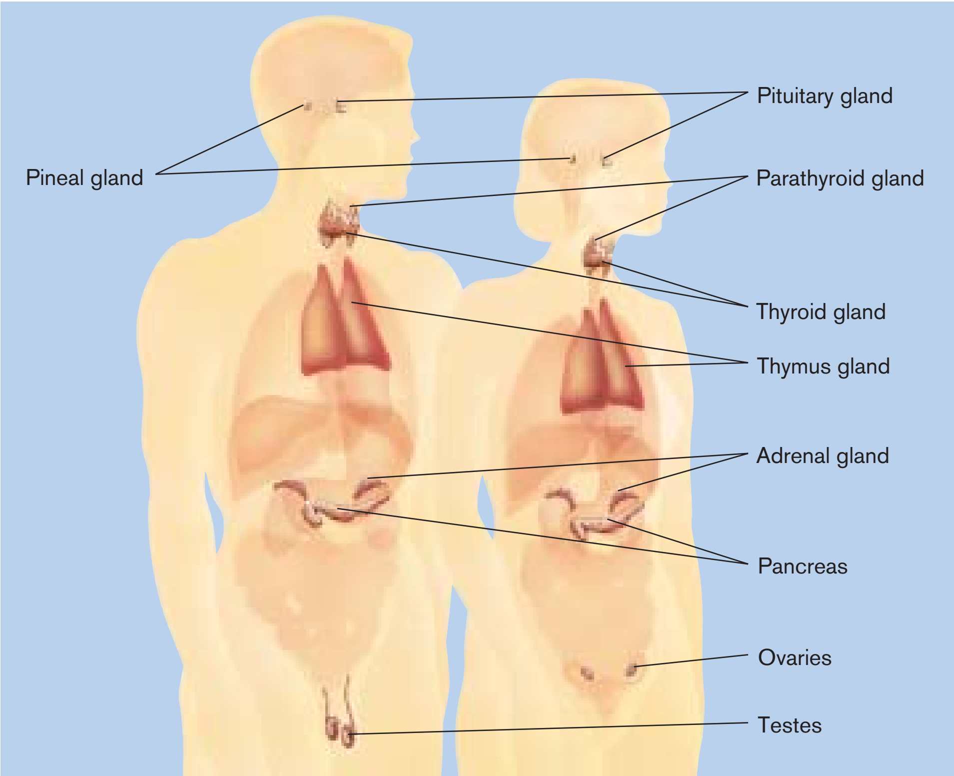

FIGURE 2.14

The Endocrine System The endocrine system is a series of glands that manufacture and secrete hormones. The hormones travel through the circulatory system and have important effects on many bodily functions.

The Endocrine System

What is the endocrine system, and what are some of the glands within it?

We have seen how chemical substances called neurotransmitters influence the 100 billion or so neurons in the nervous system. There is another system that stimulates and regulates important functions in the body by means of chemical substances. The **endocrine system** is a series of ductless glands, found in various parts of the body, that manufacture and secrete chemicals known as hormones (from the Greek word for "excite"). **Hormones** are manufactured and released in one part of the body but have an effect on other parts of the body. Hormones are released into the bloodstream and travel throughout the circulatory system, but each hormone performs its assigned job only when it connects with the body cells having receptors for it. Some neurotransmitters act as hormones as well—norepinephrine and vasopressin, to name two (Bergland, 1985). Figure 2.14 shows the glands in the endocrine system and their locations in the body.

The Pituitary Gland

The **pituitary gland** rests in the brain just below the hypothalamus and is controlled by it (refer to Figure 2.14). The pituitary is considered to be the master gland of the body because it releases the hor-

sympathetic nervous system: The division of the autonomic nervous system that mobilizes the body's resources during stress, emergencies, or heavy exertion, preparing the body for action.

parasympathetic nervous system: The division of the autonomic nervous system that is associated with relaxation and the conservation of energy and that brings the heightened bodily responses back to normal after an emergency.

endocrine system (EN-duh-krin): A system of ductless glands in various parts of the body that manufacture and secrete hormones into the bloodstream or lymph fluids, thus affecting cells in other parts of the body.

hormone: A substance manufactured and released in one part of the body that affects other parts of the body.

pituitary gland: The endocrine gland located in the brain and often called the "master gland," which releases hormones that control other endocrine glands and also releases a growth hormone.

mones that "turn on," or activate, the other glands in the endocrine system—a big job for a tiny structure about the size of a pea. The pituitary also produces the hormone that is responsible for body growth (Howard et al., 1996). Too little of this powerful substance will make one a dwarf, whereas too much will produce a giant.

The Thyroid Gland

The thyroid gland rests in the front lower part of the neck just below the voice box (larynx). The thyroid produces the important hormone thyroxin, which regulates the rate at which food is metabolized, or transformed into energy. Too much thyroxin can result in hyperthyroidism, a condition in which people are nervous and excitable, find it hard to be still and relax, and are usually thin. Hypothyroidism, an underproduction of thyroxin, has just the opposite effect. An adult with hypothyroidism may feel sluggish, lack energy, and be overweight.

The Pancreas

Curving around between the small intestine and the stomach is the pancreas (refer to Figure 2.14). The pancreas regulates the body's blood sugar levels by releasing the hormones insulin and glucagon into the bloodstream. The pancreas also produces digestive enzymes. In people with diabetes, too little insulin is produced. Without insulin to break down the sugars we ingest, the level of blood sugar can get dangerously high. In hypoglycemia, the opposite effect occurs—too much insulin is produced, resulting in low blood sugar. Both conditions may be partly controlled by diet, but in many cases the diabetic must also take daily insulin injections.

The Adrenal Glands

Lower in the body are the two **adrenal glands**, which rest just above the kidneys, as shown in Figure 2.14. The adrenal glands produce epinephrine and norep-

Apply It!

Handedness: Does It Make a Difference?

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If you are left-handed, you are in good company. Among the better-known lefties of earlier centuries were Alexander the Great, Michelangelo, Leonardo da Vinci, and Joan of Arc. Other famous lefties include Albert Einstein and Marilyn Monroe; among left-handers of more recent times are Martina Navratilova, Howie Mandel, Dan Aykroyd, Marshall McLuhan, and Wayne Gretzky.

Stanley Coren and his colleagues at the University of British Columbia have studied the implications of being left-handed. They found that most people–about 90 percent of the world's population–are right-handed (Coren & Porac, 1977). Left-handedness occurs more often in males than in females. People who are left-handed are generally also left-footed, and to a lesser extent left-eyed and left-eared as well. There is a difference in the motor control provided by the two hemispheres of the brain. Thus, in a person whose left hand is dominant, the right hemisphere provides superior motor control for that hand.

Scholars and scientists have long wondered why such a small percentage of humans are left-handed. Some researchers propose a genetic cause (Annett, 1985; Levy & Nagylaki, 1972); others maintain that handedness is learned (Porac, 1993; Provins, 1997). No theory yet proposed is able to explain all the facts, although there is strong evidence that there is a genetic element in handedness.

Some research evidence is even more controversial. Investigators at McMaster University have proposed that handedness and sexual orientation are linked. For example, Witelson (1990) found that the percentage of right-handers drops sharply among homosexual men and women. The same investigator has identified a number of physiological differences between right-handed and left-handed

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inephrine, two hormones that activate the sympathetic nervous system. The adrenal glands release the corticoids, which control the body's salt balance, and also release small amounts of the sex hormones.

The Sex Glands

The gonads are the sex glands—the ovaries in females and the testes in males (refer to Figure 2.14). Activated by the pituitary gland, the gonads release sex hormones that make reproduction possible and that are responsible for the secondary sex characteristics—pubic and underarm hair in both sexes, breasts in females, and facial hair and a deepened voice in males.

Androgens, the male sex hormones, influence sexual motivation. Estrogen and progesterone, the female sex hormones, help regulate the menstrual cycle. Although both males and females have androgens and estrogens, males have considerably more androgens, and females have considerably more estrogens.

Biology and behaviour are intimately related. However, there is much more to the scientific study of behaviour and mental processes than the biological connection can teach us. Later chapters in this text expand on other aspects of behaviour and mental processes.

LINK IT!

www.indiana.edu/~primate/brain.html
Handedness and Brain Lateralization

www.indiana.edu/~primate/forms/hand.html
Hand Preference Questionnaire: Participate in on-going research on human handedness

www.carleton.ca/49.663/web.htm
Neuropsychology and the Corpus Callosum

people. On average, the corpus callosum of left-handers is 11 percent larger and contains up to 2.5 million more nerve fibres (Witelson, 1985). In about 60 percent of left-handers, language functions are controlled by the left hemisphere; in 25 percent, by the right hemisphere; and in about 15 percent, by both hemispheres. In general, left-handers appear to be less lateralized than right-handers, meaning that the two sides of the brain are less specialized (Hellige et al., 1994). Because of this characteristic, left-handers tend to experience less language loss following an injury to either hemisphere (Geschwind, 1979); and they are more likely to recover, because the undamaged hemisphere can more easily take over the speech functions.

In many respects, left-handed people are at a disadvantage compared with right-handed people. Left-handers are five times more likely to suffer serious accidents, and they are sometimes said to be clumsier than right-handers. A more extreme suggestion is that left-handers, on average, have a shorter life span than right-handers (Coren & Halpern, 1991). This can probably be explained by the fact that they must function in a world designed for right-handers (Coren, 1989).

For example, the seats found in many college and university classrooms have a large writing surface at the end of the right arm, allowing right-handed people to rest that arm while writing. In cars with a standard shift, the gear shift is located on the right side of the driver's seat. The markings on measuring cups, thermometers, and other measuring devices cannot be read unless the object is held in the right hand. Table settings and doorknobs also assume right-handedness. The bias toward right-handedness even extends to feet: the arrangement of pedals in a car favours right-footed people.

Most left-handed people are able to adapt to these conditions. Some actually become ambidextrous as a result of using both hands for certain activities. (For example, Roberto Alomar hits from both sides in baseball.) Fortunately, some items—scissors and golf clubs, for example—are manufactured in left-hander versions.

Most children show a consistent preference for one hand over the other by the age of five; some begin to rely on the use of one hand at 18 months. Most experts in child development agree that it is harmful, if not futile, to interfere with the hand preference of a young child. It can cause emotional distress and lead to speech or reading problems.

adrenal glands (ah-DREE-nal): A pair of endocrine glands that release hormones that prepare the body for emergencies and stressful situations and also release small amounts of the sex hormones.

Remember It!

The Peripheral Nervous System

1. The ____________ nervous system connects the brain and spinal cord to the rest of the body.
   a. central
   b. peripheral
   c. somatic
   d. autonomic
2. The __________ nervous system mobilizes the body's resources during times of stress; the __________ nervous system brings the heightened bodily responses back to normal when the emergency is over.
   a. somatic; autonomic
   b. autonomic; somatic
   c. sympathetic; parasympathetic
   d. parasympathetic; sympathetic
3. The endocrine glands secrete _______ directly into the ________.
   a. hormones; bloodstream
   b. enzymes; digestive tract
   c. enzymes; bloodstream
   d. hormones; digestive tract
4. Match the endocrine gland with the appropriate description.
   ___ 1) Keeps body's metabolism in balance
   ___ 2) Acts as a master gland that activates the other glands
   ___ 3) Regulates blood sugar
   ___ 4) Makes reproduction possible
   ___ 5) Releases hormones that prepare the body for emergencies

   a. pituitary gland
   b. adrenal glands
   c. gonads
   d. thyroid gland
   e. pancreas

Answers: 1. b 2. c 3. a 4. 1) d 2) a 3) e 4) c 5) b

KEY TERMS

acetylcholine, p. 39
action potential, p. 37
adrenal glands, p. 64
alpha wave, p. 57
amygdala, p. 45
aphasia, p. 48
association areas, p. 46
axon, p. 35
beta wave, p. 57
brainstem, p. 42
Broca's aphasia, p. 48
Broca's area, p. 48
cell body, p. 35
central nervous system, p. 41
cerebellum, p. 43
cerebral cortex, p. 46
cerebral hemispheres, p. 46
cerebrum, p. 46
corpus callosum, p. 46
CT scan, p. 58
delta wave, p. 57
dendrites, p. 35
dopamine, p. 39
electroencephalogram (EEG), p.57
endocrine system, p. 63
endorphins, p. 40
fMRI, p. 60
frontal lobes, p. 46
glial cells, p. 40
hippocampus, p. 45
hormone, p. 63
hypothalamus, p. 44
lateralization, p. 52
left hemisphere, p. 52
limbic system, p. 45
medulla, p. 42
microelectrode, p. 57
motor cortex, p. 47
MRI, p. 58
myelin sheath, p. 37
neuron, p. 34
neurotransmitter, p. 37
norepinephrine, p. 40
occipital lobes, p. 50
parasympathetic nervous system, p. 62
parietal lobes, p. 50
peripheral nervous system, p. 60
PET scan, p. 58
pituitary gland, p. 63
plasticity, p. 60
primary auditory cortex, p. 50
primary visual cortex, p. 50
receptor site, p. 37
resting potential, p. 36
reticular formation, p. 42
reuptake, p. 39
right hemisphere, p. 52
serotonin, p. 40
somatosensory cortex, p. 50
spinal cord, p. 42
split-brain operation, p. 54
sympathetic nervous system, p. 62
synapse, p. 36
temporal lobes, p. 50
thalamus, p. 44
Wernicke's aphasia, p. 51
Wernicke's area, p. 51

THINKING CRITICALLY

Evaluation

Using your knowledge about how the human brain has been studied in the past and today, point out the advantages and the disadvantages of the older investigative methods: the case study, the autopsy, and the study of people with brain injuries or who have had brain surgery (including the split-brain operation). Follow the same procedure to discuss the more modern techniques: EEG, CT scan, MRI, and PET scan.

Point/Counterpoint

A continuing controversial issue is whether animals should be used in biological research. Review the chapter and find each occasion in which animals were used to advance our knowledge of the brain. Using what you have read in this chapter and any other information you have acquired, prepare arguments to support each of the following positions:

a. The use of animals in research projects is ethical and justifiable because of the possible benefits to humankind.
b. The use of animals in research projects is not ethical or justifiable on the grounds of possible benefits to humankind.

Psychology in Your Life

How would your life change if you had a massive stroke in your left hemisphere? How would it change if the stroke were in your right hemisphere? Which stroke would be more tragic for you, and why?

SUMMARY & REVIEW

The Neurons and the Neurotransmitters

What is a neuron, and what are its three parts?

A neuron is a specialized cell that conducts messages through the nervous system. Its three main parts are the cell body, dendrites, and axon.

What is a synapse?

A synapse is the junction where the axon terminal of the sending neuron communicates with the receiving neuron across the synaptic cleft.

What is the action potential?

The action potential is the firing of a neuron that results when the charge within the neuron becomes more positive than the charge outside the cell's membrane.

What are neurotransmitters, and what role do they play in the transmission of signals from one neuron to another?

Neurotransmitters are chemicals released into the synaptic cleft from the axon terminal of the sending neuron. They cross the synapse and bind to receptor sites on the receiving neuron, influencing the cell to fire or not to fire.

What are some of the ways in which neurotransmitters affect our behaviour, and what are some of the major neurotransmitters?

Neurotransmitters regulate the actions of our glands and muscles, affect learning and memory, promote sleep, stimulate mental and physical alertness, and influence our moods and emotions, from depression to euphoria. Some of the major neurotransmitters are acetylcholine, dopamine, norepinephrine, serotonin, glutamate, GABA, and endorphins.

The Central Nervous System

Why is an intact spinal cord important to normal functioning?

The spinal cord is an extension of the brain, connecting it to the peripheral nervous system so that sensory information can reach the brain, and messages from the brain can reach the muscles and glands.

What are the crucial functions handled by the brainstem?

The brainstem contains (1) the medulla, which controls heartbeat, breathing, blood pressure, coughing, and swallowing; and (2) the reticular formation, which plays a crucial role in arousal and attention.

What are the primary functions of the cerebellum?

The main functions of the cerebellum are to execute smooth, skilled movements and to regulate muscle tone and posture.

What is the primary role of the thalamus?

The thalamus acts as a relay station for information flowing into or out of the higher brain centres.

What are some of the processes regulated by the hypothalamus?

The hypothalamus controls the pituitary gland and regulates hunger, thirst, sexual behaviour, body temperature, and a variety of emotional behaviours.

What is the role of the limbic system?

The limbic system is a group of structures in the brain, including the amygdala and the hippocampus, that are collectively involved in emotion, memory, and motivation.

The Cerebral Hemispheres

What are the cerebral hemispheres, the cerebral cortex, and the corpus callosum?

The cerebral hemispheres are the two halves of the cerebrum, connected by the corpus callosum and covered by the cerebral cortex, which is responsible for higher mental processes such as language, memory, and thinking.

What are some of the main areas within the frontal lobes, and what are their functions?

The frontal lobes contain (1) the motor cortex, which controls voluntary motor activity; (2) Broca's area, which functions in speech production; and (3) the frontal association areas, which are involved in thinking, motivation, planning for the future, impulse control, and emotional responses.

What are the primary functions of the parietal lobes in general and the somatosensory cortex in particular?

The parietal lobes are involved in the reception and processing of touch stimuli. They contain the somatosensory cortex, where touch, pressure, temperature, and pain register.

What are the primary functions of the occipital lobes in general and the primary visual cortex in particular?

The occipital lobes are involved in the reception and interpretation of visual information. They contain the primary visual cortex, where vision registers in the cerebral cortex.

What are the major areas within the temporal lobes, and what are their functions?

The temporal lobes contain (1) the primary auditory cortex, where hearing registers in the cortex; (2) Wernicke's area, which is involved in comprehending the spoken word and in formulating coherent speech and written language; and (3) association areas, where memories are stored and auditory stimuli are interpreted.

Specialization of the Cerebral Hemispheres

What are the main functions of the left hemisphere?

The left hemisphere controls the right side of the body, coordinates complex movements, and handles most of the language functions, including speaking, writing, reading, and understanding the spoken word.

What are the primary functions of the right hemisphere?

The right hemisphere controls the left side of the body; is specialized for visual-spatial perception, singing, reading, and non-verbal behaviour; and is more active in the recognition and expression of emotion.

What is the significance of the split-brain operation?

In the split-brain operation, a surgeon cuts the corpus callosum. This prevents the transfer of information between the hemispheres. Research on split-brain patients has extended our knowledge of the functions of the hemispheres.

Discovering the Brain's Mysteries

What are some methods that researchers have used to learn about brain function?

Researchers have learned about brain function from clinical studies of patients, through electrical stimulation of the brain, and from studies using the EEG, microelectrodes, the CT scan, MRI, and the PET scan.

What is the electroencephalogram (EEG), and what are three of the brain-wave patterns it reveals?

The electroencephalogram (EEG) is a record of brain-wave activity. Three normal brain-wave patterns are the beta wave, alpha wave, and delta wave.

Brain Damage: Causes and Consequences

What must occur in the brain for there to be some recovery from brain damage?

In recovery from brain damage, (1) damaged neurons may sprout new dendrites and reestablish connections with other neurons, (2) areas near the damaged site may take over the lost function, or (3) the undamaged hemisphere may assume the lost language function (as in aphasia).

The Peripheral Nervous System

What is the peripheral nervous system?

The peripheral nervous system connects the central nervous system to the rest of the body. It has two subdivisions: (1) the somatic nervous system, which consists of the nerves that make it possible for us to sense and move; and (2) the autonomic nervous system.

What are the roles of the sympathetic and parasympathetic nervous systems?

The autonomic nervous system has two parts: (1) the sympathetic nervous system, which mobilizes the body's resources during emergencies or during stress; and (2) the parasympathetic nervous system, which is associated with relaxation and brings the heightened bodily responses back to normal after an emergency.

The Endocrine System

What is the endocrine system, and what are some of the glands within it?

The endocrine system is a system of glands in various parts of the body that manufacture hormones and secrete them into the bloodstream. The hormones then affect cells in other parts of the body. The pituitary gland releases hormones that control other glands in the endocrine system and also releases a growth hormone. The thyroid gland produces thyroxin, which regulates metabolism. The adrenal glands release epinephrine and norepinephrine, which prepare the body for emergencies and stressful situations, and also release small amounts of the sex hormones. The pancreas produces insulin and regulates blood sugar. The gonads are the sex glands, which produce the sex hormones and make reproduction possible.