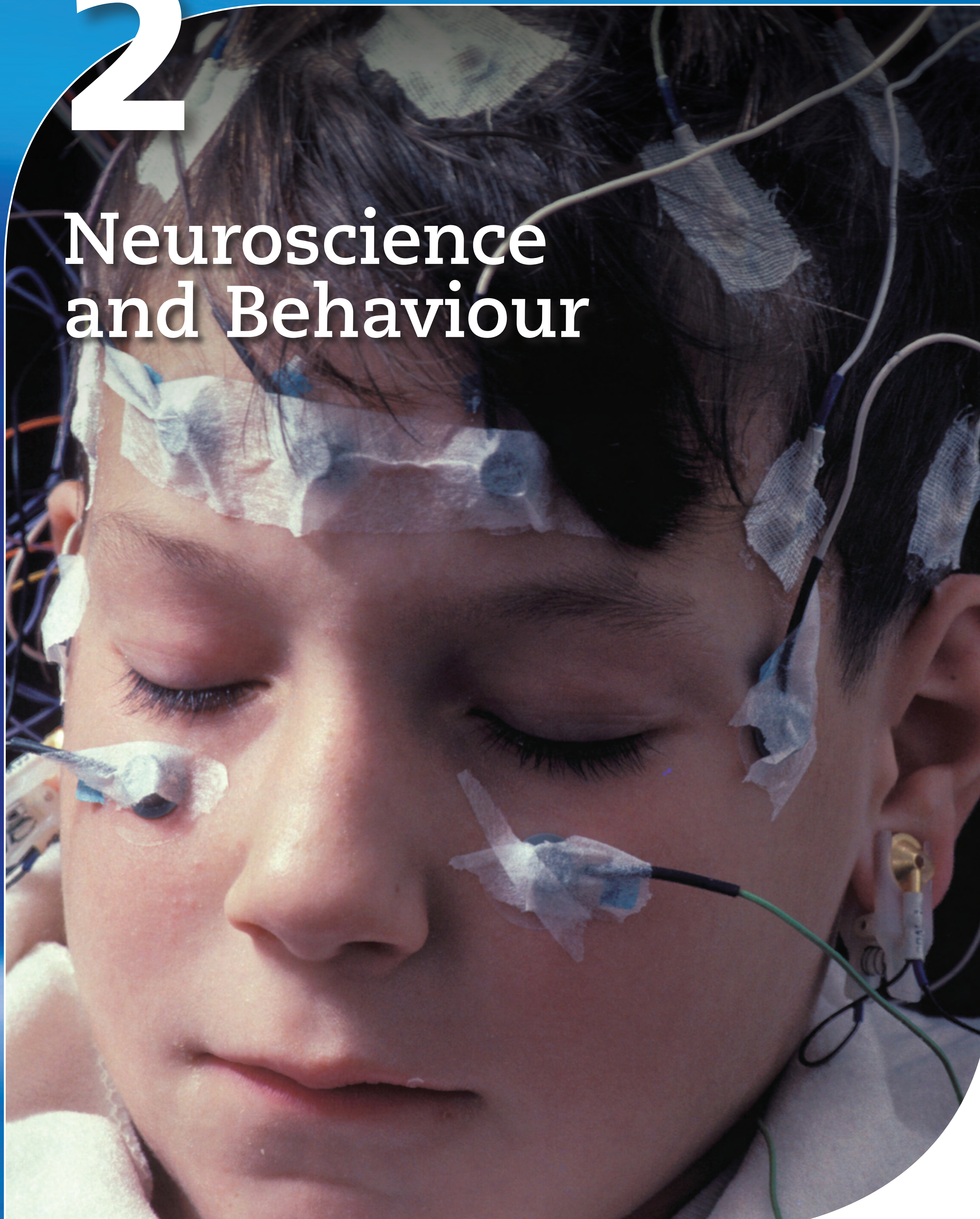
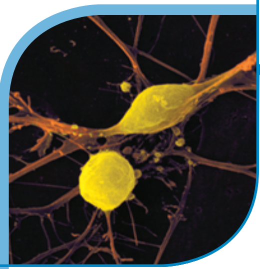
Chapter 2

Neuroscience and Behaviour



KEY CONCEPTS FOR CHAPTER 2

Module 5 NEURONS: THE BASIC ELEMENTS OF BEHAVIOUR



Why do psychologists study the brain and the nervous system?

What are the basic elements of the nervous system?

How does the nervous system communicate electrical and chemical messages from one part to another?

THE STRUCTURE OF THE NEURON

HOW NEURONS FIRE

WHERE NEURONS MEET: BRIDGING THE GAP

NEUROTRANSMITTERS: MULTITALENTED CHEMICAL COURIERS

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How do researchers identify the major parts and functions of the brain?

What are the major parts of the brain, and for what behaviours is each part responsible?

How do the halves of the brain operate interdependently?

How can an understanding of the nervous system help us find ways to alleviate disease and pain?

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How are the structures of the nervous system linked?

How does the endocrine system affect behaviour?

THE NERVOUS SYSTEM

THE ENDOCRINE SYSTEM: OF CHEMICALS AND GLANDS

Prologue CANADIAN CRUSADER FOR PARKINSON'S RESEARCH

Canadian Michael J. Fox, was diagnosed with Parkinson's disease at the young age of 30. A disease that he fought privately for seven years was a secret that was relatively easy to keep given that most people mistake Parkinson's for a "senior citizen's" disease. In actuality, as many as 1 in 10 individuals diagnosed with the disease are under the age of 40. Young-onset PD is the unique diagnosis made to this age group (Nussbaum & Ellis, 2003; Davis, 2007).

In 1998, Fox began his very public crusade to find a cure for the disease. The Michael J. Fox Foundation has raised more than $115 million for research and treatment of Parkinson's disease. In 2007, Fox received international recognition when nominated by *Time Magazine* as one of the world's Top 100 Heroes and Pioneers (Davis, 2007). On May 22, 2008, Michael J. Fox received an honorary degree from the University of British Columbia; an honour that "deeply moved and humbled" the BC born actor and Parkinson's advocate (Sinoski, 2008).

What does Parkinson's disease look like? What are the initial symptoms? How visible are they? Preliminary symptoms of PD include: tremors, rigidity, and slow movement that progressively deteriorate over time (Jung, 2004). This is the reality of Parkinson's debated in the media by radio personality Rush Limbaugh when he accused Fox of exaggerating his symptoms in a TV commercial supporting stem cell research (Davis, 2007). The ground-breaking, controversial PD research examines regenerative properties of embryonic stem cells; an area first discovered by fellow Canadians Ernest A. McCulloch and James E. Till (Becker, McCulloch, & Till, 1963). Eventually, Limbaugh apologized for his remarks—and hopefully—the one positive aspect of the media spectacle was increased attention to the progressive devastation of Parkinson's disease (Montgomery, 2006).

What treatment options are available? Current treatments range from conservative, non-pharmacological treatments (e.g., speech therapy) to non-surgical options such as dopamine replacement medications (e.g., Levodopa) to surgical interventions (e.g., deep brain stimulation (DBS)). In DBS, surgeons implant a battery-operated neurostimulator that delivers tiny electric pulses to specific areas of the brain that control movement. The electrical stimulation blocks abnormal nerve signals that produce the symptoms of Parkinson's. Because DBS requires patients to be awake during the operation, patients are well aware of the procedure as it happens (Farkas, 2004; The Michael J. Fox Foundation, 2008).

LOOKING AHEAD

The ability of surgeons to identify damaged portions of the brain and carry out repairs is little short of miraculous. The greater miracle is the brain itself. An organ roughly half the size of a loaf of bread, the brain controls our behaviour through every waking and sleeping moment. Our movements, thoughts, hopes, aspirations, dreams—our very awareness that we are human—all depend on the brain and the nerves that extend throughout the body, constituting the nervous system.

Because of the importance of the nervous system in controlling behaviour, and because humans at their most basic level are biological beings, many researchers in psychology and other fields as diverse as computer science, zoology, and medicine have made the biological underpinnings of behaviour their specialty. These experts collectively are called *neuroscientists* (Beatty, 2000; Posner & DiGiorlamo, 2000; Gazzaniga, Ivry, & Mangun, 2002).

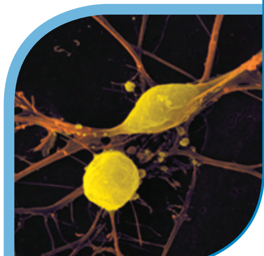
Recent developments in behavioural neuroscience examine the link between deviant behaviour and the brain. Canadian expert Dr. Robert Hare, developer of the *Hare Psychopathy Checklist*, identified structural abnormalities in the brains of psychopaths as a possible cause of psychopathology (De Oliveira-Souza, Hare, Bramati, Garrido, Ignácio, Tovar-Moll, & Moll, 2008).

Psychologists who specialize in considering the ways in which the biological structures and functions of the body affect behaviour are known as **behavioural neuroscientists** (or *biopsychologists*). They seek to answer several key questions: How does the brain control the voluntary and involuntary functioning of the body? How does the brain communicate with other parts of the body? What is the physical structure of the brain, and how does this structure affect behaviour? Are psychological disorders caused by biological factors, and how can such disorders be treated?

Clinical neuropsychologists, a sub-speciality within clinical psychology, assess brain-behaviour relationships using a battery of tests (e.g., Halstead-Reitan; Luria-Nebraska). Assessment results are used to diagnose, monitor, and in some cases, treat abnormal functioning. For instance, annual testing provides a critical benchmark of neuropsychological functioning (e.g., executive functioning, memory) for patients with neurodegenerative diseases such as Michael J. Fox's Parkinson's disease (Rourke, Hayman-Abello, & Hayman-Abello. 2003). Canadian Psychological Association (CPA) and American Psychological Association (APA) each include a neuropsychology section devoted exclusively to brain-behaviour research and interventions.

As you consider the biological processes that we'll discuss in this chapter, it is important to keep in mind why behavioural neuroscience is an essential part of psychology: our understanding of human behaviour requires knowledge of the brain and other parts of the nervous system. Biological factors are central to our sensory experiences, states of consciousness, motivation and emotion, development throughout the life span, and physical and psychological health. Furthermore, advances in behavioural neuroscience have led to the creation of drugs and other treatments for psychological and physical disorders. In short, we cannot understand behaviour without understanding our biological makeup (Kosslyn et al., 2002; Plomin, 2003; Compagni & Manderscheid, 2006).

Module 5



Neurons: The Basic Elements of Behaviour

Watching Mike Weir hit a golf ball, Serena Williams hit a stinging backhand, Dario Vaccaro carry out a complex ballet routine, or Jason Spezza score a goal, you may have marvelled at the complexity—and wondrous abilities—of the human body. But even the most everyday tasks, such as picking up a pencil, writing, and speaking, depend on a sophisticated sequence of events in the body that is itself truly impressive. For instance, the difference between saying the words *dime* and *time* rests primarily on whether the vocal cords are relaxed or tense during a period lasting no more than one one-hundredth of a second, yet it is a distinction that most of us can make with ease.

The nervous system is the pathway for the instructions that permit our bodies to carry out such precise activities. Here we will look at the structure and function of neurons, the cells that make up the nervous system, including the brain.

Key Concepts

Why do psychologists study the brain and the nervous system?

What are the basic elements of the nervous system?

How does the nervous system communicate electrical and chemical messages from one part to another?

Behavioural neuroscientists (or biopsychologists): Psychologists who specialize in considering the ways in which the biological structures and functions of the body affect behaviour.

Clinical neuropsychologists: Psychologists who examine brain-behaviour relationships using a battery of tests in order to monitor, and in some cases, treat abnormal functioning.

THE STRUCTURE OF THE NEURON

Playing the piano, driving a car, or hitting a tennis ball depends, at one level, on exact muscle coordination. But if we consider *how* the muscles can be activated so precisely, we see that there are more fundamental processes involved. For the muscles to produce the complex movements that make up any meaningful physical activity, the brain has to provide the right messages to them and coordinate those messages.

study ALERT

Remember that *d*endrites *d*etect messages from other neurons; axons carry signals away from the cell body.

Such messages—as well as those which enable us to think, remember, and experience emotion—are passed through specialized cells called neurons. **Neurons**, or nerve cells, are the basic elements of the nervous system. Their quantity is staggering—perhaps as many as 1 *trillion* neurons throughout the body are involved in the control of behaviour (Boahen, 2005).

Although there are several types of neurons, they all have a similar structure, as illustrated in Figure 1. Like most cells in the body, neurons have a cell body that contains a nucleus. The nucleus incorporates the hereditary material that determines how a cell will function. Neurons are physically held in place by *glial cells*. Glial cells provide nourishment to neurons, insulate them, help repair damage, and generally support neural functioning (Kettenmann & Ransom, 2005; Fields, 2004).

In contrast to most other cells, however, neurons have a distinctive feature: the ability to communicate with other cells and transmit information across relatively long distances. Many of the body's neurons receive signals from the environment or relay the nervous system's messages to muscles and other target cells, but the vast majority of neurons communicate only with other neurons in the elaborate information system that regulates behaviour.

Neurons: Nerve cells, the basic elements of the nervous system.

Dendrite: A cluster of fibres at one end of a neuron that receive messages from other neurons.

Axon: The part of the neuron that carries messages destined for other neurons.

Terminal buttons: Small bulges at the end of axons that send messages to other neurons.

As you can see in Figure 1, a neuron has a cell body with a cluster of fibres called **dendrites** at one end. Those fibres, which look like the twisted branches of a tree, receive messages from other neurons. On the opposite end of the cell body is a long, slim, tube-like extension called an **axon**. The axon carries messages received by the dendrites to other neurons. The axon is considerably longer than the rest of the neuron. Although most axons are several millimetres in length, some are as long as a metre. Axons end in small bulges called **terminal buttons**, which send messages to other neurons.

The messages that travel through a neuron are electrical in nature. Although there are exceptions, those electrical messages, or *impulses*, generally move across neurons in one direction only, as if they were travelling on a one-way street. Impulses follow a

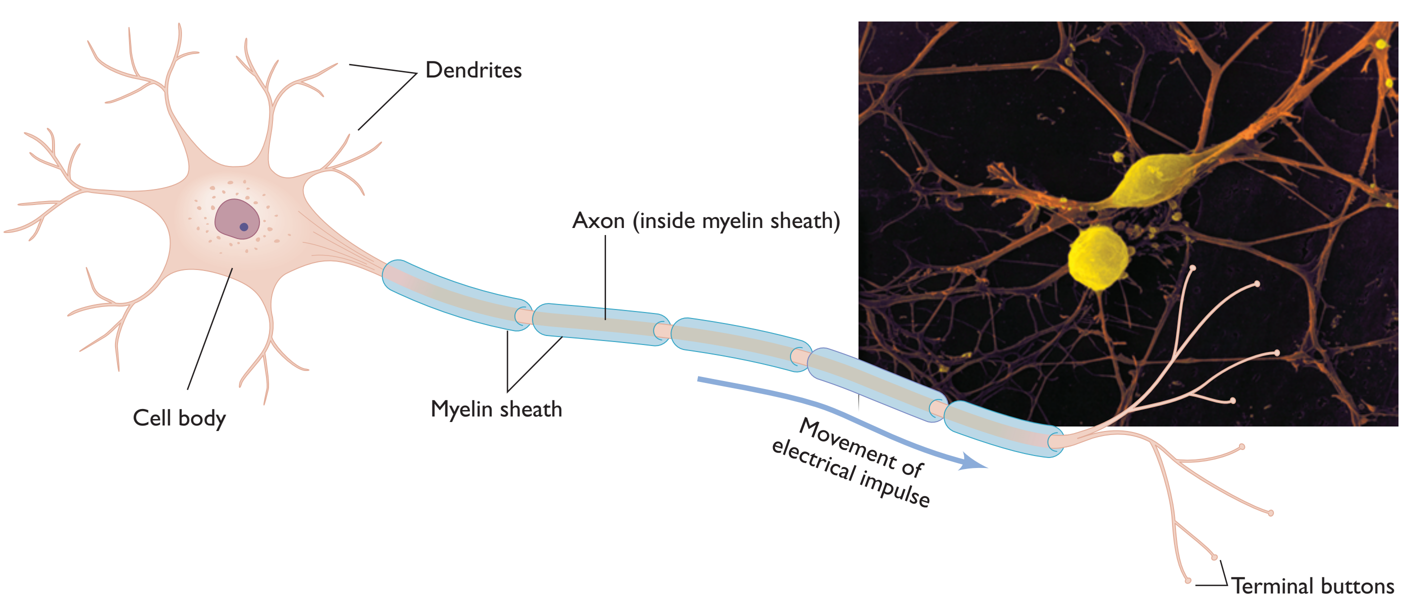


Figure 1

The primary components of the specialized cell called the neuron, the basic element of the nervous system (Van De Graaff, 2000). A neuron, like most types of cells in the body, has a cell body and a nucleus, but it also contains structures that carry messages: the dendrites, which receive messages from other neurons, and the axon, which carries messages to other neurons or body cells. In this neuron, as in most neurons, the axon is protected by the sausage-like myelin sheath. What advantages does the tree-like structure of the neuron provide?

route that begins with the dendrites, continues into the cell body, and leads ultimately along the tube-like extension, the axon, to adjacent neurons. *D*endrites, then, *d*etect messages from other neurons; *a*xons carry signals *a*way from the cell body.

To prevent messages from short-circuiting one another, axons must be insulated in some fashion (just as electrical wires must be insulated). Most axons are insulated by a **myelin sheath**, a protective coat of fat and protein that wraps around the axon like links of sausage.

The myelin sheath also serves to increase the velocity with which electrical impulses travel through axons. Those axons that carry the most important and most urgently required information have the greatest concentrations of myelin. If your hand touches a hot stove, for example, the information regarding the pain is passed through axons in the hand and arm that have a relatively thick coating of myelin, speeding the message of pain to the brain so that you can react instantly. In certain diseases, such as multiple sclerosis, the myelin sheath surrounding the axon deteriorates, exposing parts of the axon that are normally covered. This short-circuits messages between the brain and muscles and results in symptoms such as the inability to walk, difficulties with vision, and general muscle impairment.

HOW NEURONS FIRE

Like a gun, neurons either fire—that is, transmit an electrical impulse along the axon—or don't fire. There is no in-between stage, just as pulling harder on a gun trigger doesn't make the bullet travel faster. Similarly, neurons follow an **all-or-none law**: They are either on or off, with nothing in between the on state and the off state. Once there is enough force to pull the trigger, a neuron fires.

Before a neuron is triggered—that is, when it is in a **resting state**—it has a negative electrical charge of about 70 millivolts (a millivolt is one one-thousandth of a volt). This charge is caused by the presence of more negatively charged ions within the neuron than outside it. (An ion is an atom that is electrically charged.) You might think of the neuron as a miniature battery in which the inside of the neuron represents the negative pole and the outside represents the positive pole.

When a message arrives at a neuron, its cell membrane opens briefly to allow positively charged ions to rush in at rates as high as 100 million ions per second. The sudden arrival of these positive ions causes the charge within the nearby part of the cell to change momentarily from negative to positive. When the positive charge reaches a critical level, the "trigger" is pulled, and an electrical impulse, known as an action potential, travels along the axon of the neuron (see Figure 2).

The **action potential** moves from one end of the axon to the other like a flame moving along a fuse. As the impulse travels along the axon, the movement of ions causes a change in charge from negative to positive in successive sections of the axon (see Figure 3 on page 59). After the impulse has passed through a particular section of the axon, positive ions are pumped out of that section, and its charge returns to negative while the action potential continues to move along the axon.

Just after an action potential has passed through a section of the axon, the cell membrane in that region cannot admit positive ions again for a few milliseconds, and so a neuron cannot fire again immediately no matter how much stimulation it receives. It is as if the gun has to be reloaded after each shot. There then follows a period in which, though it is possible for the neuron to fire, a stronger stimulus is needed than would be needed if the neuron had reached its normal resting state. Eventually, though, the neuron is ready to fire once again.

These complex events can occur at dizzying speeds, although there is great variation among different neurons. The particular speed at which an action potential travels along an axon is determined by the axon's size and the thickness of its myelin sheath. Axons with small diameters carry impulses at about 3 km per hour; longer and thicker ones can average speeds of more than 360 km per hour.

Myelin sheath: A protective coat of fat and protein that wraps around the axon.

All-or-none law: The rule that neurons are either on or off.

Resting state: The state in which there is a negative electrical charge of about –70 millivolts within a neuron.

Action potential: An electric nerve impulse that travels through a neuron's axon when it is set off by a "trigger," changing the neuron's charge from negative to positive.

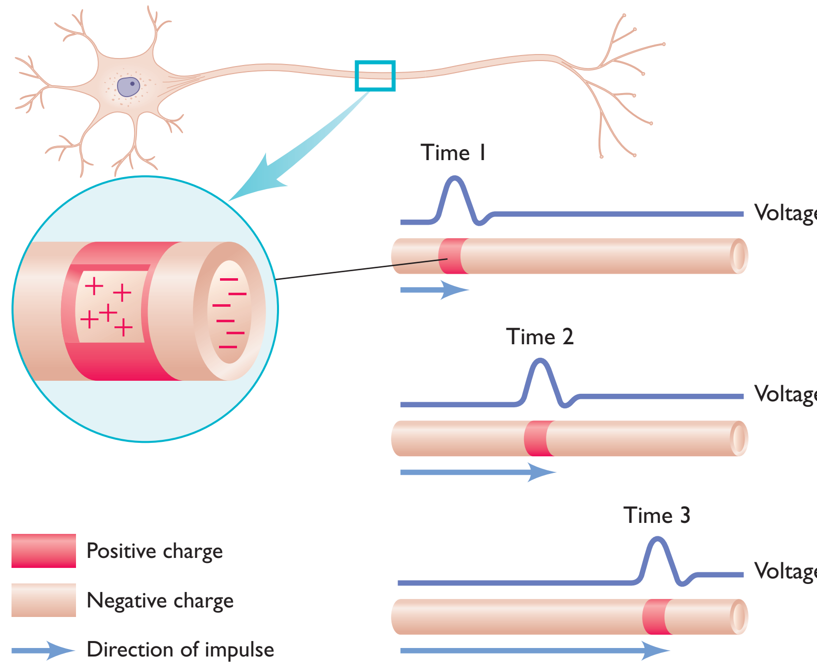


Figure 2

Movement of an action potential across an axon. Just before Time 1, positively charged ions enter the cell membrane, changing the charge in the nearby part of the neuron from negative to positive and triggering an action potential. The action potential travels along the axon, as illustrated in the changes occurring from Time 1 to Time 3 (from top to bottom in this drawing). Immediately after the action potential has passed through a section of the axon, positive ions are pumped out, restoring the charge in that section to negative. The change in voltage illustrated at the top of the axon can be seen in greater detail in Figure 3 on page 59. (Source: Stevens, 1979.)

Neurons differ not only in terms of how quickly an impulse moves along the axon but also in their potential rate of firing. Some neurons are capable of firing as many as a thousand times per second; others fire at much slower rates. The intensity of a stimulus determines how much of a neuron's potential firing rate is reached. A strong stimulus, such as a bright light or a loud sound, leads to a higher rate of firing than a less intense stimulus does. Thus, even though all impulses move at the same strength or speed through a particular axon—because of the all-or-none law—there is variation in the frequency of impulses, providing a mechanism by which we can distinguish the tickle of a feather from the weight of someone standing on our toes.

The structure, operation, and functions of the neuron are fundamental biological aspects of the body that underlie several primary psychological processes. Our understanding of the way we sense, perceive, and learn about the world would be greatly restricted without the knowledge about the neuron that behavioural neuroscientists and other researchers have acquired.

Mirror Neurons

Although all neurons operate through the firing of action potentials, there is significant specialization among different types of neurons. For example, in the last decade, neuroscientists have discovered the existence of **mirror neurons**, neurons that fire not only when a person enacts a particular behaviour but also when a person simply observes *another* individual carrying out the same behaviour (Falck-Ytter & Gredebäck, 2006; Lepage & Theoret, 2007; Schulte-Ruther et al., 2007).

Mirror neurons: Specialized neurons that fire not only when a person enacts a particular behaviour, but also when a person simply observes *another* individual carrying out the same behaviour.

Mirror neurons may help explain how (and why) humans have the capacity to understand others' intentions. Specifically, mirror neurons may fire when we view someone doing something, helping us to predict what their goals are and what they may do next.

The discovery of mirror neurons suggests that the capacity of even young children to imitate others may be an inborn behaviour. Furthermore, mirror neurons may be at the root of empathy—those feelings of concern, compassion, and sympathy for others—and even the development of language in humans (Triesch, Jasso, & Deák, 2007; Iacoboni, 2009; Ramachandran, 2009).

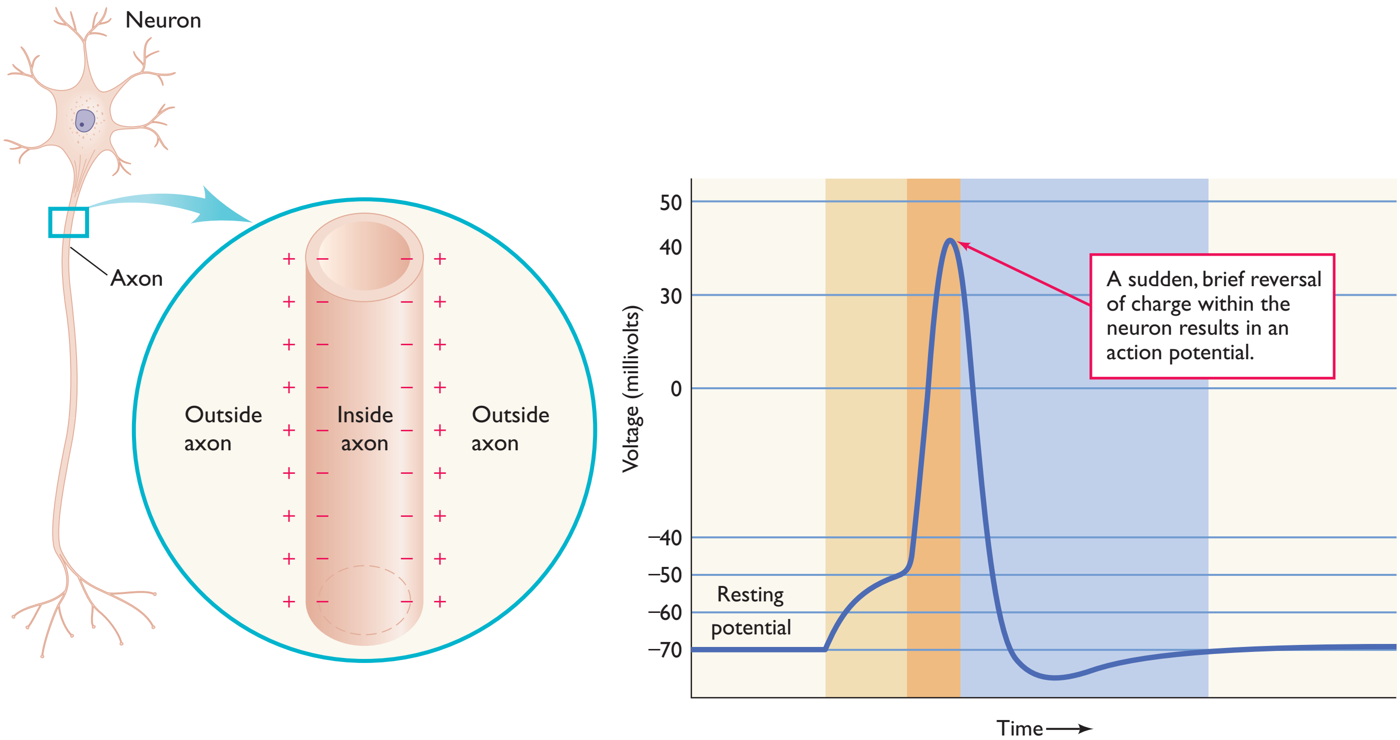


Figure 3

Changes in the electrical charge in a neuron during the passage of an action potential. In its normal resting state, a neuron has a negative charge. When an action potential is triggered, however, the charge becomes positive, increasing from around −70 millivolts to about +40 millivolts. Following the passage of the action potential, the charge becomes even more negative than it is in its typical state. It is not until the charge returns to its resting state that the neuron will be fully ready to be triggered once again. (Source: Mader, 2000.)

WHERE NEURONS MEET: BRIDGING THE GAP

If you have ever looked inside a computer, you've seen that each part is physically connected to another part. In contrast, evolution has produced a neural transmission system that at some points has no need for a structural connection between its components. Instead, a chemical connection bridges the gap, known as a synapse, between two neurons (see Figure 4). The **synapse** is the space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron by using chemical messages (Fanselow & Poulos, 2005; Dean & Dresbach, 2006).

When a nerve impulse comes to the end of the axon and reaches a terminal button, the terminal button releases a chemical courier called a neurotransmitter. **Neurotransmitters** are chemicals that carry messages across the synapse to a dendrite (and sometimes the cell body) of a receiving neuron. Like a boat that ferries passengers across a river, these chemical messengers move toward the shorelines of other neurons. The chemical mode of message transmission that occurs between neurons is strikingly different from the means by which communication occurs inside neurons: Although messages travel in electrical form *within* a neuron, they move *between* neurons through a chemical transmission system.

There are several types of neurotransmitters, and not all neurons are capable of receiving the chemical message carried by a particular neurotransmitter. In the same way that a jigsaw puzzle piece can fit in only one specific location in a puzzle, each kind of neurotransmitter has a distinctive configuration that allows it to fit into a specific type of receptor site on the receiving neuron (see Figure 4b). It is only when

study ALERT

Remember this key fact: Messages inside neurons are transmitted in electrical form, whereas messages travelling between neurons travel via chemical means.

Synapse: The space between two neurons where the axon of a sending neuron communicates with the dendrites of a receiving neuron by using chemical messages.

Neurotransmitters: Chemicals that carry messages across the synapse to the dendrite (and sometimes the cell body) of a receiver neuron.

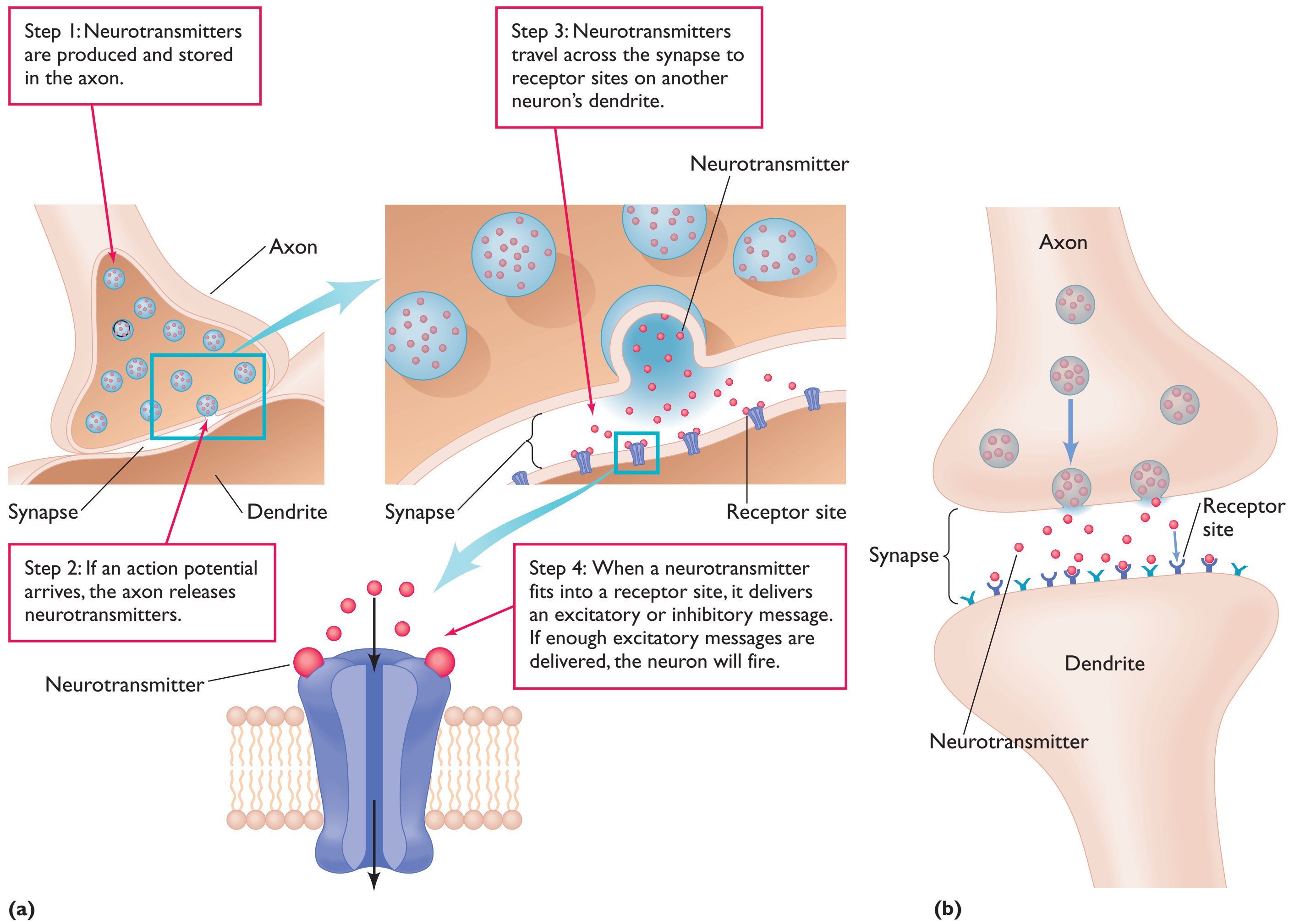


Figure 4

(a) A synapse is the junction between an axon and a dendrite. The gap between the axon and the dendrite is bridged by chemicals called neurotransmitters (Mader, 2000). (b) Just as the pieces of a jigsaw puzzle can fit in only one specific location in a puzzle, each kind of neurotransmitter has a distinctive configuration that allows it to fit into a specific type of receptor cell (Johnson, 2000). Why is it advantageous for axons and dendrites to be linked by temporary chemical bridges rather than by the hard wiring typical of a radio connection or telephone hookup?

a neurotransmitter fits precisely into a receptor site that successful chemical communication is possible.

If a neurotransmitter does fit into a site on the receiving neuron, the chemical message it delivers is basically one of two types: excitatory or inhibitory. **Excitatory messages** make it more likely that a receiving neuron will fire and an action potential will travel down its axon. **Inhibitory messages**, in contrast, do just the opposite; they provide chemical information that prevents or decreases the likelihood that the receiving neuron will fire.

Because the dendrites of a neuron receive both excitatory and inhibitory messages simultaneously, the neuron must integrate the messages by using a kind of chemical calculator. Put simply, if the concentration of excitatory messages ("fire") is greater than the concentration of inhibitory ones ("don't fire"), the neuron fires. In contrast, if the inhibitory messages outnumber the excitatory ones, nothing happens, and the neuron remains in its resting state (Mel, 2002; Rapport, 2005; Flavell et al., 2006).

If neurotransmitters remained at the site of the synapse, receiving neurons would be awash in a continual chemical bath, producing constant stimulation of the receiving

Excitatory message: A chemical message that makes it more likely that a receiving neuron will fire and an action potential will travel down its axon.

Inhibitory message: A chemical message that prevents or decreases the likelihood that a receiving neuron will fire.

neurons—and effective communication across the synapse would no longer be possible. To solve this problem, neurotransmitters are either deactivated by enzymes or—more commonly—reabsorbed by the terminal button in an example of chemical recycling called **reuptake**. Like a vacuum cleaner sucking up dust, neurons reabsorb the neurotransmitters that are now clogging the synapse. All this activity occurs at lightning speed, with the process taking just several milliseconds (Helmuth, 2000; Holt & Jahn, 2004).

Our understanding of the process of reuptake has permitted the development of a number of drugs used in the treatment of psychological disorders. As we'll discuss later in the book, some antidepressant drugs, called *SSRIs* or *selective serotonin reuptake inhibitors*, permit certain neurotransmitters to remain active for a longer period at certain synapses in the brain, thereby reducing the symptoms of depression.

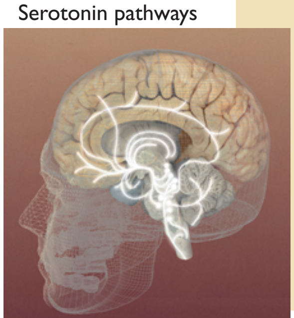
NEUROTRANSMITTERS: MULTITALENTED CHEMICAL COURIERS

Neurotransmitters are a particularly important link between the nervous system and behaviour. Not only are they important for maintaining vital brain and body functions, a deficiency or an excess of a neurotransmitter can produce severe behaviour disorders. More than a hundred chemicals have been found to act as neurotransmitters, and neuroscientists believe that more may ultimately be identified (Penney, 2000; Schmidt, 2006).

Neurotransmitters vary significantly in terms of how strong their concentration must be to trigger a neuron to fire. Furthermore, the effects of a particular neurotransmitter vary, depending on the area of the nervous system in which it is produced. The same neurotransmitter, then, can act as an excitatory message to a neuron located in one part of the brain and can inhibit firing in neurons located in another part. (The major neurotransmitters and their effects are described in Figure 5.)

Reuptake: The reabsorption of neurotransmitters by a terminal button.

Dopamine pathways



Serotonin pathways

Neurotransmitter Name	Location	Effect	Function
Acetylcholine (ACh)	Brain, spinal cord, peripheral nervous system, especially some organs of the parasympathetic nervous system	Excitatory in brain and autonomic nervous system; inhibitory elsewhere	Muscle movement, cognitive functioning
Glutamate	Brain, spinal cord	Excitatory	Memory
Gamma-amino butyric acid (GABA)	Brain, spinal cord	Main inhibitory neurotransmitter	Eating, aggression, sleeping
Dopamine (DA)	Brain	Inhibitory or excitatory	Movement control, pleasure and reward, attention
Serotonin	Brain, spinal cord	Inhibitory	Sleeping, eating, mood, pain, depression
Endorphins	Brain, spinal cord	Primarily inhibitory, except in hippocampus	Pain suppression, pleasurable feelings, appetites, placebos

Figure 5

Major neurotransmitters.

Michael J. Fox, who suffers from Parkinson's disease, has become a strong advocate for research into the disorder.

One of the most common neurotransmitters is *acetylcholine* (or ACh, its chemical symbol), which is found throughout the nervous system. ACh is involved in our every move, because—among other things—it transmits messages relating to our skeletal muscles. ACh is also involved in memory capabilities, and diminished production of ACh may be related to Alzheimer's disease (Mohapel et al., 2005; Bazalakova et al., 2007).

Another common excitatory neurotransmitter, *glutamate*, plays a role in memory. Memories appear to be produced by specific biochemical changes at particular synapses, and glutamate, along with other neurotransmitters, plays an important role in this process (Riedel, Platt, & Micheau, 2003; Winters & Bussey, 2005; Carvalho et al., 2006).

Gamma-amino butyric acid (GABA), which is found in both the brain and the spinal cord, appears to be the nervous system's primary inhibitory neurotransmitter. It moderates a variety of behaviours, ranging from eating to aggression. Several common substances, such as the tranquilizer Valium and alcohol, are effective because they permit GABA to operate more efficiently (Ball, 2004; Criswell et al., 2008; Lobo & Harris, 2008).

Another major neurotransmitter is *dopamine (DA)*, which is involved in movement, attention, and learning. The discovery that certain drugs can have a significant effect on dopamine release has led to the development of effective treatments for a wide variety of physical and mental ailments. For instance, Parkinson's disease, from which actor Michael J. Fox suffers, is caused by a deficiency of dopamine in the brain. Techniques for increasing the production of dopamine in Parkinson's patients are proving effective (Willis, 2005; Antonini & Barone, 2008).

In other instances, *over*production of dopamine produces negative consequences. For example, researchers have hypothesized that schizophrenia and some other severe mental disturbances are affected or perhaps even caused by the presence of unusually high levels of dopamine. Drugs that block the reception of dopamine reduce the symptoms displayed by some people diagnosed with schizophrenia (Di Forti, Lappin, & Murray, 2007; Murray, Lappin, & Di Forti, 2008; Howes & Kapur, 2009).

Another neurotransmitter, *serotonin*, is associated with the regulation of sleep, eating, mood, and pain. A growing body of research points toward a broader role for serotonin, suggesting its involvement in such diverse behaviours as alcoholism, depression, suicide, impulsivity, aggression, and coping with stress (Murray, Lappin, & Di Forti, 2008; Popa et al., 2008; Carrillo et al., 2009).

Endorphins, another class of neurotransmitters, are a family of chemicals produced by the brain that are similar in structure to painkilling drugs such as morphine. The production of endorphins seems to reflect the brain's effort to deal with pain as well as to elevate mood. People who are afflicted with diseases that produce long-term, severe pain often develop large concentrations of endorphins in their brains.

Endorphins also may produce the euphoric feelings that runners sometimes experience after long runs. Although the research evidence is not firm, the exertion and perhaps the pain involved in a long run stimulate the production of endorphins, ultimately resulting in what has been called "runner's high" (Kolata, 2002; Pert, 2002; Stanojevic, Mitic, & Vujic, 2007).

Endorphin release might also explain other phenomena that have long puzzled psychologists. For example, the act of taking placebos (pills or other substances that contain no actual drugs but that patients *believe* will make them better) may induce the release of endorphins, leading to the reduction of pain. In support of such reasoning, increasing evidence shows that people who are given placebos actually exhibit changes in brain functioning (Wager, 2005; Rajagopal, 2006; Crum & Langer, 2007).

RECAP/EVALUATE/RETHINK

RECAP

Why do psychologists study the brain and the nervous system?

- A full understanding of human behaviour requires knowledge of the biological influences underlying that behaviour, especially those originating in the nervous system. Psychologists who specialize in studying the effects of biological structures and functions on behaviour are known as behavioural neuroscientists. Psychologists who assess brain-behaviour relationships using a battery of tests are known as clinical neuropsychologists. (p. 55)

What are the basic elements of the nervous system?

- Neurons, the most basic elements of the nervous system, carry nerve impulses from one part of the body to another. Information in a neuron generally follows a route that begins with the dendrites, continues into the cell body, and leads ultimately down the tube-like extension, the axon. (pp. 55–56)

How does the nervous system communicate electrical and chemical messages from one part to another?

- Most axons are insulated by a coating called the myelin sheath. When a neuron receives a message to fire, it releases an action potential, an electric charge that travels through the axon. Neurons operate according to an all-or-none law: Either they are at rest, or an action potential is moving through them. There is no in-between state. (pp. 56–57)
- Once a neuron fires, nerve impulses are carried to other neurons through the production of chemical substances, neurotransmitters, that actually bridge the gaps—known as synapses—between neurons. Neurotransmitters may be either excitatory, telling other neurons to fire, or inhibitory, preventing or decreasing the likelihood of other neurons firing. Among the major neurotransmitters are acetylcholine (ACh), which produces contractions of skeletal muscles, and dopamine, which is involved in movement, attention, and learning and has been linked to Parkinson's disease and certain mental disorders, such as schizophrenia. (pp. 57–62)
- Endorphins, another type of neurotransmitter, are related to the reduction of pain. Endorphins aid in the production of a natural painkiller and are probably responsible for creating the kind of euphoria that joggers sometimes experience after running. (p. 62)

EVALUATE

1. The ______________ is the fundamental element of the nervous system.
2. Neurons receive information through their ____________ and send messages through their ___________.
3. Just as electrical wires have an outer coating, axons are insulated by a coating called the ____________.
4. The gap between two neurons is bridged by a chemical connection called a ____________.
5. Endorphins are one kind of ____________, the chemical "messengers" between neurons.

RETHINK

1. How might psychologists use drugs that mimic the effects of neuro-transmitters to treat psychological disorders?
2. *From the perspective of a health-care provider:* How would you explain the placebo effect and the role of endorphins to patients who wish to try unproven treatment methods that they find on the Web?

Answers to Evaluate Questions

1. neuron; 2. dendrites, axons; 3. myelin sheath; 4. synapse; 5. neurotransmitter

KEY TERMS

action potential p. 57
all-or-none law p. 57
axon p. 56
behavioural neuroscientists (or biopsychologists) p. 55
clinical neuropsychologists p. 55
dendrite p. 56
excitatory message p. 60
inhibitory message p. 60
mirror neurons p. 58
myelin sheath p. 57
neurons p. 56
neurotransmitters p. 59
resting state p. 57
reuptake p. 61
synapse p. 59
terminal buttons p. 56

Module

6

The Brain

Key Concepts

How do researchers identify the major parts and functions of the brain?

What are the major parts of the brain, and for what behaviours is each part responsible?

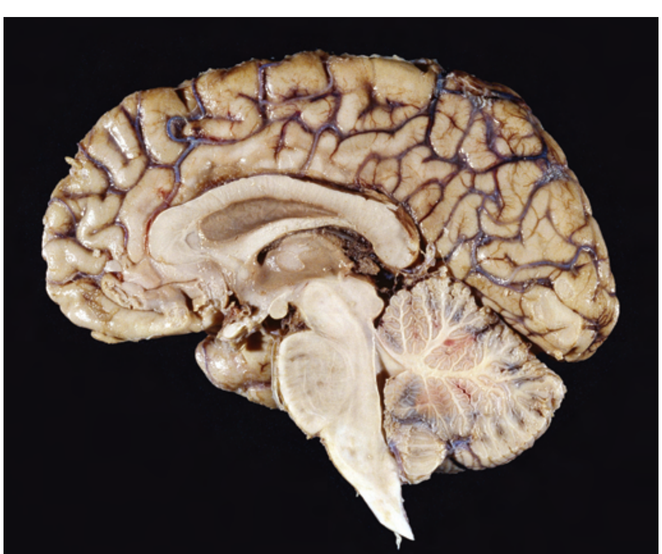
How do the halves of the brain operate interdependently?

How can an understanding of the nervous system help us find ways to alleviate disease and pain?

It is not much to look at. Soft, spongy, mottled, and pinkish-grey in colour, it hardly can be said to possess much in the way of physical beauty. Despite its physical appearance, however, it ranks as the greatest natural marvel that we know and has a beauty and sophistication all its own.

The object to which this description applies: the brain. The brain is responsible for our loftiest thoughts—and our most primitive urges. It is the overseer of the intricate workings of the human body. If one were to attempt to design a computer to mimic the range of capabilities of the brain, the task would be nearly impossible; in fact, it has proved difficult even to come close. The sheer quantity of nerve cells in the brain is enough to daunt even the most ambitious computer engineer. Many billions of neurons make up a structure weighing just 1.3 kg in the average adult. However, it is not the number of cells that is the most astounding thing about the brain but its ability to allow the human intellect to flourish by guiding our behaviour and thoughts.

We turn now to a consideration of the particular structures of the brain and the primary functions to which they are related. However, a caution is in order. Although we'll discuss specific areas of the brain in relation to specific behaviours, this approach is an oversimplification. No simple one-to-one correspondence exists between a distinct part of the brain and a particular behaviour. Instead, behaviour is produced by complex interconnections among sets of neurons in many areas of the brain: Our behaviour, emotions, thoughts, hopes, and dreams are produced by a variety of neurons throughout the nervous system working in concert.

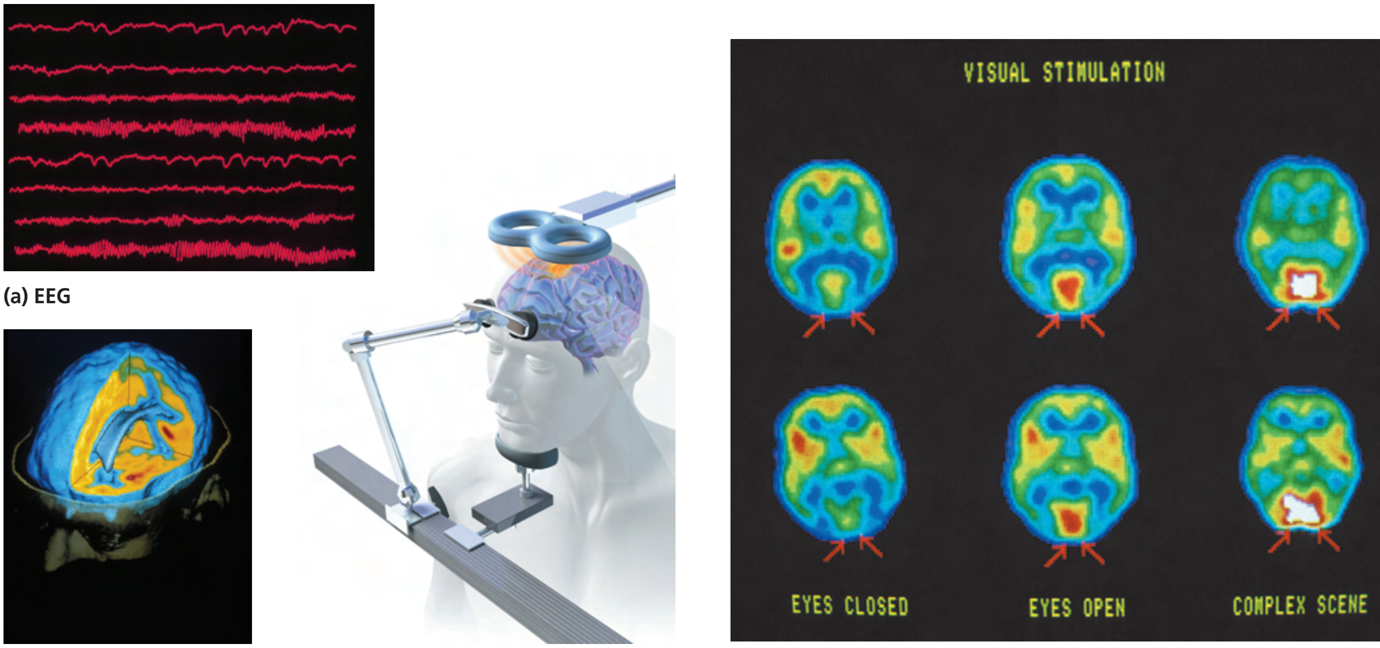


The brain (shown here in cross section) may not be much to look at, but it represents one of the great marvels of human development. Why do most scientists believe that it will be difficult, if not impossible, to duplicate the brain's abilities?

STUDYING THE BRAIN'S STRUCTURE AND FUNCTIONS: SPYING ON THE BRAIN

The brain has posed a continual challenge to those who would study it. For most of history, its examination was possible only after an individual had died. Only then could the skull be opened and the brain cut into without serious injury. Although informative, this procedure could hardly tell us much about the functioning of the healthy brain.

Today, however, brain-scanning techniques provide a window into the living brain. Using these techniques, investigators can take a "snapshot" of the internal workings of the brain without having to cut open a person's skull. The most important scanning techniques, illustrated in Figure 1, are the electroencephalogram (EEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation imaging (TMS).



(a) EEG

(b) fMRI scan **(c) TMS apparatus** **(d) PET scan**

Figure 1

Brain scanning techniques. (a) A computer-produced EEG image. (b) The fMRI scan uses a magnetic field to provide a detailed view of brain activity on a moment-by-moment basis. (c) Transcranial magnetic stimulation (TMS), the newest type of scan, produces a momentary disruption in an area of the brain, allowing researchers to see what activities are controlled by that area. TMS also has the potential to treat some psychological disorders. (d) The PET scan displays the functioning of the brain at a given moment.

The *electroencephalogram (EEG)* records electrical activity in the brain through electrodes placed on the outside of the skull. Although traditionally the EEG could produce only a graph of electrical wave patterns, new techniques are now used to transform the brain's electrical activity into a pictorial representation of the brain that, as a result of their greater detail, allows more precise diagnosis of disorders such as epilepsy and learning disabilities.

Positron emission tomography (PET) scans show biochemical activity within the brain at a given moment. PET scans begin with the injection of a radioactive (but safe) liquid into the bloodstream, which makes its way to the brain. By locating radiation within the brain, a computer can determine which are the more active regions, providing a striking picture of the brain at work. For example, PET scans may be used in cases of memory problems, seeking to identify the presence of brain tumours (Gronholm et al., 2005; McMurtray et al., 2007).

Functional magnetic resonance imaging (fMRI) scans provide a detailed, three-dimensional computer-generated image of brain structures and activity by aiming a powerful magnetic field at the body. With fMRI scanning, it is possible to produce vivid, detailed images of the functioning of the brain.

Using fMRI scans, researchers are able to view features of less than a millimetre in size and view changes occurring in intervals of one-tenth of a second. For example, fMRI scans can show the operation of individual bundles of nerves by tracing the flow of blood, opening the way for improved diagnosis of ailments ranging from chronic back pain to nervous system disorders such as strokes, multiple sclerosis, and Alzheimer's. Scans using fMRI are routinely used in planning brain surgery, because they can help surgeons distinguish areas of the brain involved in normal and disturbed functioning. In addition, fMRI scans have become a valuable research tool in a variety of areas of psychology, ranging from better understanding thinking,

study ALERT

Remember that EEG, fMRI, PET, and TMS differ in terms of whether they examine brain *structures* or brain *functioning.*

and memory to learning about the development of language (Knops et al., 2005; Mazard et al., 2005; Quenot et al., 2005). Canadians may be especially interested in research on the bilingual brain given the country's two official languages. For instance, do fMRI scans differ when a subject is speaking their native tongue versus a second language? Module 22 in Chapter 7 includes detailed research on the different cortical areas of the brain involved in native and second languages (Kim, Relkin, Lee, & Hirsch, 1997)

Transcranial magnetic stimulation (TMS) is one of the newest types of scans. By exposing a tiny region of the brain to a strong magnetic field, TMS causes a momentary interruption of electrical activity. Researchers then are able to note the effects of this interruption on normal brain functioning. The procedure is sometimes called a "virtual lesion" because it produces effects analogous to what would occur if areas of the brain were physically cut. The enormous advantage of TMS, of course, is that the virtual cut is only temporary.

In addition to identifying areas of the brain that are responsible for particular functions, TMS has the potential to treat certain kinds of psychological disorders, such as depression and schizophrenia, by shooting brief magnetic pulses through the brain. Also, TMS might be used on patients who have suffered brain damage due to a stroke. TMS has the potential to activate undamaged areas of the brain to take over the functions of the damaged areas (Fitzgerald & Daskalakis, 2008; Rado, Dowd, & Janicak, 2008; Pallanti & Bernardi, 2009).

Future discoveries may yield even more sophisticated methods of examining the brain. For example, the emerging field of *optogenetics* involves genetic engineering and the use of special types of light to view individual circuits of neurons (Miesenbock, 2008; Gradinaru et al., 2009).

Advances in our understanding of the brain also are paving the way for the development of new methods for harnessing the brain's neural signals. We consider some of these intriguing findings in the *Applying Psychology in the Real World* box.

Although the cerebellum is involved in several intellectual functions, its main duty is to control balance, constantly monitoring feedback from the muscles to coordinate their placement, movement, and tension. Do you think the cerebellum is under conscious or automatic control as people negotiate difficult balancing tasks?

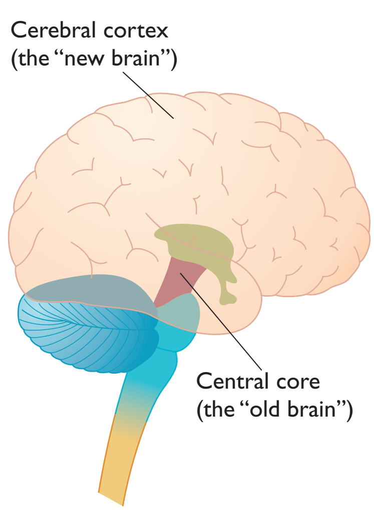


Figure 2

The major divisions of the brain: the cerebral cortex and the central core. (Source: Seeley, Stephens, & Tate, 2000.)

Central core: The "old brain," which controls basic functions such as eating and sleeping and is common to all vertebrates.

Cerebellum (ser uh BELL um): The part of the brain that controls bodily balance.

THE CENTRAL CORE: OUR "OLD BRAIN"

Although the capabilities of the human brain far exceed those of the brain of any other species, humans share some basic functions, such as breathing, eating, and sleeping, with more primitive animals. Not surprisingly, those activities are directed by a relatively primitive part of the brain. A portion of the brain known as the **central core** (see Figure 2) is quite similar in all vertebrates (species with backbones). The central core is sometimes referred to as the "old brain" because its evolution can be traced back some 500 million years to primitive structures found in nonhuman species.

If we were to move up the spinal cord from the base of the skull to locate the structures of the central core of the brain, the first part we would come to would be the *hindbrain*, which contains the *medulla*, pons, and cerebellum (see Figure 3 on page 68). The medulla controls a number of critical body functions, the most important of which are breathing and heartbeat. The *pons* comes next, joining the halves of the cerebellum, which lies adjacent to it. Containing large bundles of nerves, the pons acts as a transmitter of motor information, coordinating muscles and integrating movement between the right and left halves of the body. It is also involved in regulating sleep.

The **cerebellum** is found just above the medulla and behind the pons. Without the help of the cerebellum we would be unable to walk a straight line without staggering and lurching forward, for it is the job of the cerebellum to control bodily balance. It constantly monitors feedback from the muscles to coordinate their placement, movement, and tension. In fact, drinking too much alcohol seems to depress the activity of the cerebellum, leading to the unsteady gait and movement characteristic of drunkenness. The cerebellum is also involved in several intellectual functions, ranging from the analysis and coordination of sensory information to problem solving (Bower & Parson, 2003; Paquier & Mariën, 2005; Vandervert, Schimpf, & Liu, 2007).

Applying PSYCHOLOGY in the Real World

Mind Reading: Harnessing Brainpower to Improve Lives

A baggage screener at Toronto Pearson International Airport is looking at his nine-hundredth bag of the day. Just as his attention begins to wander, an alarm sounds, reminding him that he needs to focus more carefully. While this is happening, an air controller in the control tower, working an overtime shift, begins to feel sleepy. At that very moment, a buzzer sounds, jolting her to full attention.

Although for the moment this scenario remains the stuff of fiction, it may soon become a reality. According to researchers working in a new field called *neuroergonomics*, innovative brain imaging technologies will soon allow employers to anticipate when wandering attention or fatigue may impair workers' performance. Neuroergonomics combines neuroscience and ergonomics, a field that examines how objects and environments can best be designed to make use of human capabilities (Parasuraman & Rizzo, 2005).

The main stumbling block to applying neuroergonomics to job situations is the awkward nature of brain scanning devices. Most now require that scans be carried out in large, body-encompassing equipment. However, more sophisticated devices are on the horizon, such as near infrared spectroscopy (NIRS), which makes use of laser optics and requires only a headpiece during a scan (Huff, 2004).

Neuroscientists are also developing techniques whereby brain waves can be harnessed to activities outside the mind. Even now, it is possible for people to control computers by using only their thoughts. For example, using EEG scanning techniques that react to the pattern of brain waves originating in the brain, one patient who suffered from paralysis learned to boost and curtail certain types of brain waves. After hundreds of hours of practice, he was able to select letters that appeared on a video screen. By stringing letters together, he could spell out messages. The process, which makes use of brain waves called slow cortical potentials, permitted the patient to communicate effectively for the first time in years. Although the method is slow and tedious—the patient can produce only about two characters per minute—it holds great promise (Mitchener, 2001; Hinterberger, Birbaumer, & Flor, 2005).

As our understanding of the meaning of brain wave patterns becomes more sophisticated, significant privacy issues are likely to emerge. Conceivably, the Canadian Forces could screen soldiers for disloyalty, or prison authorities could screen for potential violence in prisoners up for parole. Police could use "brain profiling" to search suspects for brain wave patterns indicative of an inclination to violence. Employers might use brain scans to weed out job applicants who are dishonest. Such possibilities, once seen as merely theoretical, may need to be addressed within the next few years (Goldberg, 2003; Ross, 2003; Grezes, Frith, & Passingham, 2004; Rosen, 2005).

After extensive practise, people can learn to control a computer using only their thoughts.

Rethink Should the technology become available, do you think it would be appropriate to observe brain wave patterns of students in classes to make sure that they were paying attention to an instructor? Would it be ethical to require convicted sex offenders to have their brains monitored constantly to ensure that they don't sexually assault a child?

The **reticular formation** extends from the medulla through the pons, passing through the middle section of the brain—or *midbrain*—and into the front-most part of the brain, called the *forebrain*. Like an ever-vigilant guard, the reticular formation is made up of groups of nerve cells that can activate other parts of the brain immediately to produce general bodily arousal. If, for example, we are startled by a loud noise, the reticular formation can prompt a heightened state of awareness to

Reticular formation: The part of the brain extending from the medulla through the pons and made up of groups of nerve cells that can immediately activate other parts of the brain to produce general bodily arousal.

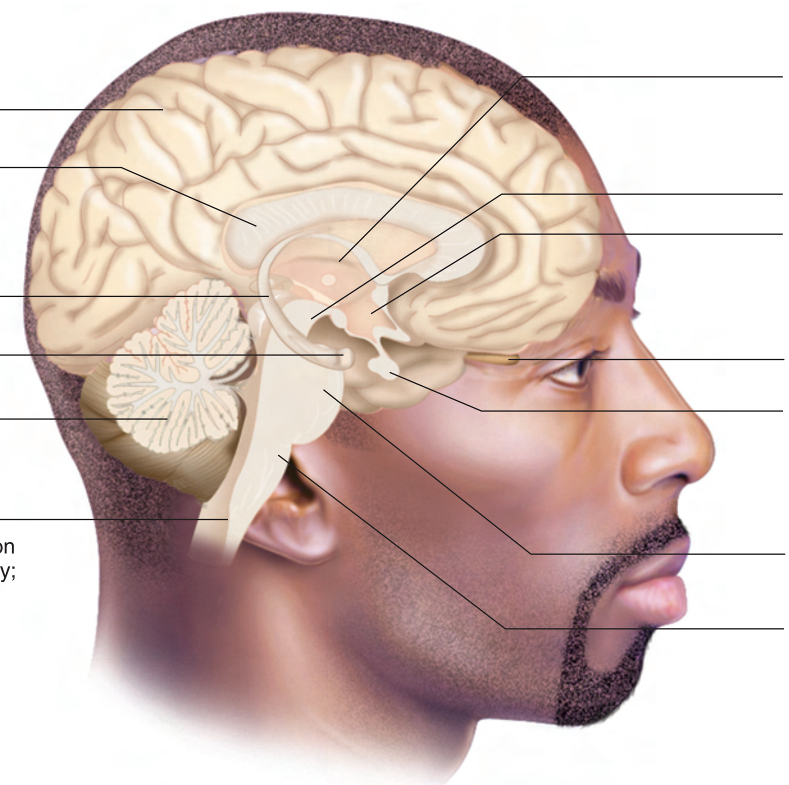


Figure 3

The major structures in the brain. (Source: Brooker, Widmaier, Graham, & Stiling, 2008.)

determine whether a response is necessary. The reticular formation serves a different function when we are sleeping, seeming to filter out background stimuli to allow us to sleep undisturbed.

Hidden within the forebrain, the **thalamus** acts primarily as a relay station for information about the senses. Messages from the eyes, ears, and skin travel to the thalamus to be communicated upward to higher parts of the brain. The thalamus also integrates information from higher parts of the brain, sorting it out so that it can be sent to the cerebellum and medulla.

The **hypothalamus** is located just below the thalamus. Although tiny—about the size of a fingertip—the hypothalamus plays an extremely important role. One of its major functions is to maintain *homeostasis*, a steady internal environment for the body. The hypothalamus helps provide a constant body temperature and monitors the amount of nutrients stored in the cells. A second major function is equally important: The hypothalamus produces and regulates behaviour that is critical to the basic survival of the species, such as eating, self-protection, and sex.

Thalamus: The part of the brain located in the middle of the central core that acts primarily to relay information about the senses.

Hypothalamus: A tiny part of the brain, located below the thalamus, that maintains homeostasis and produces and regulates vital behaviour, such as eating, drinking, and sexual behaviour.

THE LIMBIC SYSTEM: BEYOND THE CENTRAL CORE

In an eerie view of the future, some science fiction writers have suggested that people someday will routinely have electrodes implanted in their brains. Those electrodes will permit them to receive tiny shocks that will produce the sensation of pleasure by stimulating certain centres of the brain. When they feel upset, people will simply activate their electrodes to achieve an immediate high.

Although far-fetched—and ultimately improbable—such a futuristic fantasy is based on fact. The brain does have pleasure centres in several areas, including some in the **limbic system**. Consisting of a series of doughnut-shaped structures that include the *amygdala*, *hippocampus*, and *fornix*, the limbic system borders the top of the central core and has connections with the cerebral cortex (see Figure 4).

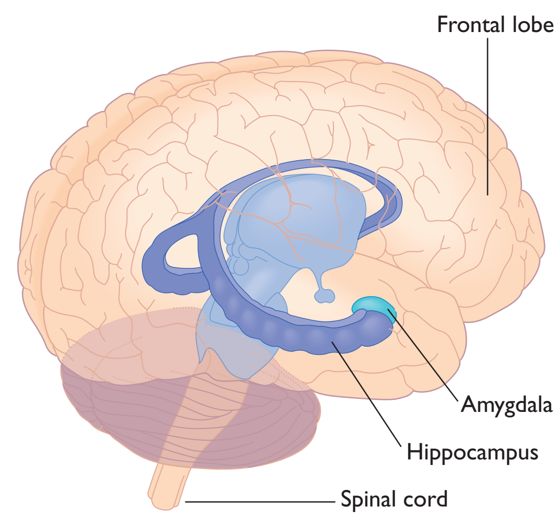


Figure 4

The limbic system consists of a series of doughnut-shaped structures that are involved in self-preservation, learning, memory, and the experience of pleasure.

The structures of the limbic system jointly control a variety of basic functions relating to emotions and self-preservation, such as eating, aggression, and reproduction. Injury to the limbic system can produce striking changes in behaviour. Such injuries can turn animals that are usually docile and tame into belligerent savages. Conversely, animals that are usually wild and uncontrollable may become meek and obedient following injury to the limbic system (Bedard & Parsinger, 1995; Gontkovsky, 2005).

Research examining the effects of mild electric shocks to parts of the limbic system and other parts of the brain has produced some thought-provoking findings (Olds & Milner, 1954; Olds & Fobes, 1981). In one experiment, rats that pressed a bar received mild electric stimulation through an electrode implanted in their brains, which produced pleasurable feelings. Even starving rats on their way to food would stop to press the bar as many times as they could. Some rats would actually stimulate themselves literally thousands of times an hour—until they collapsed with fatigue (Routtenberg & Lindy, 1965; Fountas & Smith, 2007).

The extraordinarily pleasurable quality of certain kinds of stimulation has also been experienced by humans, who, as part of the treatment for certain kinds of brain disorders, have received electrical stimulation to certain areas of the limbic system. Although at a loss to describe just what it feels like, these people report the experience to be intensely pleasurable, similar in some respects to sexual orgasm.

The limbic system also plays an important role in learning and memory, a finding demonstrated in patients with epilepsy. In an attempt to stop their seizures, such patients have had portions of the limbic system removed. One unintended consequence of the surgery is that individuals sometimes have difficulty learning and remembering new information. In one case, a patient who had undergone surgery was unable to remember where he lived, although he had resided at the same address for eight years. Further, even though the patient was able to carry on animated conversations, he was unable, a few minutes later, to recall what had been discussed (Milner, 1966; Rich & Shapiro, 2007).

The limbic system, then, is involved in several important functions, including self-preservation, learning, memory, and the experience of pleasure. These functions are hardly unique to humans; in fact, the limbic system is sometimes referred to as the "animal brain" because its structures and functions are so similar to those of other mammals. To identify the part of the brain that provides the complex and subtle capabilities that are uniquely human, we need to turn to another structure—the cerebral cortex.

THE CEREBRAL CORTEX: OUR "NEW BRAIN"

As we have proceeded up the spinal cord and into the brain, our discussion has centred on areas of the brain that control functions similar to those found in less sophisticated organisms. But where, you may be asking, are the portions of the brain that enable humans to do what they do best and that distinguish humans from all other animals? Those unique features of the human brain—indeed, the very capabilities that allow you to come up with such a question in the first place—are embodied in the ability to think, evaluate, and make complex judgments. The principal location of these abilities, along with many others, is the **cerebral cortex**.

The cerebral cortex is referred to as the "new brain" because of its relatively recent evolution. It consists of a mass of deeply folded, rippled, convoluted tissue. Although only about 2 mm thick, it would, if flattened out, cover an area more than 0.69 m^2. This

Limbic system: The part of the brain that controls eating, aggression, and reproduction.

Cerebral cortex: The "new brain," responsible for the most sophisticated information processing in the brain; contains four lobes.

configuration allows the surface area of the cortex to be considerably greater than it would be if it were smoother and more uniformly packed into the skull. The uneven shape also permits a high level of integration of neurons, allowing sophisticated information processing.

The cortex has four major sections called **lobes**. If we take a side view of the brain, the *frontal lobes* lie at the front centre of the cortex and the *parietal lobes* lie behind them. The *temporal lobes* are found in the lower centre portion of the cortex, with the *occipital lobes* lying behind them. These four sets of lobes are physically separated by deep grooves called sulci. Figure 5 shows the four areas.

Another way to describe the brain is in terms of the functions associated with a particular area. Figure 5 also shows the specialized regions within the lobes related to specific functions and areas of the body. Three major areas are known: the motor areas, the sensory areas, and the association areas. Although we will discuss these areas as though they were separate and independent, keep in mind that this is an oversimplification. In most instances, behaviour is influenced simultaneously by several structures and areas within the brain, operating interdependently. To give one example, people use different areas of the brain when they create sentences (a verbal task) compared with when they improvise musical tunes. Furthermore, when people suffer brain injury, uninjured portions of the brain can sometimes take over the functions that were previously handled by the damaged area. (Also see *PsychWork* on page 73.) In short, the brain is extraordinarily adaptable (Sacks, 2003; Boller, 2004; Brown, Martinez, & Parson, 2006).

Lobes: The four major sections of the cerebral cortex: frontal, parietal, temporal, and occipital.

Motor area: The part of the cortex that is largely responsible for the body's voluntary movement.

The Motor Area of the Cortex

If you look at the frontal lobe in Figure 5, you will see a shaded portion labelled **motor area**. This part of the cortex is largely responsible for the body's voluntary movement. Every portion of the motor area corresponds to a specific locale within the body. If we

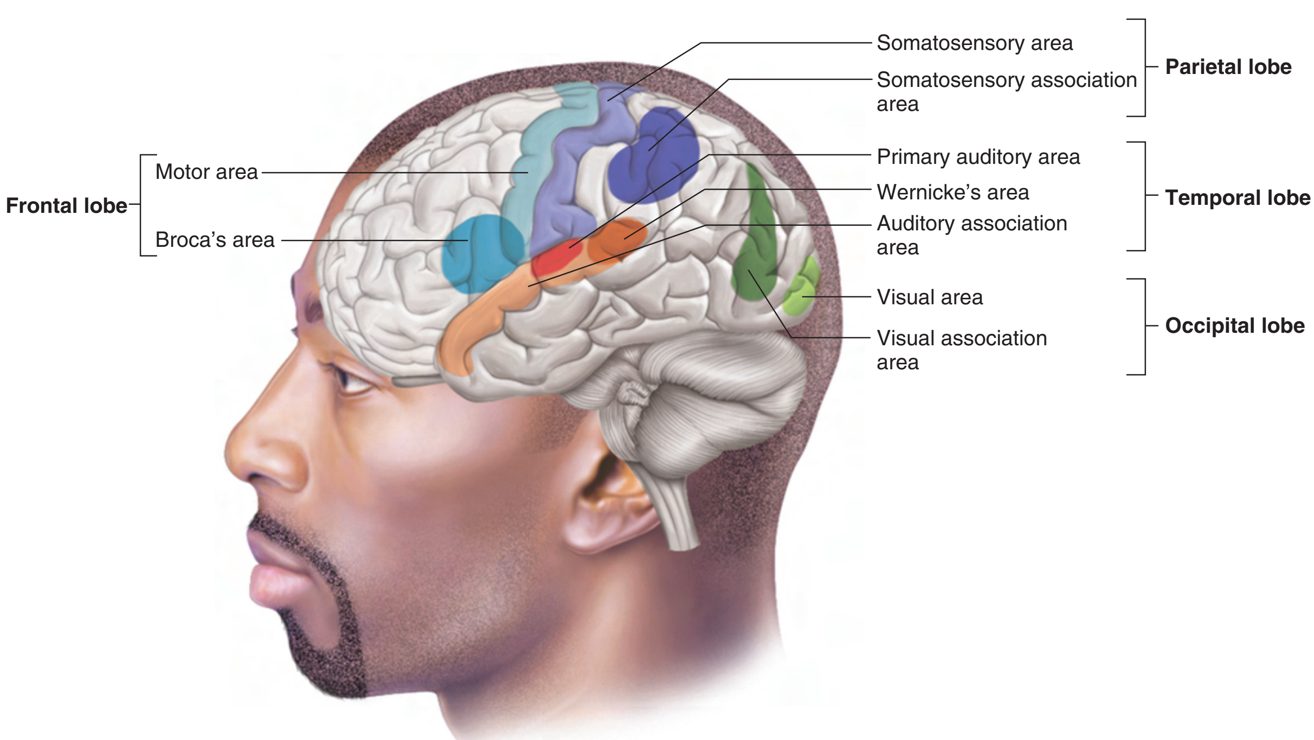


Figure 5

The cerebral cortex of the brain. The major physical structures of the cerebral cortex are called lobes. This figure also illustrates the functions associated with particular areas of the cerebral cortex. Are any areas of the cerebral cortex present in nonhuman animals?

were to insert an electrode into a particular part of the motor area of the cortex and apply mild electrical stimulation, there would be involuntary movement in the corresponding part of the body. If we moved to another part of the motor area and stimulated it, a different part of the body would move.

The motor area is so well mapped that researchers have identified the amount and relative location of cortical tissue used to produce movement in specific parts of the human body. For example, the control of movements that are relatively large scale and require little precision, such as the movement of a knee or a hip, is centred in a very small space in the motor area. In contrast, movements that must be precise and delicate, such as facial expressions and finger movements, are controlled by a considerably larger portion of the motor area.

In short, the motor area of the cortex provides a guide to the degree of complexity and the importance of the motor capabilities of specific parts of the body. It may do even more, in fact, increasing evidence shows that not only does the motor cortex control different parts of the body, but it may also direct body parts into complex postures, such as the stance of a football centre just before the ball is snapped to the quarterback or a swimmer standing at the edge of a diving board (Graziano, Taylor, & Moore, 2002; Dessing et al., 2005).

Figure 6

The greater the amount of tissue in the somatosensory area of the brain that is related to a specific body part, the more sensitive is that body part. If the size of our body parts reflected the corresponding amount of brain tissue, we would look like this strange creature.

Ultimately, movement, like other behaviour, is produced through the coordinated firing of a complex variety of neurons in the nervous system. The neurons that produce movement are linked in elabourate ways and work closely together.

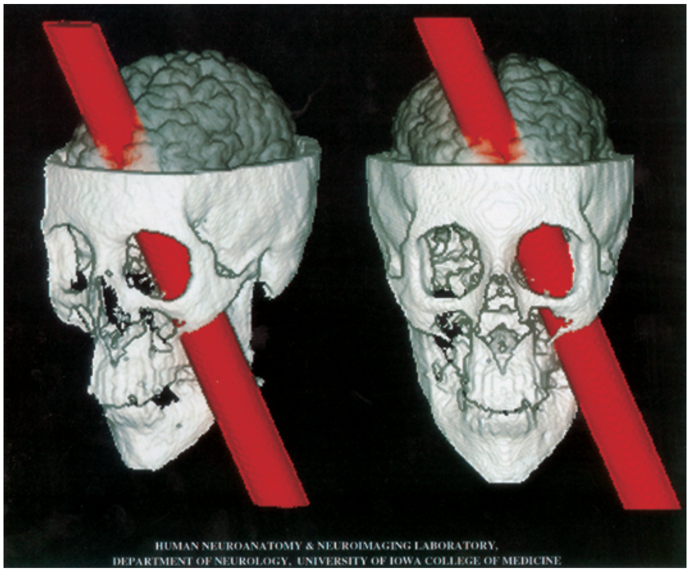
The Sensory Area of the Cortex

Given the one-to-one correspondence between the motor area and body location, it is not surprising to find a similar relationship between specific portions of the cortex and the senses. The **sensory area** of the cortex includes three regions: one that corresponds primarily to body sensations (including touch and pressure), one relating to sight, and a third relating to sound. For instance, the *somatosensory area* encompasses specific locations associated with the ability to perceive touch and pressure in a particular area of the body. As with the motor area, the amount of brain tissue related to a particular location on the body determines the degree of sensitivity of that location: the greater the area devoted to a specific area of the body within the cortex, the more sensitive that area of the body. As you can see from the weird-looking individual in Figure 6, parts such as the fingers are related to proportionally more area in the somatosensory area and are the most sensitive.

The senses of sound and sight are also represented in specific areas of the cerebral cortex. An *auditory area* located in the temporal lobe is responsible for the sense of hearing. If the auditory area is stimulated electrically, a person will hear sounds such as clicks or hums. It also appears that particular locations within the auditory area respond to specific pitches (Hudspeth, 2000; Brown & Martinez, 2007; Hyde, Peretz, & Zatorre, 2008; Bizley et al., 2009).

The visual area in the cortex, located in the occipital lobe, responds in the same way to electrical stimulation. Stimulation by electrodes produces the experience of flashes of light or colours, suggesting that the raw sensory input of images from the eyes is received in this area of the brain and transformed into meaningful stimuli. The visual area provides another example of how areas of the brain are intimately related to specific areas of the body: Specific structures in the eye are related to a particular part of the cortex—with, as you might guess, more area of the brain given to the most sensitive portions of the retina (Wurtz & Kandel, 2000; Stenbacka & Vanni, 2007).

Sensory area: The site in the brain of the tissue that corresponds to each of the senses, with the degree of sensitivity related to the amount of tissue.



A model of the injury sustained by Phineas Gage.

Association Areas of the Cortex

> Twenty-five-year-old Phineas Gage, a railroad employee, was blasting rock one day in 1848 when an accidental explosion punched a 3-foot-long [1-m-long] spike, about an inch [almost 3 cm] in diameter, completely through his skull. The spike entered just under his left cheek, came out the top of his head, and flew into the air. Gage immediately suffered a series of convulsions, yet a few minutes later was talking with rescuers. In fact, he was able to walk up a long flight of stairs before receiving any medical attention. Amazingly, after a few weeks his wound healed, and he was physically close to his old self again. Mentally, however, there was a difference: Once a careful and hard-working person, Phineas now became enamored with wild schemes and was flighty and often irresponsible. As one of his physicians put it, "Previous to his injury, though untrained in the schools, he possessed a well-balanced mind, and was looked upon by those who knew him as a shrewd, smart businessman, very energetic and persistent in executing all his plans of operation. In this regard his mind was radically changed, so decidedly that his friends and acquaintances said he was 'no longer Gage'" (Harlow, 1869, p. 14).

What had happened to the old Gage? Although there is no way of knowing for sure—science being what it was in the 1800s—we can speculate that the accident may have injured the region of Gage's cerebral cortex known as the **association areas**, which generally are considered to be the site of higher mental processes such as thinking, language, memory, and speech (Rowe et al., 2000).

The association areas make up a large portion of the cerebral cortex and consist of the sections that are not directly involved in either sensory processing or directing movement. Most of our understanding of the association areas comes from patients who, like Phineas Gage, have suffered some type of brain injury. In some cases, the injury stemmed from natural causes, such as a tumour or a stroke, either of which would block certain blood vessels in the cerebral cortex. In other cases, accidental causes were the culprits, as was true of Gage. In any event, damage to these areas can result in unusual behavioural changes, indicating the importance of the association areas to normal functioning (Gannon et al., 1998; Macmillan, 2000).

Gage's case provides evidence that there are specialized areas for making rational decisions. When those areas are damaged, people undergo personality changes that affect their ability to make moral judgments and process emotions. At the same time, people with damage in those areas can still be capable of reasoning logically, performing calculations, and recalling information (Damasio, 1999).

Injuries to other parts of the association areas can produce a condition known as *apraxia*. Apraxia occurs when an individual is unable to integrate activities in a rational or logical manner. The disorder is most evident when people are asked to carry out a sequence of behaviours requiring a degree of planning and foresight, suggesting that the association areas act as "master planners," that is, organizers of actions.

Injuries to the association areas of the brain can also produce aphasia, problems with language. In *Broca's aphasia* (caused by damage to the part of the brain first identified by a French physician, Paul Broca, in 1861), speech becomes halting, laborious, and often ungrammatical. The speaker is unable to find the right words in a kind of tip-of-the-tongue phenomenon that we all experience from time to time. People with aphasia, though, grope for words almost constantly, eventually blurting out a kind of "verbal telegram." A phrase like "I put the book on the table" comes out as "I . . . put . . . book . . . table" (Kearns, 2005).

Association areas: One of the major regions of the cerebral cortex; the site of the higher mental processes, such as thought, language, memory, and speech.

Wernicke's aphasia is a disorder named for Carl Wernicke, who identified it in the 1870s. Wernicke's aphasia produces difficulties both in understanding others' speech and in the production of language. The disorder is characterized by speech that sounds fluent but makes no sense. For instance, one patient, asked what brought him to a hospital, gave this rambling reply: "Boy, I'm sweating, I'm awful nervous, you know, once in a while I get caught up, I can't mention the tarripoi, a month ago, quite a little, I've done a lot well, I impose a lot, while, on the other hand, you know what I mean, I have to run around, look it over, trebbin and all that sort of stuff" (Gardner, 1975, p. 68).

Foreign accent syndrome is another unusual disorder that originates from injuries to association areas of the brain. Karin Humphreys, a cognitive psychologist specializing in psycholinguistics at McMaster University in Hamilton, Ontario, studies this rare syndrome. Foreign accent syndrome is an acquired brain injury resulting in articulation errors that sound like a "foreign accent." A recent case involved an extraordinary transformation of a speaker's accent from Southern Ontario to a distinctive Atlantic Canadian accent (Naidoo, Warriner, Oczkowski, Sévigny, & Humphreys, 2008).

NEUROPLASTICITY AND THE BRAIN

> Shortly after he was born, Jacob Stark's arms and legs started jerking every 20 minutes. Weeks later he could not focus his eyes on his mother's face. The diagnosis: uncontrollable epileptic seizures involving his entire brain.
>
> His mother, Sally Stark, recalled: "When Jacob was 2½ months old, they said he would never learn to sit up, would never be able to feed himself. . . . They told us to take him home, love him, and find an institution. (Blakeslee, 1992: C3)

Instead, Jacob had brain surgery when he was five months old in which physicians removed 20 percent of his brain. The operation was a complete success. Three years later Jacob seemed normal in every way, with no sign of seizures.

The surgery that helped Jacob was based on the premise that the diseased part of his brain was producing seizures throughout the brain. Surgeons reasoned that if they removed the misfiring portion, the remaining parts of the brain, which appeared intact in PET scans, would take over. They correctly bet that Jacob could still lead a normal life after surgery, particularly because the surgery was being done at so young an age.

PsychWork

REHABILITATION COUNSELLOR

Name: Monique J. Tremaine
Position: Rehabilitation Counsellor
Education: Honours BSc in Biopsychology, University of Ottawa; MA in Clinical Neuropsychology, University of Windsor

Rehabilitation counsellor Monique Tremaine helps individuals who have suffered severe brain injury regain as much normal functioning as possible. She does this by systematically assessing patients' problems, providing psychological and behavioural treatment, and ensuring that the treatment is state-of-the-art and is grounded in evidence gleaned from research. According to Tremaine, her work requires an understanding of the structure of the brain and nervous system as well as expertise in clinical psychology in order to understand how brain injury affects emotion, function, and behaviour. "Sudden acquired or traumatic brain injury can impact many aspects of an individual's life, including their personality, cognition, sense of physical well-being, family roles, and occupational functioning," she noted. "It is my role to communicate such changes to a multidisciplinary staff, to the patient, and to the family to develop a comprehensive treatment plan."

study ALERT

Remember that *neuroplasticity* is the reorganization of existing neuronal connections, whereas *neurogenesis* is the creation of new neurons.

The success of Jacob's surgery illustrates that the brain has the ability to shift functions to different locations after injury to a specific area or in cases of surgery. But equally encouraging are some new findings about the *regenerative* powers of the brain and nervous system.

Scientists have learned in recent years that the brain continually reorganizes itself in a process termed **neuroplasticity**. Although for many years conventional wisdom held that no new brain cells are created after childhood, new research finds otherwise. Not only do the interconnections between neurons become more complex throughout life, but it now appears that new neurons are also created in certain areas of the brain during adulthood—a process called **neurogenesis**. Each day, thousands of new neurons are created, especially in areas of the brain related to learning and memory (Jang, You, & Ahn, 2007; Poo & Isaacson, 2007; Shors, 2009).

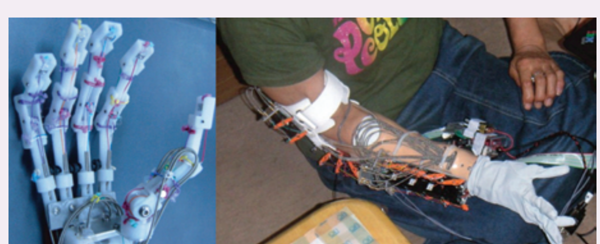
The ability of neurons to renew themselves during adulthood has significant implications for the potential treatment of disorders of the nervous system (see Figure 7). For example, drugs that trigger the development of new neurons might be used to counter such diseases as Alzheimer's, which are produced when neurons die (Tsai, Tsai, & Shen, 2007; Eisch et al., 2008; Waddell & Shors, 2008).

Furthermore, specific experiences can modify the way in which information is processed. For example, if you learn to read Braille, the amount of tissue in your

NEUROSCIENCE IN YOUR LIFE: The Plastic Brain

Figure 7

The brain is incredibly plastic, meaning that it can change structurally (through changing connections between neurons) and chemically (through changing levels of neurotransmitters and hormones) throughout our lifetime. This plasticity can also be used to adapt to new situations. For example, it can reorganize how it represents the motor system when limbs are lost. (a) Here we see how the brain learns to respond and control a new artificial robotic hand. In the brain scans in (b) and (c), we see the areas responsible for hand movement. They appear in red and yellow. The first scan (b) shows the activation in the motor and parietal cortex before the person has used the robotic hand. The second scan (c) shows greater activation after the person has used it for a month, demonstrating the brain's ability to alter its functioning to better utilize the new prosthetic hand. (Source: Kato et al., 2009.)



(a)

(b) (c)

Neuroplasticity: Changes in the brain that occur throughout the life span relating to the addition of new neurons, new interconnections between neurons, and the reorganization of information-processing areas.

Neurogenesis: The creation of new neurons.

cortex related to sensation in the fingertips will expand. Similarly, if you take up the violin, the area of the brain that receives messages from your fingers will grow—but only relating to the fingers that actually move across the violin's strings (Schwartz & Begley, 2002; Kolb, Gibb, & Robinson, 2003).

The future also holds promise for people who suffer from the tremors and loss of motor control produced by Parkinson's disease, although the research is mired in controversy. Because Parkinson's disease is caused by a gradual loss of cells that stimulate the production of dopamine in the brain, many investigators have reasoned that a procedure that would increase the supply of dopamine might be effective. They seem to be on the right track. When stem cells—immature cells from human fetuses that have the potential to develop into a variety of specialized cell types, depending on where they are implanted—are injected directly into the brains of Parkinson's sufferers, they take root and stimulate dopamine production. Preliminary results have been promising, with some patients showing great improvement (Korecka, Verhaagen, & Hol, 2007; Parish & Arenas, 2007; Newman & Bakay, 2008).

Stem cells thus hold great promise. When a stem cell divides, each newly created cell has the potential to be transformed into more specialized cells that have the potential to repair damaged cells. Because many of the most disabling diseases, ranging from cancer to stroke, result from cell damage, the potential of stem cells to revolutionize medicine is significant.

However, because the source of implanted stem cells typically is aborted fetuses, their use is controversial. Some critics have argued that the use of stem cells in research and treatment should be prohibited, while supporters argue that the potential benefits of the research are so great that stem cell research should be unrestricted. The issue has been politicized, and the question of whether and how stem cell research should be regulated is not clear (Rosen, 2005; Giacomini, Baylis, & Robert, 2007; Holden, 2007).

THE SPECIALIZATION OF THE HEMISPHERES: TWO BRAINS OR ONE?

The most recent development, at least in evolutionary terms, in the organization and operation of the human brain probably occurred in the last million years: a specialization of the functions controlled by the left and right sides of the brain (Hopkins & Cantalupo, 2008; MacNeilage, Rogers, & Vallortigara, 2009; Tommasi, 2009).

The brain is divided into roughly mirror-image halves. Just as we have two arms, two legs, and two lungs, we have a left brain and a right brain. Because of the way nerves in the brain are connected to the rest of the body, these symmetrical left and right halves, called **hemispheres**, control motion in—and receive sensation from—the side of the body opposite their location. The left hemisphere of the brain, then, generally controls the right side of the body, and the right hemisphere controls the left side of the body. Thus, damage to the right side of the brain is typically indicated by functional difficulties in the left side of the body.

Despite the appearance of similarity between the two hemispheres of the brain, they are somewhat different in the functions they control and in the ways they control them. Certain behaviours are more likely to reflect activity in one hemisphere than in the other. Early evidence for the functional differences between the halves of the brain came from studies of people with aphasia. Researchers found that people with the speech difficulties characteristic of aphasia tended to have physical damage to the left hemisphere of the brain. In contrast, physical abnormalities in the right hemisphere tended to produce far fewer problems with language. This finding led researchers to conclude that for most people, language is **lateralized**, or located more in one hemisphere than in the other—in this case, in the left side of the brain (Grossi et al., 1996; Ansaldo, Arguin, & Roch-Locours, 2002).

study ALERT

Although the hemispheres of the brain specialize in particular kinds of functions, the degree of specialization is not great, and the two hemispheres work interdependently.

Hemispheres: Symmetrical left and right halves of the brain that control the side of the body opposite to their location.

Lateralization: The dominance of one hemisphere of the brain in specific functions, such as language.

It now seems clear that the two hemispheres of the brain are somewhat specialized in the functions they carry out. The left hemisphere concentrates more on tasks that require verbal competence, such as speaking, reading, thinking, and reasoning. The right hemisphere has its own strengths, particularly in nonverbal areas such as the understanding of spatial relationships, recognition of patterns and drawings, music, and emotional expression. Cerebral specialization starts at a very early age. For example, even before infants under the age of one year have developed real language skills, their babbling involves left hemisphere specialization (Holowka & Petitto, 2002).

In addition, information is processed somewhat differently in each hemisphere. The left hemisphere tends to consider information sequentially, one bit at a time, whereas the right hemisphere tends to process information globally, considering it as a whole (Turkewitz, 1993; Banich & Heller, 1998; Hines, 2004).

However, it is important to keep in mind that the differences in specialization between the hemispheres are not great and that the degree and nature of lateralization vary from one person to another. If, like most people, you are right-handed, the control of language is probably concentrated more in your left hemisphere. By contrast, if you are among the 10 percent of people who are left-handed or are ambidextrous (you use both hands interchangeably), it is much more likely that the language centres of your brain are located more in the right hemisphere or are divided equally between the left and right hemispheres.

Researchers have also unearthed evidence that there may be subtle differences in brain lateralization patterns between males and females. In fact, some scientists have suggested that there are slight differences in the structure of the brain according to gender and culture. As we see next, such findings have led to a lively debate in the scientific community.

THE SPLIT BRAIN: EXPLORING THE TWO HEMISPHERES

> The patient, V.J., had suffered severe seizures. By cutting her corpus callosum, the fibrous portion of the brain that carries messages between the hemispheres, surgeons hoped to create a firebreak to prevent the seizures from spreading. The operation did decrease the frequency and severity of V.J.'s attacks. But V.J. developed an unexpected side effect: She lost the ability to write at will, although she could read and spell words aloud (Strauss, 1998, p. 287).

People like V.J., whose corpus callosum has been surgically cut to stop seizures and who are called *split-brain patients*, offer a rare opportunity for researchers investigating the independent functioning of the two hemispheres of the brain. For example, psychologist Roger Sperry—who won the Nobel Prize for his work—developed a number of ingenious techniques for studying how each hemisphere operates (Sperry, 1982; Baynes et al., 1998; Gazzaniga, 1998).

In one experimental procedure, blindfolded patients touched an object with their right hand and were asked to name it. Because the right side of the body corresponds to the language-oriented left side of the brain, split-brain patients were able to name it. However, if blindfolded patients touched the object with their left hand, they were unable to name it aloud, even though the information had registered in their brains: When the blindfold was removed, patients could identify the object they had touched. Information can be learned and remembered, then, using only the right side of the brain. (By the way, unless you've had a split-brain operation, this experiment won't work with you, because the bundle of fibres connecting the two hemispheres of a normal brain immediately transfers the information from one hemisphere to the other.)

Exploring DIVERSITY

Human Diversity and the Brain

The interplay of biology and environment in behaviour is particularly clear when we consider evidence suggesting that even in brain structure and function there are both sex and cultural differences. Let's consider sex first. Accumulating evidence seems to show intriguing differences in males' and females' brain lateralization and weight, although the nature of those differences—and even their existence—is the source of considerable controversy (Hugdahl & Davidson, 2002; Boles, 2005; Clements, Rimrodt, & Abel, 2006).

Canadian neuroscientist and behavioural psychologist Doreen Kimura adds to the controversy by using her research on sex differences in the brain to condemn preferential treatment for women in male-dominated fields such as engineering and mathematics. Kimura argues that it is natural for men and women to choose different fields based on their unique brain functioning and associated inborn strengths. Kimura believes that social policy that goes against natural gender-based differences is the most horrible kind of discrimination. Accordingly, she became the founding president of the Society of Academic Freedom and Scholarship in 1992. It is interesting to note that Kimura is a former student of Donald O. Hebb, an important Canadian figure in the history of psychology (discussed in more detail in Module 2 of Chapter 1). Kimura credits Hebb for teaching her how to think about behaviour in terms of the nervous system at McGill University in Montreal (Kimura, 1999).

Some statements can be made with reasonable confidence. For instance, most males tend to show greater lateralization of language in the left hemisphere. For them, language is clearly relegated largely to the left side of the brain. In contrast, women display less lateralization, with language abilities apt to be more evenly divided between the two hemispheres (Gur et al., 1982; Kulynych et al., 1994; Shaywitz et al., 1995). Such differences in brain lateralization may account, in part, for the superiority often displayed by females on certain measures of verbal skills, such as the onset and fluency of speech, and the fact that far more boys than girls have reading problems in elementary school (Kitterle, 1991).

Other research suggests that men's brains are somewhat bigger than women's brains even after taking differences in body size into account. In contrast, part of the *corpus callosum*, a bundle of fibres that connects the hemispheres of the brain, is proportionally larger in women than in men. Furthermore, some research suggests that in women, a higher proportion of brain neurons are actually involved in thinking compared with men (Falk et al., 1999; Gur et al., 1999; Cahill, 2005).

Men and women also may process information differently. For example, in one study, fMRI brain scans of men making judgments discriminating real from false words showed activation of the left hemisphere of the brain, whereas women used areas on both sides of the brain (Rossell et al., 2002). Similarly, PET brain scans of men and women while they are not engaged in mental activity show differences in the use of glucose (Gur et al., 1995; Gur, 1996).

The meaning of such sex differences is far from clear. Consider one possibility related to differences in the proportional size of the corpus callosum. Its greater size in women may permit stronger connections to develop between the parts of the brain that control speech. In turn, this would explain why speech tends to emerge slightly earlier in girls than in boys.

Before we rush to such a conclusion, though, it is important to consider an alternative hypothesis: The reason verbal abilities emerge earlier in girls may be that infant girls receive greater encouragement to talk than do infant boys. In turn, this greater early experience may foster the growth of certain parts of the brain. Hence, physical brain differences may be a *reflection* of social and environmental influences rather than a *cause* of the differences in men's and women's behaviour. At this point, it is impossible to confirm which of these two alternative hypotheses is correct.

The culture in which people are raised also may give rise to differences in brain lateralization. Native speakers of Japanese seem to process information regarding vowel sounds primarily in the brain's left hemisphere. In contrast, North and South Americans, Europeans, and individuals of Japanese ancestry who learn Japanese later in life handle vowel sounds principally in the right hemisphere.

The reason for this cultural difference in lateralization? One explanation is that certain characteristics of the Japanese language, such as the ability to express complex ideas by using only vowel sounds, result in the development of a specific type of brain lateralization in native speakers. Differences in lateralization may account for other dissimilarities between the ways in which native Japanese speakers and Westerners think about the world (Tsunoda, 1985; Kess & Miyamoto, 1994; Lin et al., 2005).

Becoming an Informed Consumer of PSYCHOLOGY

Learning to Control Your Heart—and Mind—Through Biofeedback

When Tammy DeMichael was involved in a horrific car accident that broke her neck and crushed her spinal cord, experts told her that she was doomed to be a quadriplegic for the rest of her life, unable to move from the neck down. But they were wrong. Not only did she regain the use of her arms, but she was able to walk 18 metres with a cane (Morrow & Wolff, 1991; Hess, Houg, & Tammaro, 2007).

The key to DeMichael's astounding recovery: **biofeedback**. Biofeedback is a procedure in which a person learns to control through conscious thought internal physiological processes such as blood pressure, heart and respiration rate, skin temperature, sweating, and the constriction of particular muscles. Although it traditionally had been thought that the heart rate, respiration rate, blood pressure, and other bodily functions are under the control of parts of the brain over which we have no influence, psychologists have discovered that these responses are actually susceptible to voluntary control (Nagai et al., 2004; Cho, Holyoak, & Cannon, 2007). In biofeedback, a person is hooked up to electronic devices that provide continuous feedback relating to the physiological response in question. For instance, a person interested in controlling headaches through biofeedback might have electronic sensors placed on certain muscles on her head and learn to control the constriction and relaxation of those muscles. Later, when she felt a headache starting, she could relax the relevant muscles and abort the pain (Andrasik, 2007; Nestoriuc et al., 2008).

In DeMichael's case, biofeedback was effective because not all of the nervous system's connections between the brain and her legs were severed. Through biofeedback, she learned how to send messages to specific muscles, "ordering" them to move. Although it took more than a year, DeMichael was successful in restoring a large degree of her mobility.

Although the control of physiological processes through the use of biofeedback is not easy to learn, it has been employed with success in a variety of ailments, including emotional problems (such as anxiety, depression, phobias, tension headaches, insomnia, and hyperactivity), physical illnesses with a psychological component (such as asthma, high blood pressure, ulcers, muscle spasms, and migraine headaches), and physical problems (such as DeMichael's injuries, strokes, cerebral palsy, and curvature of the spine) (Cho, Holyoak, & Cannon, 2007; Morone & Greco, 2007; Reiner, 2008).

In Canada, biofeedback is an unregulated, emerging sector of alternative medicine. Consequently, Health Canada does not restrict who can perform biofeedback treatment. As such, it remains the responsibility of Canadian consumers to ensure that practitioners have proper training and experience in biofeedback techniques. Take into account that biofeedback is also a complementary therapy incorporated into the practices of government regulated service providers such as psychologists, social workers, nurses, and physicians (Schwartz & Andrasik, 2005).

Biofeedback: A procedure in which a person learns to control through conscious thought internal physiological processes such as blood pressure, heart and respiration rate, skin temperature, sweating, and the constriction of particular muscles.

RECAP/EVALUATE/RETHINK

RECAP

How do researchers identify the major parts and functions of the brain?

- Brain scans take a "snapshot" of the internal workings of the brain without having to cut surgically into a person's skull. Major brain-scanning techniques include the electroencephalogram (EEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and transcranial magnetic stimulation imaging (TMS). (pp. 64–65)

What are the major parts of the brain, and for what behaviours is each part responsible?

- The central core of the brain is made up of the medulla (which controls functions such as breathing and the heartbeat), the pons (which coordinates the muscles and the two sides of the body), the cerebellum (which controls balance), the reticular formation (which acts to heighten awareness in emergencies), the thalamus (which communicates sensory messages to and from the brain), and the hypothalamus (which maintains homeostasis, or body equilibrium, and regulates behaviour related to basic survival). The functions of the central core structures are similar to those found in other vertebrates. This central core is sometimes referred to as the "old brain." Increasing evidence also suggests that male and female brains may differ in structure in minor ways. (pp. 66–68)
- The cerebral cortex—the "new brain"—has areas that control voluntary movement (the motor area); the senses (the sensory area); and thinking, reasoning, speech, and memory (the association areas). The limbic system, found on the border of the "old" and "new" brains, is associated with eating, aggression, reproduction, and the experiences of pleasure and pain. (pp. 69–71)

How do the halves of the brain operate interdependently?

- The brain is divided into left and right halves, or hemispheres, each of which generally controls the opposite side of the body. Each hemisphere can be thought of as being specialized in the functions it carries out: The left is best at verbal tasks, such as logical reasoning, speaking, and reading; the right is best at nonverbal tasks, such as spatial perception, pattern recognition, and emotional expression. (pp. 75–76)

How can an understanding of the nervous system help us find ways to alleviate disease and pain?

- Biofeedback is a procedure by which a person learns to control internal physiological processes. By controlling what were once considered involuntary responses, people are able to relieve anxiety, tension, migraine headaches, and a wide range of other psychological and physical problems. (pp. 78–79)

EVALUATE

1. Match the name of each brain scan with the appropriate description:

a. EEG
b. fMRI
c. PET

1. By locating radiation within the brain, a computer can provide a striking picture of brain activity.
2. Electrodes placed around the skull record the electrical signals transmitted through the brain.
3. Provides a three-dimensional view of the brain by aiming a magnetic field at the body.

2. Match the portion of the brain with its function:

a. medulla
b. pons
c. cerebellum
d. reticular formation

1. Maintains breathing and heartbeat
2. Controls bodily balance
3. Coordinates and integrates muscle movements
4. Activates other parts of the brain to produce general bodily arousal

3. A surgeon places an electrode on a portion of your brain and stimulates it. Immediately, your right wrist involuntarily twitches. The doctor has most likely stimulated a portion of the ______________ area of your brain.

4. Each hemisphere controls the _____________ side of the body.

5. Nonverbal realms, such as emotions and music, are controlled primarily by the ______________ hemisphere of the brain, whereas the ________________ hemisphere is more responsible for speaking and reading.

6. The left hemisphere tends to consider information ________________, whereas the right hemisphere tends to process information ________________.

RETHINK

1. Before sophisticated brain-scanning techniques were developed, behavioural neuroscientists' understanding of the brain was based largely on the brains of people who had died. What limitations would this pose, and in what areas would you expect the most significant advances once brain-scanning techniques became possible?
2. Could personal differences in people's specialization of right and left hemispheres be related to occupational success? For example, might an architect who relies on spatial skills have a different pattern of hemispheric specialization than a writer?
3. *From the perspective of an educator:* How might you use different techniques to teach reading to boys and girls based on research showing difference in male and female brains?

Answers to Evaluate Questions

1. a-2, b-3, c-1; 2. a-1, b-3, c-2, d-4; 3. motor; 4. opposite; 5. right, left; 6. sequentially, globally

KEY TERMS

association areas p. 72
biofeedback p. 78
central core p. 66
cerebellum (ser uh BELL um) p. 66
cerebral cortex p. 69
hemispheres p. 75
hypothalamus p. 68
lateralization p. 75
limbic system p. 69
lobes p. 70
motor area p. 70
neurogenesis p. 74
neuroplasticity p. 74
reticular formation p. 67
sensory area p. 71
thalamus p. 68

Module 7

The Nervous System and the Endocrine System: Communicating Within the Body

In light of the complexity of individual neurons and the neurotransmission process, it should come as no surprise that the connections and structures formed by the neurons are complicated. Because each neuron can be connected to 80,000 other neurons, the total number of possible connections is astonishing. For instance, estimates of the number of neural connections within the brain fall in the neighbourhood of 10 quadrillion—a 1 followed by 16 zeros—and some experts put the number even higher. However, connections among neurons are not the only means of communication within the body; as we'll see, the endocrine system, which secretes chemical messages that circulate through the blood, also communicates messages that influence behaviour and many aspects of biological functioning (Kandel, Schwartz, & Jessell, 2000; Forlenza & Baum, 2004; Boahen, 2005).

Key Concepts

How are the structures of the nervous system linked?

How does the endocrine system affect behaviour?

study ALERT

Use Figures 1 and 2 to learn the components of the central and peripheral nervous systems.

THE NERVOUS SYSTEM

Whatever the actual number of neural connections, the human nervous system has both logic and elegance. We turn now to a discussion of its basic structures.

The Central and Peripheral Nervous Systems

As you can see from the schematic representation in Figure 1, the nervous system is divided into two main parts: the central nervous system and the peripheral nervous system. The **central nervous system (CNS)** is composed of the brain and spinal cord. The **spinal cord**, which is about the thickness of a pencil, contains a bundle of neurons that leaves the brain and runs down the length of the back (see Figure 2). As you can see in Figure 1, the spinal cord is the primary means for transmitting messages between the brain and the rest of the body.

However, the spinal cord is not just a communication channel. It also controls some simple behaviours on its own, without any help from the brain. An example is the way the knee jerks forward when it is tapped with a rubber hammer. This behaviour is a type of **reflex**, an automatic, involuntary response to an incoming stimulus. A reflex is also at work when you touch a hot stove and immediately withdraw your hand. Although the brain eventually analyzes and reacts to the situation ("Ouch—hot stove—pull away!"), the initial withdrawal is directed only by neurons in the spinal cord.

Three kinds of neurons are involved in reflexes. **Sensory (afferent) neurons** transmit information from the perimeter of the body to the central nervous system. **Motor (efferent) neurons** communicate information from the nervous system to muscles and glands. **Interneurons** connect sensory and motor neurons, carrying messages between the two.

Central nervous system (CNS): The part of the nervous system that includes the brain and spinal cord.

Spinal cord: A bundle of neurons that leaves the brain and runs down the length of the back and is the main means for transmitting messages between the brain and the body.

Reflex: An automatic, involuntary response to an incoming stimulus.

Sensory (afferent) neurons: Neurons that transmit information from the perimeter of the body to the central nervous system.

Motor (efferent) neurons: Neurons that communicate information from the nervous system to muscles and glands.

Interneurons: Neurons that connect sensory and motor neurons, carrying messages between the two.

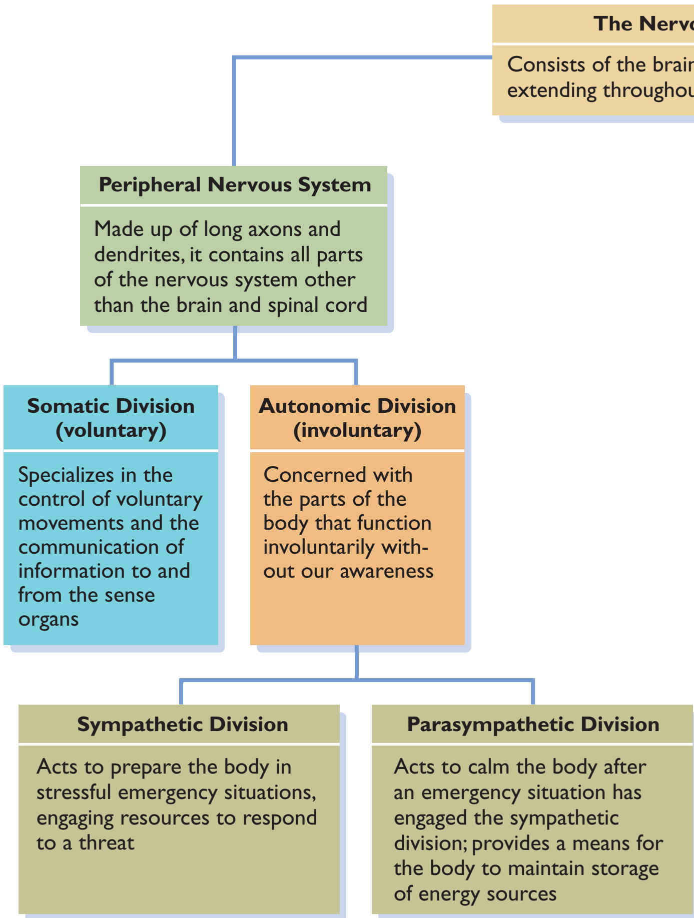


Figure 1

A schematic diagram of the structure and functions of the parts of the nervous system.

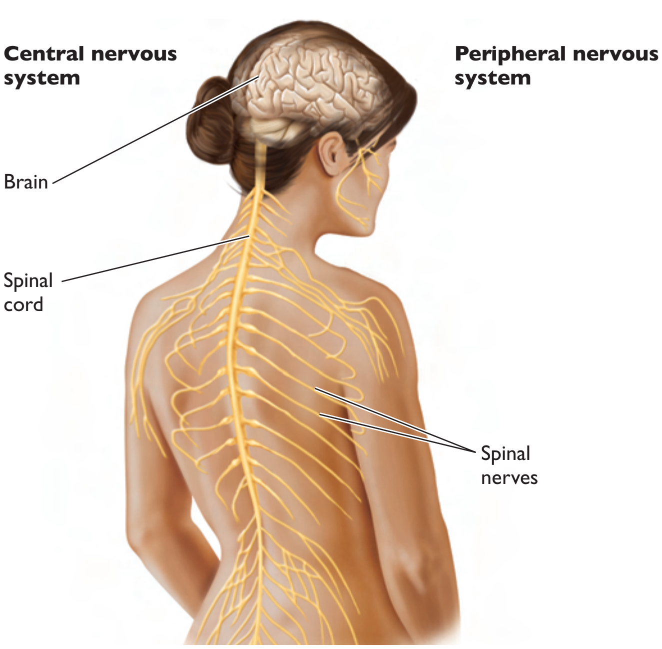


Figure 2

The central nervous system, consisting of the brain and spinal cord, and the peripheral nervous system encompasses the network of nerves connecting the brain and spinal cord to other parts of the body.

The importance of the spinal cord and reflexes is illustrated by the outcome of accidents in which the cord is injured or severed. In some cases, injury results in *quadriplegia*, a condition in which voluntary muscle movement below the neck is lost. In a less severe but still debilitating condition, *paraplegia*, people are unable to voluntarily move any muscles in the lower half of the body.

As suggested by its name, the **peripheral nervous system** branches out from the spinal cord and brain and reaches the extremities of the body. Made up of neurons with long axons and dendrites, the peripheral nervous system encompasses all the parts of the nervous system other than the brain and spinal cord. There are two major divisions—the **somatic division** and the autonomic division—both of which connect the central nervous system with the sense organs, muscles, glands, and other organs. The somatic division specializes in the control of voluntary movements—such as the motion of the eyes to read this sentence or those of the hand to turn this page—and the communication of information to and from the sense organs. On the other hand, the **autonomic division** controls the parts of the body that keep us alive—the heart, blood vessels, glands, lungs, and other organs that function involuntarily without our awareness. As you are reading at this moment, the autonomic division of the peripheral nervous system is pumping blood through your body, pushing your lungs in and out, overseeing the digestion of the meal you had a few hours ago, and so on—all without a thought or care on your part.

Activating the Divisions of the Autonomic Nervous System. The autonomic division plays a particularly crucial role during emergencies. Suppose that as you are reading you suddenly sense that a stranger is watching you through the window. As you look up, you see the glint of something that might be a knife. As confusion clouds your mind and fear overcomes your attempts to think rationally, what happens to your body? If you are like most people, you react immediately on a physiological level. Your heart rate increases, you begin to sweat, and you develop goose bumps all over your body.

The physiological changes that occur during a crisis result from the activation of one of the two parts of the autonomic nervous system: the **sympathetic division**. The sympathetic division acts to prepare the body for action in stressful situations by engaging all of the organism's resources to run away or confront the threat. This response is often called the "fight or flight" response. In contrast, the **parasympathetic division** acts to calm the body after the emergency has ended. When you find, for instance, that the stranger at the window is actually your roommate, who has lost his keys and is climbing in the window to avoid waking you, your parasympathetic division begins to predominate, lowering your heart rate, stopping your sweating, and returning your body to the state it was in before you became alarmed. The parasympathetic division also directs the body to store energy for use in emergencies. The sympathetic and parasympathetic divisions work together to regulate many functions of the body (see Figure 3). For instance, sexual arousal is controlled by the parasympathetic division but sexual orgasm is a function of the sympathetic division.

The Evolutionary Foundations of the Nervous System

The complexities of the nervous system can be better understood if we take the course of evolution into consideration. The forerunner of the human nervous system is found in the earliest simple organisms to have a spinal cord. Basically, those organisms were simple input-output devices: When the upper side of the spinal cord was stimulated by, for instance, being touched, the organism reacted with a simple response, such as jerking away. Such responses were completely a consequence of the organism's genetic makeup.

Over millions of years, the front end of the spinal cord became more specialized, and organisms became capable of distinguishing between different kinds of stimuli and responding appropriately to them. Ultimately, the front end of the spinal cord evolved into what we would consider a primitive brain. At first, it had just three parts, devoted to close stimuli (such as smell), more distant stimuli (such as sights and sounds), and the ability to maintain balance and bodily coordination. In fact, many animals, such as fish, still have a nervous system that is structured in roughly similar fashion today. In contrast, the human brain evolved from this three-part configuration into an organ that is far more complex and differentiated (Merlin, 1993).

Furthermore, the nervous system is *hierarchically organized*, meaning that relatively newer (from an evolutionary point of view) and more sophisticated regions of the brain regulate the older, and more primitive, parts of the nervous system. As we move up along the spinal cord and continue upward into the brain, then, the functions controlled by the various regions become progressively more advanced.

Why should we care about the evolutionary background of the human nervous system? The answer comes from researchers working in the area of **evolutionary psychology**, the branch of psychology that seeks to identify how behaviour is influenced and produced by our genetic inheritance from our ancestors.

Evolutionary psychologists argue that the course of evolution is reflected in the structure and functioning of the nervous system and that evolutionary factors consequently have a significant influence on our everyday behaviour. Their work, in conjunction with the research of scientists studying genetics, biochemistry, and medicine,

Peripheral nervous system: The part of the nervous system that includes the autonomic and somatic subdivisions; made up of neurons with long axons and dendrites, it branches out from the spinal cord and brain and reaches the extremities of the body.

Somatic division: The part of the peripheral nervous system that specializes in the control of voluntary movements and the communication of information to and from the sense organs.

Autonomic division: The part of the peripheral nervous system that controls involuntary movement of the heart, glands, lungs, and other organs.

Sympathetic division: The part of the autonomic division of the nervous system that acts to prepare the body for action in stressful situations, engaging all the organism's resources to respond to a threat.

Parasympathetic division: The part of the autonomic division of the nervous system that acts to calm the body after an emergency has ended.

Evolutionary psychology: The branch of psychology that seeks to identify behaviour patterns that are a result of our genetic inheritance from our ancestors.

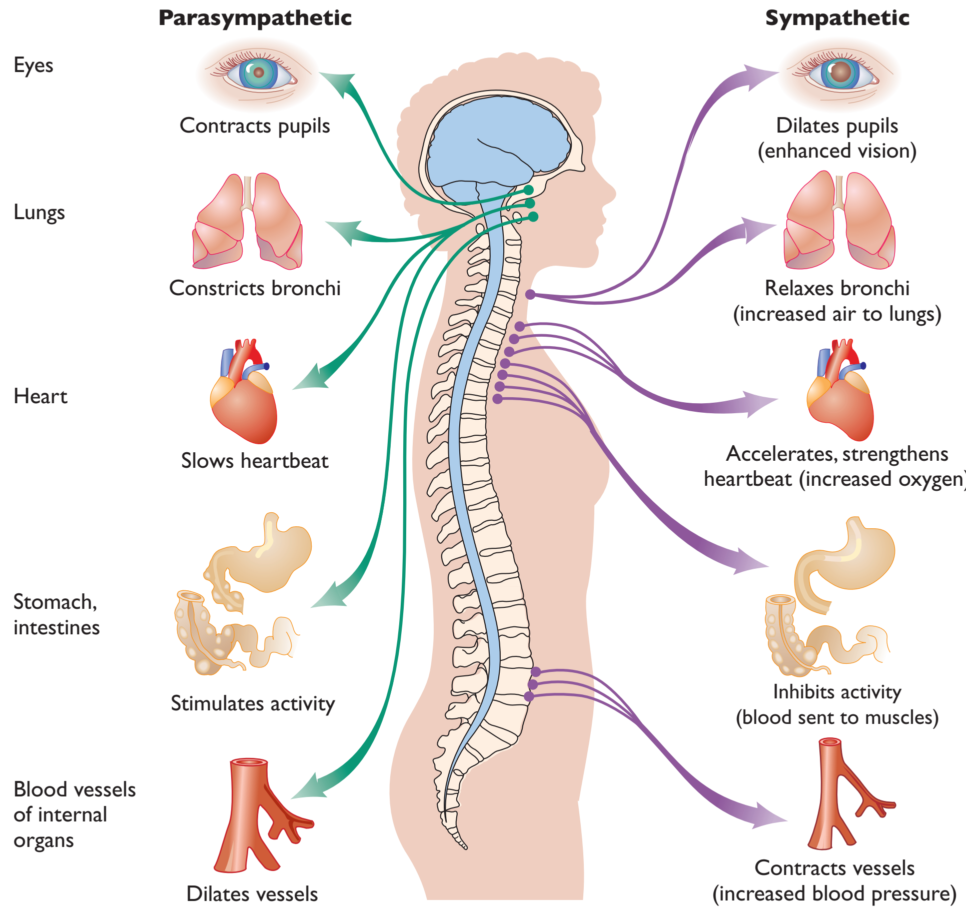


Figure 3

The major functions of the autonomic nervous system. The sympathetic division acts to prepare certain organs of the body for stressful situations, and the parasympathetic division acts to calm the body after the emergency has been passed. Can you explain why each response of the sympathetic division might be useful in an emergency?

has led to an understanding of how our behaviour is affected by heredity, our genetically determined heritage. In fact, evolutionary psychologists have spawned a new and increasingly influential field: behavioural genetics.

Behavioural Genetics

Our evolutionary heritage manifests itself not only through the structure and functioning of the nervous system but through our behaviour as well. In the view of a growing area of study, people's personality and behavioural habits are affected in part by their genetic heritage. **Behavioural genetics** studies the effects of heredity on behaviour. Behavioural genetics researchers are finding increasing evidence that cognitive abilities, personality traits, sexual orientation, and psychological disorders are determined to some extent by genetic factors (Ilies, Arvey, & Bouchard, 2006; Livesley & Jang, 2008; Vernon et al., 2008).

Behavioural genetics lies at the heart of the nature–nurture question, one of the key issues in the study of psychology. Although no one would argue that our behaviour is determined *solely* by inherited factors, evidence collected by behavioural geneticists does suggest that our genetic inheritance predisposes us to respond in particular ways to our environment, and even to seek out particular kinds of environments. For instance, research indicates that genetic factors may be related to such diverse behaviours as level of family conflict, schizophrenia, learning disabilities, and general sociability (Ball et al., 2008; Davis, Haworth, & Plomin, 2009; Lakhan & Vieira, 2009).

Furthermore, important human characteristics and behaviours are related to the presence (or absence) of particular *genes*, the inherited material that controls the transmission of traits. For example, researchers have found evidence that novelty-seeking behaviour is determined, at least in part, by a certain gene.

Behavioural genetics: The study of the effects of heredity on behaviour.

As we will consider later in the book when we discuss human development, researchers have identified some 25,000 individual genes, each of which appears in a specific sequence on a particular *chromosome*, a rod-shaped structure that transmits genetic information across generations. In 2003, after a decade of effort, researchers identified the sequence of the 3 billion chemical pairs that make up human *DNA*, the basic component of genes. Understanding the basic structure of the human *genome*—the "map" of humans' total genetic makeup—brings scientists a giant step closer to understanding the contributions of individual genes to specific human structures and functioning (Andreasen, 2005; Dale & von Schantz, 2007; Plomin & Davis, 2009).

Molecular Genetics and Psychological Disorders. Despite its relative infancy, the field of behavioural genetics has already made substantial contributions to our understanding of behaviour. One branch of behavioural genetics, *molecular genetics*, seeks to identify specific genes that are associated with behaviour and, in particular, psychological disorders. Genes that are physically close to one another on a particular chromosome tend to be linked and inherited together. By finding *genetic markers*—genes with a known location—that are linked to a disorder, scientists are beginning to learn how disorders such as schizophrenia and depression develop and can potentially be treated.

Molecular geneticists have already found that the risk of developing autism (a severe disorder that influences the development of language and effective social functioning) is increased in the presence of a gene related to early brain development. Children with this gene, a variation of the gene called *HOXA1*, are twice as likely to develop the disorder as children who do not have this variant (Hyman, 2003; Gregg et al., 2007).

Yet having the variant gene does not always lead to autism. More than 99.5 percent of people with the variant do not develop the disorder, and 60 percent of those with autism do not have the variant. It is probable that autism, like other disorders with a genetic basis, is not triggered by the presence or absence of a single, particular gene. More likely, it is produced by several genes in combination, as well as perhaps requiring the presence of certain environmental influences, such as infection or brain injury. The challenge for behaviour geneticists, then, is not only to determine what genes are responsible for particular behaviours, but also to identify the environmental triggers that activate those genes.

Recent advances in molecular genetics involve treating brain diseases with gene therapy. Dr. Max Cynader, director of the Brain Research Centre at University of British Columbia (UBC), researches the use of biotechnology to treat neurological conditions (e.g., Parkinson's disease) and psychological disorders (e.g., clinical depression). The Canadian government demonstrated their commitment to these new technologies and treatments with a $25-million contribution to brain health research on March 11, 2008 by the BC government (Skelton, 2008).

In examining the genetic roots of various behaviours, the study of behavioural genetics has stirred controversy. For instance, questions about the existence of genetic influences on criminality, intelligence, and homosexuality raise considerable emotion. Furthermore, it is unclear what the social and political consequences of discoveries in behavioural genetics would be. Might the discovery of a set of genes that cause homosexuality lead to greater or less prejudice against gays and lesbians? Would finding a strong genetic basis for criminal behaviour lead to genetic screening and restricted civil rights for individuals having "criminal" genes? Clearly, behavioural genetic discoveries could have an impact on a number of important social issues.

Behavioural Genetics, Gene Therapy, and Genetic Counselling. Behavioural genetics also holds the promise of developing new diagnostic and treatment techniques for genetic deficiencies that can lead to physical and psychological difficulties. In *gene therapy,* scientists inject genes meant to cure a particular disease into a patient's bloodstream. When the genes arrive at the site of defective genes that are producing the illness, they trigger the production of chemicals that can treat the disease (Jaffé, Prasad, & Larcher, 2006; Eberling et al., 2008; Isacson & Kordower, 2008).

The number of diseases that can be treated through gene therapy is growing, as we will see when we discuss human development. For example, gene therapy is now being used with patients suffering from cancer, leukemia, and Hodgkin's disease (Nakamura, 2004; Wagner et al., 2004; Hirschler, 2007).

Advances in behavioural genetics also have led to the development of a profession that did not exist several decades ago: genetic counselling. Genetic counsellors help people deal with issues related to inherited disorders. For example, genetic counsellors provide advice to prospective parents about the potential risks in a future pregnancy, based on their family history of birth defects and hereditary illnesses. In addition, the counsellor will consider the parents' age and problems with children they already have. They also can take blood, skin, and urine samples to examine specific chromosomes.

Scientists have already developed genetic tests to determine whether someone is susceptible to certain types of cancer or heart disease, and it may not be long before analysis of a drop of blood can indicate whether a child—or potentially an unborn fetus—is susceptible to certain psychological disorders. How such knowledge will be used is a source of considerable speculation and controversy, controversy that is certain to grow as genetic testing becomes more common (Etchegary, 2004; Malpas, 2008).

THE ENDOCRINE SYSTEM: OF CHEMICALS AND GLANDS

Another of the body's communication systems, the **endocrine system** is a chemical communication network that sends messages throughout the body via the bloodstream. Its job is to secrete **hormones**, chemicals that circulate through the blood and regulate the functioning or growth of the body. It also influences—and is influenced by—the functioning of the nervous system. Although the endocrine system is not part of the brain, it is closely linked to the hypothalamus.

studyALERT

The endocrine system produces hormones, chemicals that circulate through the body via the bloodstream.

As chemical messengers, hormones are like neurotransmitters, although their speed and mode of transmission are quite different. Whereas neural messages are measured in thousandths of a second, hormonal communications may take minutes to reach their destination. Furthermore, neural messages move through neurons in specific lines (like a signal carried by wires strung along telephone poles), whereas hormones travel throughout the body, similar to the way radio waves are transmitted across the entire landscape. Just as radio waves evoke a response only when a radio is tuned to the correct station, hormones flowing through the bloodstream activate only those cells which are receptive and "tuned" to the appropriate hormonal message.

A key component of the endocrine system is the tiny **pituitary gland**, which is found near—and regulated by—the hypothalamus. The pituitary gland has sometimes been called the "master gland" because it controls the functioning of the rest of the endocrine system. But the pituitary gland is more than just the taskmaster of other glands; it has important functions in its own right. For instance, hormones secreted by the pituitary gland control growth. Extremely short people and unusually tall ones usually have pituitary gland abnormalities. Other endocrine glands, shown in Figure 4, affect emotional reactions, sexual urges, and energy levels.

Despite its designation as the "master gland," the pituitary is actually a servant of the brain, because the brain is ultimately responsible for the endocrine system's functioning. The brain regulates the internal balance of the body, ensuring that homeostasis is maintained through the hypothalamus.

Individual hormones can wear many hats, depending on circumstances. For example, the hormone oxytocin is at the root of many of life's satisfactions and pleasures. In new mothers, oxytocin produces an urge to nurse newborn offspring. The same hormone also seems to stimulate cuddling between species members. And—at least in rats—it encourages sexually active males to seek out females more passionately, and females to be more receptive to males' sexual advances. There's even evidence that oxytocin is related to the development of trust in others, helping to grease the

Endocrine system: A chemical communication network that sends messages throughout the body via the bloodstream.

Hormones: Chemicals that circulate through the blood and regulate the functioning or growth of the body.

Pituitary gland: The major component of the endocrine system, or "master gland," which secretes hormones that control growth and other parts of the endocrine system.

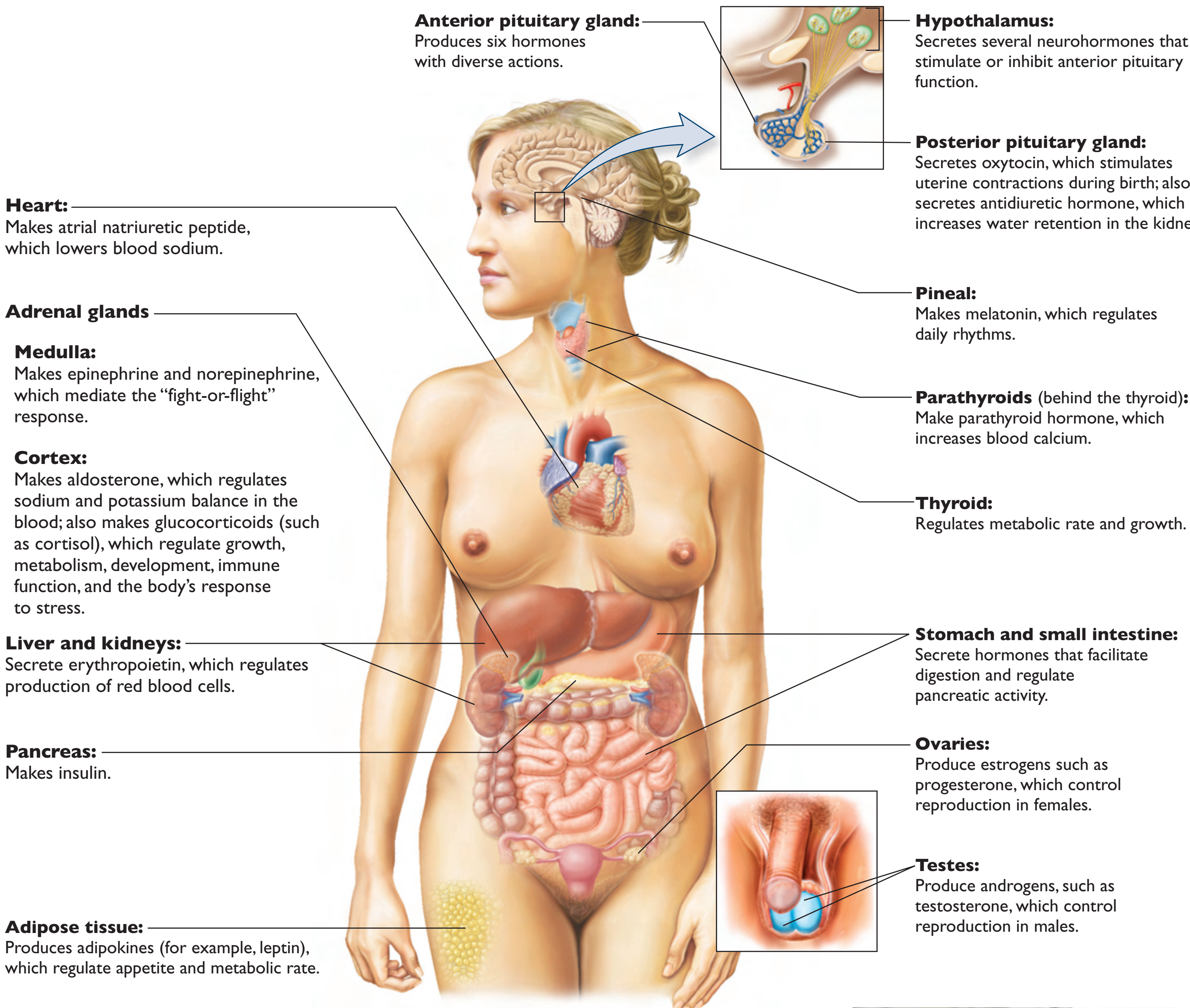


Figure 4

Location and function of the major endocrine glands. The pituitary gland controls the functioning of the other endocrine glands and in turn is regulated by the hypothalamus.

Steroids can provide added muscle and strength, but they have dangerous side effects. A number of well-known athletes, such as Roger Clemens, above, have been accused of using the drugs illegally.

wheels of effective social interaction (Kosfeld et al., 2005; Meinlschmidt & Heim, 2007; Guastella, Mitchell, & Dadds, 2008).

Although hormones are produced naturally by the endocrine system, the ingestion of artificial hormones has proved to be both beneficial and potentially dangerous. For example, before the early 2000s, physicians frequently prescribed hormone replacement therapy (HRT) to treat symptoms of menopause in older women. However, because recent research suggests that the treatment has potentially dangerous side effects, health experts now warn that the dangers outweigh the benefits (Herrington & Howard, 2003).

The use of testosterone, a male hormone, and drugs known as *steroids*, which act like testosterone, is increasingly common. For athletes and others who want to bulk up their appearance, steroids provide a way to add muscle weight and increase strength. However, these drugs can lead to heart attacks, strokes, cancer, and even violent behaviour, making them extremely dangerous. For example, in one infamous case, professional wrestler Chris Benoit strangled his wife, suffocated his son, and later hanged himself—acts that were attributed to his use of steroids (Klötz et al., 2006; Pagonis, Angelopoulos, & Koukoulis, 2006; Sandomir, 2007).

RECAP/EVALUATE/RETHINK

RECAP

How are the structures of the nervous system linked?

- The nervous system is made up of the central nervous system (the brain and spinal cord) and the peripheral nervous system. The peripheral nervous system is made up of the somatic division, which controls voluntary movements and the communication of information to and from the sense organs, and the autonomic division, which controls involuntary functions such as those of the heart, blood vessels, and lungs. (pp. 81–82)
- The autonomic division of the peripheral nervous system is further subdivided into the sympathetic and parasympathetic divisions. The sympathetic division prepares the body in emergency situations, and the parasympathetic division helps the body return to its typical resting state. (pp. 82–83)
- Evolutionary psychology, the branch of psychology that seeks to identify behaviour patterns that are a result of our genetic inheritance, has led to increased understanding of the evolutionary basis of the structure and organization of the human nervous system. Behavioural genetics extends this study to include the evolutionary and hereditary basis of human personality traits and behaviour. (pp. 83–86)

How does the endocrine system affect behaviour?

- The endocrine system secretes hormones, chemicals that regulate the functioning of the body, via the bloodstream. The pituitary gland secretes growth hormones and influences the release of hormones by other endocrine glands, and in turn is regulated by the hypothalamus. (pp. 86–88)

EVALUATE

1. If you put your hand on a red-hot piece of metal, the immediate response of pulling it away would be an example of a(n) __________.
2. The central nervous system is composed of the __________ and __________.
3. In the peripheral nervous system, the __________ division controls voluntary movements, whereas the ____________ division controls organs that keep us alive and functioning without our awareness.
4. Maria saw a young boy run into the street and get hit by a car. When she got to the fallen child, she was in a state of panic. She was sweating, and her heart was racing. Her biological state resulted from the activation of what division of the nervous system?
   - **a.** Parasympathetic
   - **b.** Central
   - **c.** Sympathetic
5. The emerging field of ____________ studies ways in which our genetic inheritance predisposes us to behave in certain ways.

RETHINK

1. In what ways is the fight-or-flight response helpful to humans in emergency situations?
2. *From the perspective of a genetic counsellor:* How would you explain the pros and cons of genetic counselling to someone who was interested in receiving genetic screening for various diseases and disorders?

Answers to Evaluate Questions

1. reflex; 2. brain, spinal cord; 3. somatic, autonomic; 4. sympathetic; 5. behavioural genetics

KEY TERMS

autonomic division p. 83
behavioural genetics p. 84
central nervous system (CNS) p. 81
endocrine system p. 86
evolutionary psychology p. 83
hormones p. 86
interneurons p. 81
motor (efferent) neurons p. 81
parasympathetic division p. 83
peripheral nervous system p. 83
pituitary gland p. 86
reflex p. 81
sensory (afferent) neurons p. 81
somatic division p. 83
spinal cord p. 81
sympathetic division p. 83

LOOKING BACK

Psychology on the Web

1. Biofeedback research is continuously changing and being applied to new areas of human functioning. Find at least two websites that discuss recent research on biofeedback and summarize the research and any findings it has produced. Include in your summary your best estimate of future applications of this technique.
2. Find one or more websites on Parkinson's disease and learn more about this topic. Specifically, find reports of new treatments for Parkinson's disease that do not involve the use of fetal tissue. Write a summary of your findings.

Epilogue

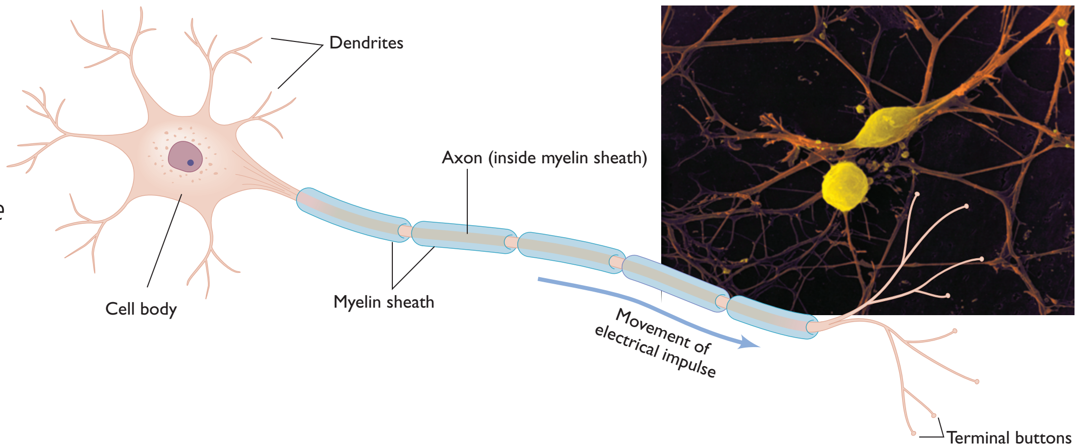
In our examination of neuroscience, we've traced the ways in which biological structures and functions of the body affect behaviour. Starting with neurons, we considered each of the components of the nervous system, culminating in an examination of how the brain permits us to think, reason, speak, recall, and experience emotions—the hallmarks of being human.

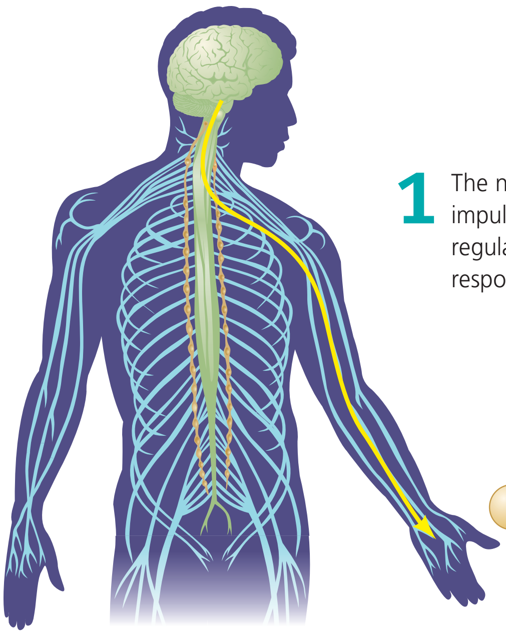
Before proceeding, turn back for a moment to the chapter prologue about Michael J. Fox. Consider the following questions:

1. Using what you now know about brain structures and functioning, can you explain what might have produced Michael J. Fox's Parkinson's disease in the first place?
2. Deep brain stimulation (DBS), a surgical operation used to treat Parkinson's disease, disrupts the functioning of certain neurons in the brain. What part of the brain might the operation have affected?
3. Do you think biofeedback techniques could be used to control the symptoms of Parkinson's disease? Why or why not?

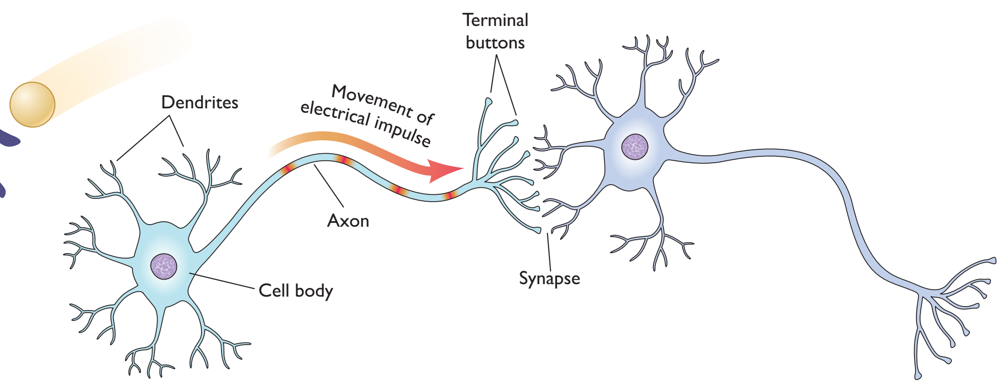
MASTERING THE ACTION POTENTIAL

The action potential is an electrical impulse that travels along the axon of a neuron. Use this visual guide to understand the process by which the impulse travels through a neuron and on to other neurons. Then answer the questions below to test your understanding of the concepts.





1 The nervous system communicates by means of electrical signals or impulses that travel from one neuron to another. These impulses regulate our behaviour, instructing our muscles, for example, how to respond to a ball moving toward us through the air.



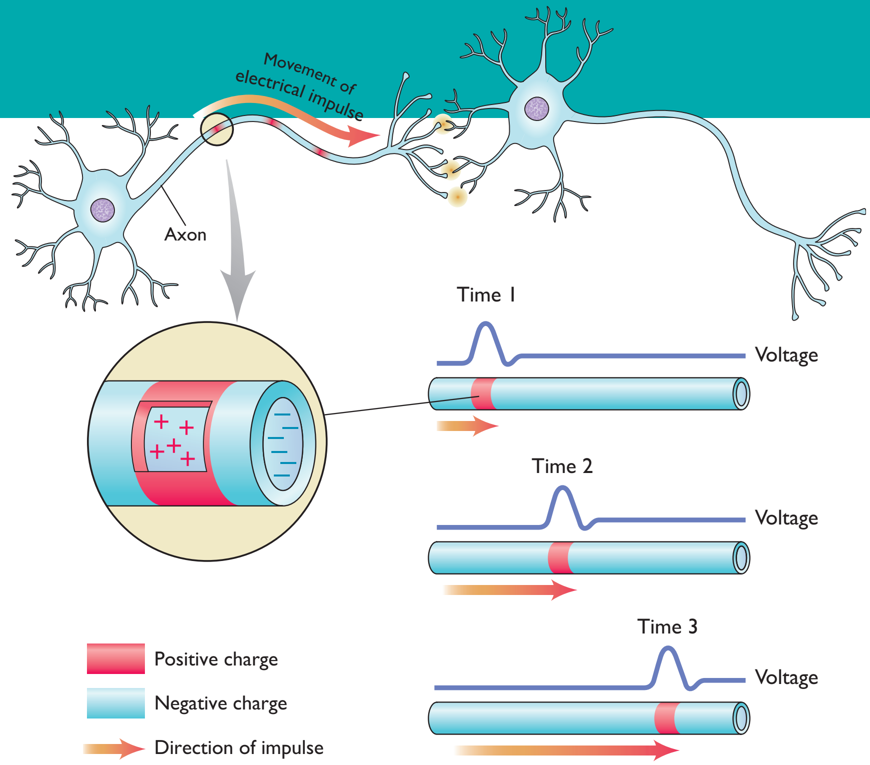
2 Impulses travel from the neuron's dendrites, through the cell body and the axon to the terminal buttons. The terminal buttons release chemicals called neurotransmitters into the synapse, where they are sent to the dendrites of the adjacent neuron to transmit the impulse to the next neuron.

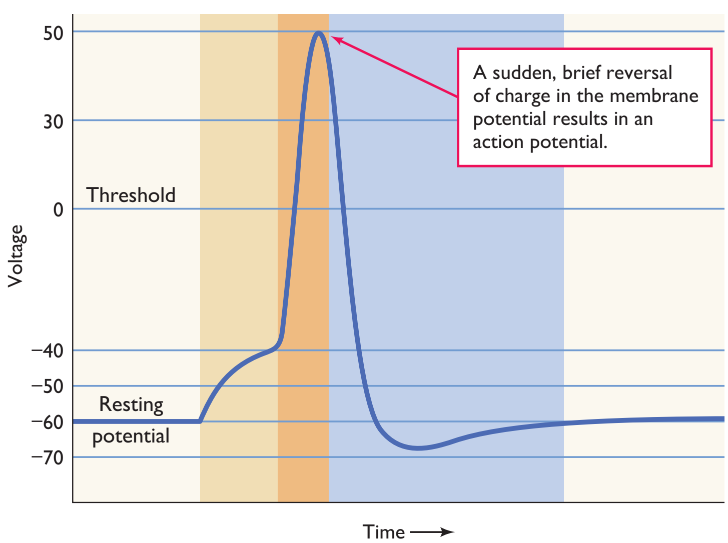
EVALUATE

1. An action potential travels across an axon
- **a.** in a chemical form
- **b.** as an electrical impulse
- **c.** as a sound wave
- **d.** in a corkscrew pattern

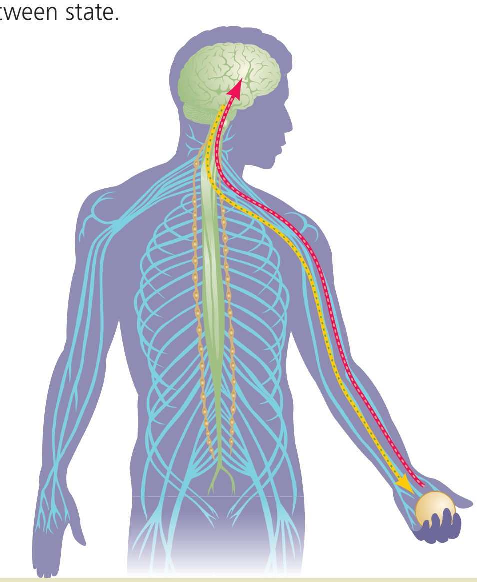
2. The _____________ is the space between neurons that is bridged by chemicals released from the terminal buttons.

3 In its normal, resting state, a neuron has a negative internal electrical charge. When the neuron is activated, its internal charge briefly becomes positive as an electrical impulse, called an *action potential*, moves through the neuron. An action potential travels through the neuron like a flame along a fuse. After it has passed, the negative charge is restored.





4 An action potential is generated only if the charge of the incoming impulse is sufficiently strong to cross the neuron's cell membrane and raise the neuron's charge to a level of +40 millivolts. Equally important, the impulse does not travel faster, nor is it stronger, if the voltage exceeds the threshold. Neurons operate according to an *all-or-none law*: Either a neuron is at rest, or an action potential is moving through it. There is no in-between state.



5 Most impulses move in one direction, either away from or toward the brain or spinal cord. When we catch a ball, neurons in the hand send a signal to the brain for interpretation; the brain, in turn, sends a signal telling the hand what to do next. Due to the speed at which nerve impulses travel—some move as quickly as 360 km per hour—the whole process occurs with amazing rapidity and coordination.

RETHINK

1. What is the process by which one neuron sends a message to another neuron?

3. The all-or-none law says that all neurons must fire at the same time for an impulse to be transmitted. True or False?

Answers to Evaluate questions: 1. b; 2. synapse; 3. false