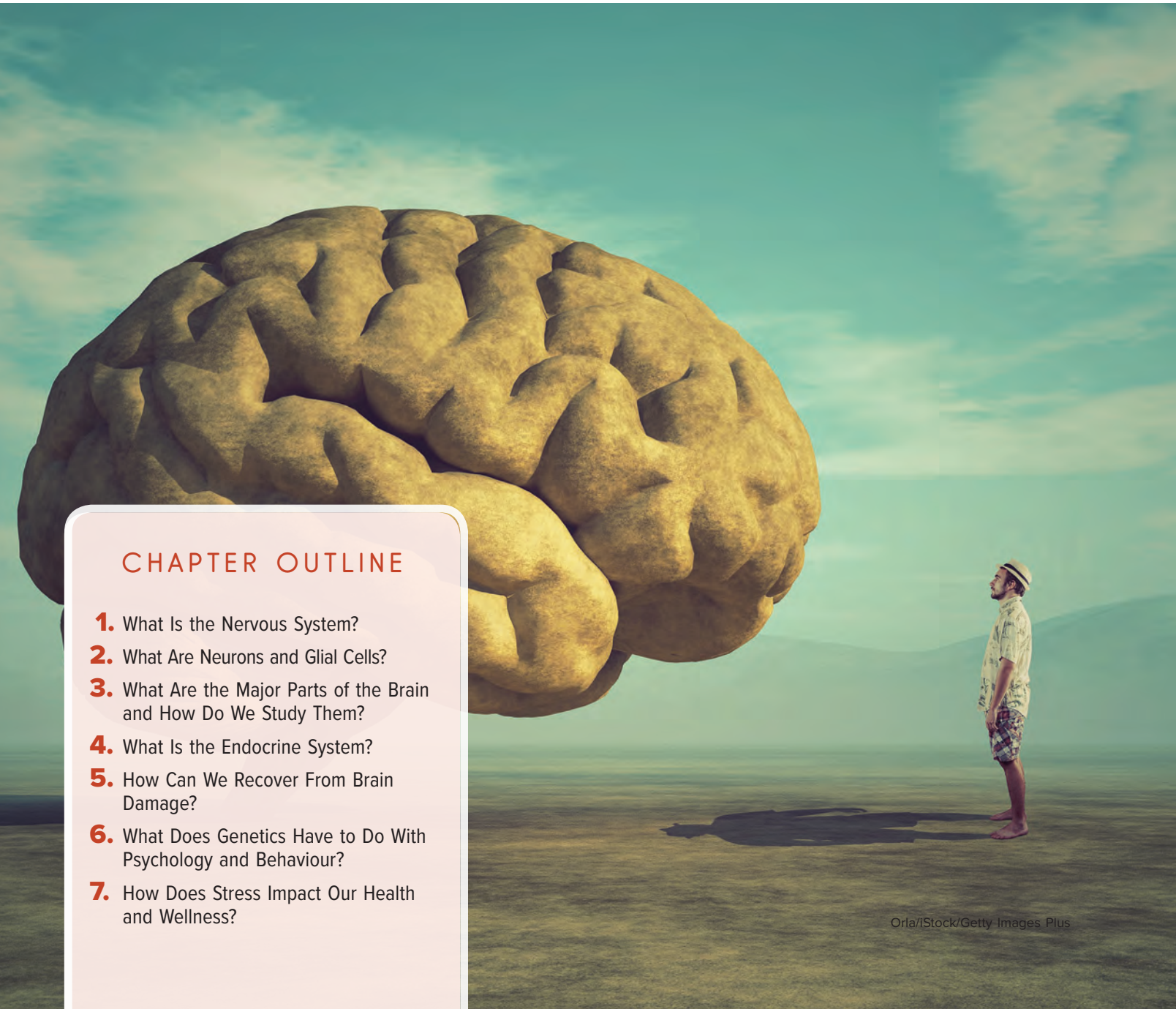
chapter 3

# What Are the Biological Foundations of Behaviour?



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## CHAPTER OUTLINE

1. What Is the Nervous System?
2. What Are Neurons and Glial Cells?
3. What Are the Major Parts of the Brain and How Do We Study Them?
4. What Is the Endocrine System?
5. How Can We Recover From Brain Damage?
6. What Does Genetics Have to Do With Psychology and Behaviour?
7. How Does Stress Impact Our Health and Wellness?

# Do Zombies Walk Among Us?

**For days, an elderly woman insisted that her daughters cover her with a death shroud and place her in a coffin (Forstl & Beats, 1992).** She was convinced that she was dead. Her family eventually agreed to her request, but even during her "funeral," while lying in her coffin, the woman fussed with her shroud and expressed her disapproval of its colour.

This woman's story is one of the earliest documented examples of Cotard's delusion, first described in 1880 by the French neurologist Jules Cotard. This rare condition is characterized by a person's conviction that their organs, sometimes including their brain, are missing, or that they no longer have blood, specific body parts, or even a soul.

A central task of the brain is to make sense of the world by assigning meaning to the sensory input to the brain. In people with Cotard's delusion, the brain may interpret input in such a way that the individual feels they smell of rotting flesh, their heart has stopped beating, or their organs have melted. Though they interact with the living, they see themselves as dead.

To understand how a person could believe they are dead—in fact, to help understand the secrets of all of human beliefs, behaviour, memories, thoughts, and feelings—we must look to the incredible organ that is reading these words right now. This intricate structure, the brain, makes up just two percent of your body weight. The brain is at once the object of study and the reason we are able to study it.

# Preview

**In this chapter, our focus is on the biological foundations of human behaviour. We review the essentials of what we know about the nervous system and its command centre—the brain. We then look at the hormonal systems and how genetic processes influence who we are and how we behave. Finally, we explore the role of the brain and nervous system in the experience of stress and consider ways to unlock the brain's unique resources to better meet life's challenges and maintain health and well-being.**

# 1. WHAT IS THE NERVOUS SYSTEM?

● **nervous system** The body's electrochemical communication circuitry.

The brain is the central component of the **nervous system**, which includes the cellular circuits that allow for electrical and chemical communication in our bodies. The study of this communication is called *neuroscience*. The human nervous system is made up of billions of communicating cells, and it is likely the most complex matter on earth. A single cubic centimetre (about the size of a snack cube of cheese) of the human brain consists of well over 50 million nerve cells. Each of these cells communicates with thousands of other nerve cells in information-processing networks that make the most elaborate computer seem primitive.

## What Are Characteristics of the Nervous System?

The nervous system, and in particular our brain, guides our interactions with the world around us. The nervous system relays input from what we see, hear, feel, taste, and smell to the brain and allows us to move our bodies in response to the complex input from our changing environment. Four extraordinary characteristics allow the nervous system to command our behaviour: complexity, integration, adaptability, and electrochemical transmission.

### WHAT DOES COMPLEXITY MEAN?

The nervous system is extremely complex. This complexity is demonstrated in the orchestration of the billions of nerve cells in the brain that allow you to talk, write, sing, text, and think. This capacity is awe-inspiring. As you read this textbook, your brain is carrying out a multitude of functions, including seeing, reading, learning, and (we hope) breathing. Extensive groups of nerve cells participate in each of these activities, all at once.

● **neurons** One of two types of cells in the nervous system: neurons receive, process, and communicate information.

Neuroscientists estimate that the brain consists of 85 billion neurons and about the same number of supporting, non-neuronal cells called *glial cells* (von Bartheld et al., 2016). **Neurons** are the cells in the body that receive, process, and communicate information throughout the nervous system so we can make sense of input from our senses and move. Each neuron communicates, on average, with 10,000 others, making an astronomical number of connections. The complexity of connections in the brain is one of its most notable features (Park & Friston, 2013). Glial cells perform a wide range of supporting functions for the neurons, including providing protection, nutrients, maintenance, and repair. Glial cells have the important role of increasing the speed and efficiency of neurons.

*As we dance, write, play sports, talk, think, and connect with the world in countless other ways, the nervous system guides our every interaction, movement, and adaptation.*

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### WHAT IS INTEGRATION?

The brain does an amazing job of pulling information together. Right now you are receiving an impressive array of sensory input that may include hearing noises from other people, seeing the words and photos in this textbook, and feeling the chair you are sitting on. Somehow, you make sense of all of this input. The shapes on this page are not simply splashes of ink. They are letters, and those letters form words that make sense. Your brain draws your experiences together into a coherent whole. Sounds, sights, touches, tastes, and smells—the brain integrates all of these sensory inputs so that you can function in the world. In addition to receiving inputs, you are engaged in multiple behaviours. You may be moving your eyes across the page, scratching an itch, and checking your

phone. Simultaneously, your nervous system is responsible for digesting your last meal, healing a cut, breathing, and beating your heart (Veiga-Fernandes & Artis, 2018).

The nervous system has different levels and many different parts. Brain activity is integrated across these levels through countless interconnections of neurons and extensive pathways that link different parts of the brain and body. These connections are active when you engage in any activity—for example, when a loved one takes your hand. How does your brain know, and tell you, what has happened? Bundles of interconnected nerve cells relay information about the sensation in your hand through the nervous system in a very orderly fashion, to the areas of the brain involved in recognizing that someone you love is holding your hand. Then the brain might send a reply and prompt your hand to give your loved one a little squeeze.

## WHAT IS ADAPTABILITY?

Think about all the different places humans live or could live some day. People inhabit both deserts where the temperature can exceed 45 degrees Celsius and frozen tundra where the temperature drops below minus 30. People live in bustling cities and small rural communities that change from day to night and from season to season. Yet, in all these different environments, people depend on the same amazing tool to help them solve the problems of survival. They hunt and farm, they work online, and they foster relationships with others. The brain has allowed humans to visit the moon and may one day allow us to inhabit another planet. Our brains not only make it possible for us to survive in today's world, but must be able to help us meet the varied challenges of our future world.

To survive, we must adapt to new conditions. The nervous system is our agent for adapting to the world. Although neurons reside in individual brain regions, they are not unchanging structures. They have a hereditary, biological foundation, but they are constantly adapting to changes in the body and the environment (Zich et al., 2015).

The term **plasticity** refers to the brain's special physical capacity for change. Although injuries to the brain can often produce devastating effects, sometimes the brain heals in extraordinary ways. You may recall from the beginning of Chapter 1 the story of Jason Padgett. Jason was a young man who worked as a clerk at a futon store. He was brutally attacked by muggers one night and suffered a concussion. During the months of recovery that followed, Jason noticed a dramatic change in himself. A college dropout who had never been particularly interested in math, he suddenly began seeing the world as made up of intricate mathematical patterns. He then discovered that he had a special talent for creating artwork based on the arithmetic laws he saw everywhere in his world. During his recovery, Jason's brain seems to have unlocked capacities he had never known before (Karlinsky & Frost, 2012). There are a number other cases of individuals gaining special skills or talents after suffering brain injury or disease, and these have come to be known as *acquired savant syndrome.* Acquired savant syndrome provides an amazing example of the human brain's plasticity and its unexplained, hidden powers.

● **plasticity** The brain's special physical capacity for change.

Due to the brain's plasticity, it can change in response to experience. Less dramatic examples of plasticity occur in all of us. For example, you might believe that thinking, learning, and remembering are all mental, not physical, processes. Yet, these are all physical events represented by physical changes in your brain.

The brain is changed by experience. Cab drivers in London, England, who have developed a familiarity with their city show increases in the size of the area of the brain thought to be responsible for reading maps (Maguire et al., 2000). Think about that: When you change the way you think, you are *literally* changing the brain's physical processes and even its shape. Our daily experiences contribute to the wiring or rewiring


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of the brain, just as do the experiences of those London cab drivers (Petrosini et al., 2013). You may not consider this example relevant to your own life—after all, you are not a London cab driver. But the underlying nervous system, used for navigating the real world as well as virtual reality gaming, is fundamentally the same (Starrett & Ekstrom, 2018).

### WHAT IS ELECTROCHEMICAL TRANSMISSION?

The nervous system functions as an information-processing system powered by electrical impulses and chemical messengers. When an impulse travels down a *neuron,* it does so electrically. When that impulse gets to the end of the cell, it communicates with the next neuron using chemicals, as we will consider in detail later in this chapter.

## What Are the Pathways in the Nervous System?

As you interact with and adapt to the world, the nervous system receives and transmits sensory input (like sounds, smells, and sights), integrates the information taken in from the environment, and directs the body's motor activities. Information flows into the brain through input from our senses, and the brain makes sense of this information, pulling it together and giving it meaning. In turn, information moves out of the brain to the rest of the body, directing all of the physical things we do.

The nervous system has specialized pathways that are adapted for different functions. These pathways are made up of afferent nerves, efferent nerves, and neural networks (discussed later in the chapter). **Afferent nerves** or **sensory nerves** carry information from the sensory receptors *to* the brain and spinal cord. These sensory pathways communicate information about the external environment (for example, you feel your phone vibrate) and internal conditions (for example, fatigue or hunger) from sensory receptors to the brain and spinal cord. **Efferent nerves** or **motor nerves** carry information *out of* the brain and spinal cord—that is, they carry the nervous system's output. These motor pathways communicate information from the brain and spinal cord to other areas of the body, including muscles and glands, instructing them, in a sense, to get busy. The fact that we have separate afferent and efferent nerves tells us something interesting about neurons: Each neuron is a one-way street in the nervous system.

- **afferent nerves or sensory nerves** Nerves that carry information about the external environment *to* the brain and spinal cord via sensory receptors.

- **efferent nerves or motor nerves** Nerves that carry information out of the brain and spinal cord to other areas of the body.

These terms can be complicated. Remember that sensory nerves are afferent nerves. They bring the brain and spinal cord information about the world. Motor nerves are efferent nerves that send information out from the brain and spinal cord. It might help to remember the functions of afferent and efferent nerves by noting that *a*fferent nerves *a*rrive at the brain and spinal cord, and *e*fferent nerves *e*xit these components of the nervous system.

## What Are the Divisions of the Nervous System?

The nervous system is highly ordered and organized for effective functioning. Figure 3.1 shows the two primary divisions of the human nervous system: the central nervous system and the peripheral nervous system.

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

- **peripheral nervous system (PNS)** The network of nerves that connects the brain and spinal cord to other parts of the body.

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

- **somatic nervous system** The body system consisting of the sensory nerves, whose function is to convey information from the skin and muscles to the CNS about conditions such as pain and temperature, and the motor nerves, whose function is to tell muscles what to do.

- **autonomic nervous system** The body system that takes messages to and from the body's internal organs, monitoring such processes as breathing, heart rate, and digestion.

The peripheral nervous system has two major divisions: the somatic nervous system and the autonomic nervous system. The **somatic nervous system** consists of sensory and motor nerves. Sensory nerves convey information from the skin and muscles to the CNS about conditions such as pain and temperature. Motor nerves tell the muscles what to do. The function of the **autonomic nervous system** is to take messages to and

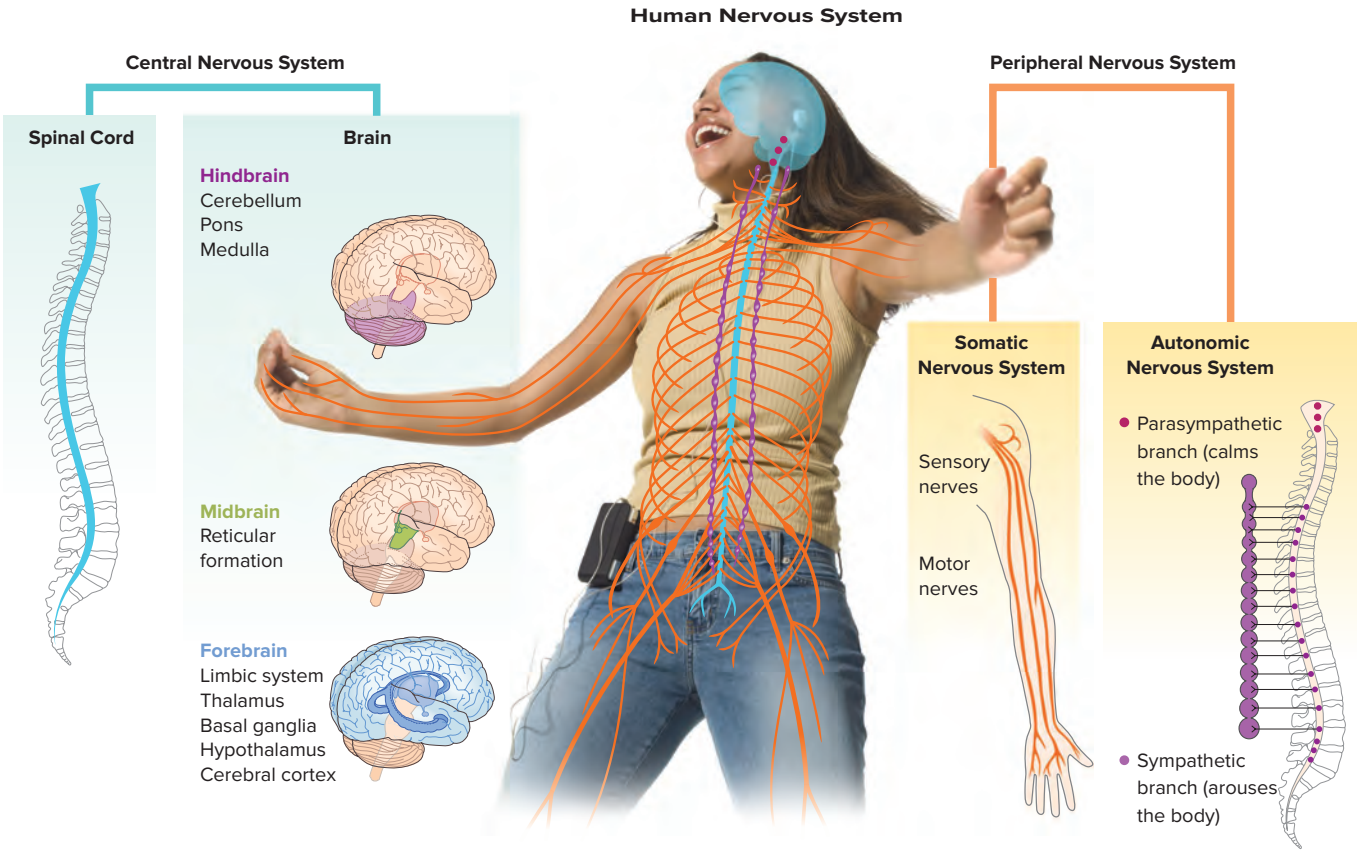



**FIGURE 3.1** **Major Divisions of the Human Nervous System** The nervous system has two main divisions. One, the *central nervous system* (left), comprises the brain and the spinal cord. Two, the *peripheral nervous system* (right), which has two parts: 1) the *somatic nervous system*, which controls sensory and motor neurons, and 2) the *autonomic nervous system*, which monitors the organs for processes such as breathing, heart rate, and digestion. These complex systems work together to help us successfully navigate the world.
(photo) ©RubberBall Productions

from the body's internal organs, monitoring such processes as breathing, heart rate, and digestion.

The autonomic nervous system is divided into two parts: 1) the **sympathetic nervous system** arouses the body to mobilize it for action, and 2) the **parasympathetic nervous system** calms the body. The sympathetic nervous system is involved in the "fight or flight" response, the body's reaction to a threat (an incident where you can either stay and fight, or flee). When you feel your heart pounding and your hands sweating under stress, those experiences reveal the sympathetic nervous system in action. If you need to run away from a dangerous situation, the sympathetic nervous system sends blood out to your extremities to prepare you for your escape. The parasympathetic nervous system is responsible for the ways you calm down once you have escaped the danger. While the sympathetic nervous system is associated with "fight or flight," the parasympathetic nervous system might be thought of as the system that "rests and digests."

In an emergency, the sympathetic nervous system also triggers the body's release of powerful hormones (Owen et al., 2015). These stress hormones allow you to focus attention on what needs to be done *now*. For example, in an emergency, people sometimes report feeling strangely calm and doing what has to be done, whether calling 911 or applying pressure to a serious wound. Such experiences reveal the benefits of stress hormones in times of acute emergency (Dougall et al., 2013). We will revisit the relationship between the experience of stress and the nervous system at the close of this chapter.

● **sympathetic nervous system** The part of the autonomic nervous system that arouses the body to mobilize it for action and thus is involved in the experience of stress.

● **parasympathetic nervous system** The part of the autonomic nervous system that calms the body.

# 2. WHAT ARE NEURONS AND GLIAL CELLS?

Within each division of the nervous system, much is happening at the cellular level. The nervous system is made up of two types of cells: neurons and glia. Neurons, glia, chemicals, and electrical impulses work together to transmit information at speeds of up to 530 kilometres per hour. As a result, if you accidentally touch a hot stove, your brain receives this information in a matter of milliseconds. Just how fast is 530 kilometres per hour? Consider that the NASCAR speed record is 342.5 kilometres per hour. The new Cessna Denali turboprop passenger plane has a cruising speed of 530 kilometres per hour.

● **mirror neurons** Nerve cells in the brain that are activated (in human and nonhuman primates) both when an action is performed and when the organism observes the action being performed by another.

Researchers have been particularly interested in a special class of neurons called **mirror neurons**. Mirror neurons are activated (in human and nonhuman primates) when we perform an action and when we watch someone else perform that same activity (Ferrari & Rizzolatti, 2015; Oztop et al., 2013). Why is this such a big deal? Remember, neurons are specialized: Motor neurons do not respond to sensory information, and sensory neurons do not respond to motor information. Yet, mirror neurons respond to both kinds of information—doing and seeing (Gallese et al., 2011; Oztop et al., 2013). This responsiveness to two different kinds of input is one characteristic that makes mirror neurons so fascinating.

The discovery of mirror neurons has led to provocative predictions about the function of these neurons in imitation, social cognition (that is, thinking about oneself and others), empathy, and understanding behaviour (Vanderwert et al., 2013). Some scientists have argued that "broken mirror neurons" play an important role in autism, a disorder of neural development characterized by impairment in communication and social interaction (Lauvin et al., 2012; Ramachandran & Oberman, 2006). Indeed, some scholars hail mirror neurons as a promising new direction in understanding the origins of human sociability (Ramachandran, 2000). Others consider that such claims far overstep the evidence (Gernsbacher & Pripas-Kapit, 2012; Hickok, 2009).

● **glial cells** The second of two types of cells in the nervous system; glial cells provide support, nutritional benefits, protection, and other functions to keep neurons running faster and more efficiently. Also known as *glia*.

In addition to neurons, the brain is made up of glial cells. **Glial cells** or **glia** provide support, nutritional benefits, protection, and other functions in the nervous system (Allen & Lyons, 2018; Jäkel & Dimou, 2017; Trevisiol & Nave, 2015). Glial cells keep neurons running faster and more efficiently. Our knowledge of glial cells shows how scientific understanding is always improving. Until recently, researchers believed that glial cells were not specialized to process information and that there were perhaps ten times more glial cells than neurons. Our current understanding is that glial cells both receive and transmit information, and that they are similar in number to neurons (von Bartheld et al., 2016). You might think of the glial cells as a combination of the pit crew in a raceway and the parents of an active child. They are like a pit crew in making sure that the neurons can perform at a high level of speed and efficiency, and they are like parents in making sure that the neurons are well fed and protected.

Neuroscientists know much less about the function of glial cells than neurons, but a growing literature is shedding light on ways in which glial cells might be involved in behaviour (Edgar & Sibille, 2012; Gundersen et al., 2015). Until recently, it was thought that glia do not have synapses or release neurotransmitters, both of which, as we will see, are crucial for neural transmission. However, research now suggests that some glial cells are more than just passive bystanders to neural transmission; they may detect neural impulses and send signals to other glial cells (Fields et al., 2015). Glial cells have been recognized in a host of important human experiences, including memory (Hassanpoor et al., 2012), neurodegenerative diseases such as Alzheimer disease (Melo et al., 2011), pain (Hanani, 2015), and psychological disorders (Noda, 2015). Still, the majority of information processing in the brain seems to be done by neurons, not glial cells.

## What Is the Structure of a Neuron?

Much more so than glial cells, neurons show a wide range of variability, including in their size and distribution (Herculano-Houzel & Dos Santos, 2018). Not all neurons are alike, as they are specialized to handle different functions. However, all neurons share

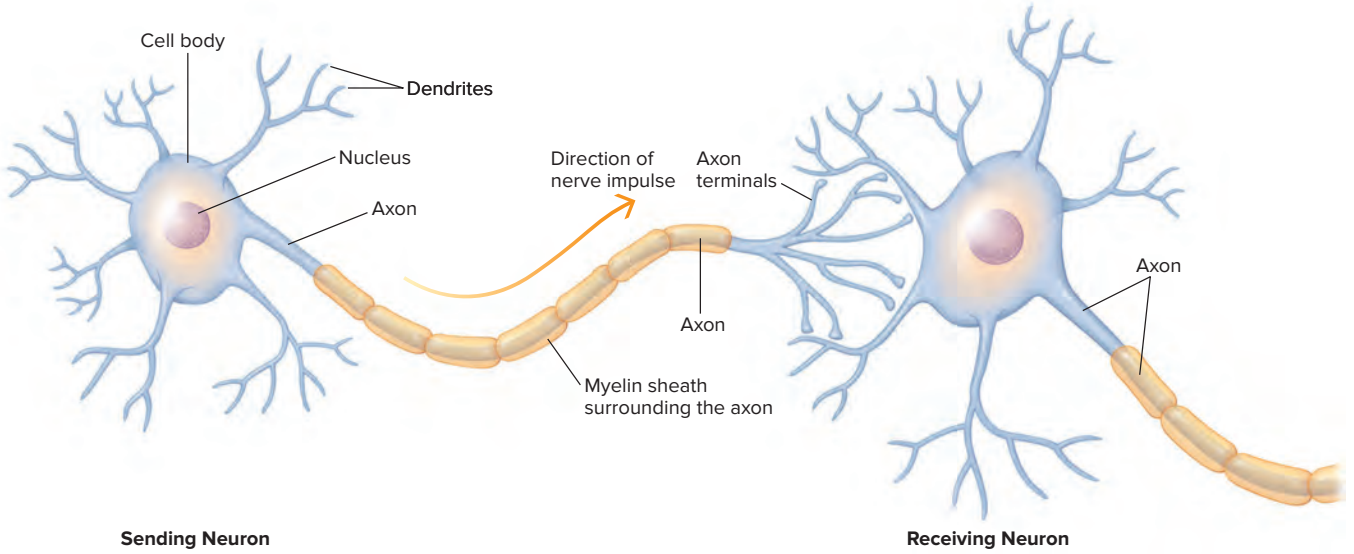



**FIGURE 3.2** **The Neuron** The drawing shows the parts of a neuron and the connection between one neuron and another. Note the cell body, the branching of dendrites, and the axon with a myelin sheath.

some common characteristics. Most neurons are created very early in life, but their shape, size, and connections can change throughout the life span. The way neurons function reflects the major characteristic of the nervous system described at the beginning of this chapter: plasticity. That is, neurons change.

Neurons all share five anatomical structures: cell bodies, dendrites, axons, axon terminals, and cell membranes (Figure 3.2). In the **cell body** two important functions are carried out. First, the building blocks of proteins and **neurotransmitters** are assembled in the cell bodies. These products are essential for the cells to grow, maintain themselves, and communicate with other cells. Second, in the cell bodies the input from other cells is organized to determine how the cells respond.

**Dendrites**, branchlike fibres projecting from a neuron's cell body, receive input from other cells. Most nerve cells have numerous dendrites, which increase the cell's surface area, allowing each neuron to receive input from many other neurons.

The **axon** is a single projection from the cell body that carries information away from the cell body toward the ends of the cells. (Remember that *axon* and *away* both start with the letter *a*). Although extremely thin (one tenth the thickness of a human hair), they can be very long, with many branches. In fact, some extend about a metre—all the way from the top of the brain to the base of the spinal cord.

At the end of the axon are the **axon terminals** where chemicals manufactured in the cell body are stored, and then released to affect other neurons.

Finally, covering all surfaces of the neurons, including the dendrites and axons, is a cell membrane. The cell membrane is like your skin; it is very thin, covers the entire cell, and keeps the inside in and the outside out. Importantly, the cell membrane has small passageways that allow for substances to move in and out of the cell. We will examine this membrane and its functions in more detail next.

- **cell body** The part of the neuron that contains the nucleus, which directs the manufacture of substances that the neuron needs for its growth and maintenance and to communicate with other cells.
- **neurotransmitters** Chemical messengers (molecules) released into the synapses that allow the nervous system to send messages between neurons or from neurons to muscles.
- **dendrites** Branchlike fibres projecting from a neuron, which receive information and orient it toward the neuron's cell body.
- **axon** The part of the neuron that carries information away from the cell body toward other cells.
- **axon terminal** The end of the axon, where chemicals are stored and intermittently released to affect the functioning of neighbouring neurons.

## How Does Information Travel Inside a Neuron?

To transmit information along the length of a neuron, the neuron sends brief electrical impulses through its axon. As you reach to turn this page, hundreds of these impulses stream down the axons in your arm to tell your muscles when to flex or extend and how quickly. Similarly, when you feel the touch of the page with your fingertips, hundreds of these impulses along a different set of axons alert your brain to the fact that you are touching paper. These impulses travelling down the axon are electrical. How does a

neuron—a living cell—generate electricity? To answer this question, we need to take a moment to examine the axon and the cell membrane that surrounds it.

The axon is a tube encased in a membrane. There is fluid both inside and outside the axon. Floating in this fluid are electrically charged particles called *ions.* Ions are atoms that have gained (negatively charged) or lost (positively charged) electrons. Some of these ions, notably sodium and potassium, carry positive charges. Negatively charged ions of chlorine and other elements also are present. The membrane surrounding the axon prevents negative and positive ions from randomly flowing into and out of the cell. That membrane has thousands of tiny gates in it. These gates are generally closed, but they can open. We call the membrane *semipermeable* because fluids and some ions can sometimes flow into and out of it. In fact, the neuron creates electrical signals by moving positive and negative ions back and forth through its outer membrane.

Normally, when the neuron is resting—that is, not transmitting information—the tiny gates in the membrane, called *ion channels,* are closed. During this time, a slight negative charge is present along the inside of the cell membrane. On the outside of the cell membrane, the charge is positive. Because of the difference in charge, the membrane of the resting neuron is said to be *polarized,* with more negatively charged ions on the inside of the cell and more positively charged ions on the outside. This polarization creates a voltage between the inside and outside of the axon wall (Figure 3.3). That voltage, called the neuron's **resting potential**, is between –60 and –75 millivolts. A millivolt (mV) is 1/1000th of a volt.

● **resting potential** The stable, negative charge of an inactive neuron.

How does the movement of ions occur across the membrane? Those ion channels open to let the ions pass into and out of the cell. For ions, it is true that opposites attract. The negative ions on the inside of the membrane and the positive ions on the outside of the membrane will rush toward each other if given the chance. Impulses that travel down the neuron do so by opening and closing ion channels, allowing the ions to flow in and out.

Recall that each neuron receives information from thousands of other cells. When the summed input from all these other cells pushes the electrical potential from its resting state (–70 mV) to a critical tipping point (around –45 mV), the cell is activated. For example, when incoming impulses from a pinprick or the sight of your friend's face raises a neuron's voltage to this critical level, the sodium gates in the cell membrane at the base of the axon open briefly. This opening allows positively charged sodium ions to rush into the neuron, reversing the voltage of the neuron from negative to positive. This reversal, called *depolarization*, can result in a small section of the cell membrane having a positive charge. At this small section, following the influx of sodium ions, potassium channels open, and positively charged potassium ions move out through the

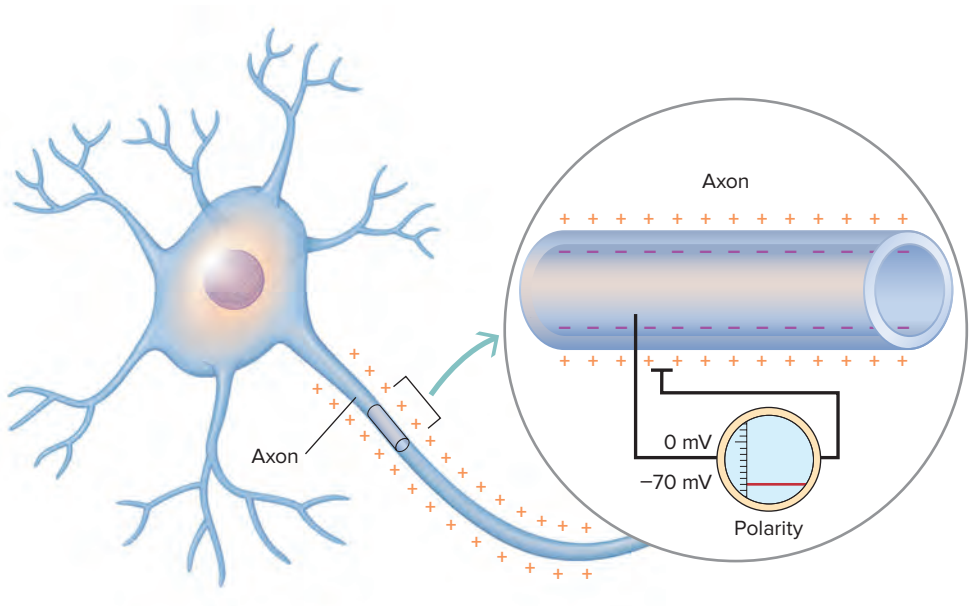
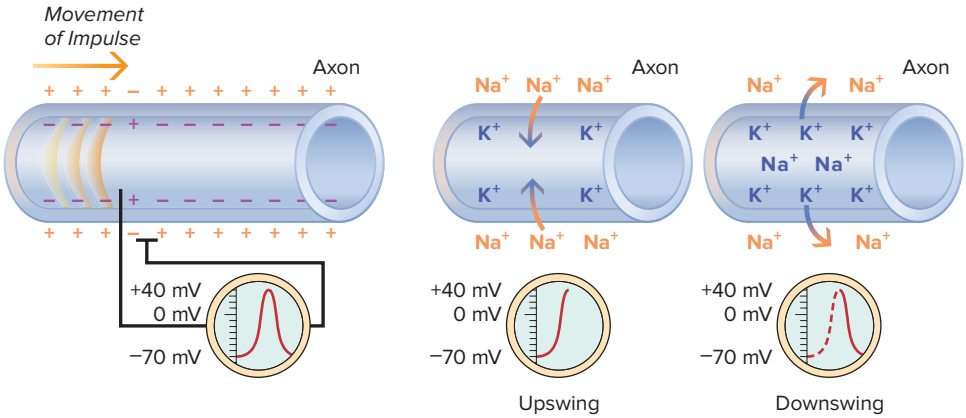



**FIGURE 3.3 The Resting Potential** An oscilloscope measures the difference in electrical potential between two electrodes. When one electrode is placed inside an axon at rest and one is placed outside, the electrical potential inside the cell is −70 millivolts (mV) relative to the outside. This potential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




(a) Action potential generated by an impulse within a neuron

(b) Movement of sodium ($Na^+$) and potassium ($K^+$) ions responsible for the action potential

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

cell membrane. Then this exchange of sodium and potassium ions at one tiny section of the cell membrane is repeated in the next adjacent section of the cell body.

The opening and closing of sodium and potassium channels in sequence along the length of the axon allow for an electrical impulse to be propagated from around the cell body down to the axon terminals. To help visualize this, imagine a rope stretched out in front of you. If you flicked one end, the rope would have a wave that moved down its length. The rope is like the axon, and the wave moving down its length represents the electrical impulse. This process of opening and closing tiny ion channels is responsible for the precise movements of a hip hop dancer, the flying fingers of a pianist, and the sensation of a loving kiss.

The term **action potential** describes the brief wave of positive electrical charge that sweeps down the axon (Figure 3.4). When a neuron sends an action potential, it is commonly said to be "firing." An action potential lasts only about 1/1000th of a second, because the sodium channels can stay open for only a very brief time. They quickly close again and then the cell can no longer have an action potential until it resets back to its –70 mV resting potential. This "time out" period is called the *refractory period*. During the refractory period the cell uses energy to export three sodium ions out of the cell in exchange for two potassium ions that are imported into the cell. About half the energy that the brain uses is devoted to recovering and maintaining the resting potential.

● **action potential** The brief wave of positive electrical charge that sweeps down the axon.

In short, the electrical activity of neurons can be summarized as involving three steps:

1. Resting Potential: the neuron maintains a small negative charge, of –70 mV. This charge is created by the cell using energy to create an uneven distribution of ions across its cell membrane. In particular, sodium is more concentrated outside of the cell membrane.
2. Action Potential: when the neuron is sufficiently stimulated by the release of neurotransmitters from thousands of other cells, it fires. During this firing, tiny channels open up and sodium ions rush into the neuron, reversing the polarity (the cell goes from having a negative charge to a positive charge). This activity races down the length of the axon as the channels open and then close.
3. Refractory Period: the cell now has a "time out" period where it has to regain its resting potential before it can fire again. During this time out, sodium ions are expelled out of the cell until it again reaches the –70mV resting potential.

The action potential follows the **all-or-nothing principle**, meaning that once the electrical impulse reaches a certain level of intensity, called its *threshold,* it fires and moves all the way down the axon without losing any of its intensity. The impulse travelling down an axon is comparable to the burning fuse of a firecracker. Whether you use a match or a blowtorch to light the fuse, once the fuse has been lit, the spark travels quickly and with the same intensity down the fuse.

● **all-or-nothing principle** The principle that once the electrical impulse reaches a certain level of intensity (its threshold), it fires and moves all the way down the axon without losing any intensity.

The all-or-nothing principle creates a bit of a puzzle. If there are no differences in the intensity of the action potentials, how can we detect differences in the intensity of a stimulus? How can we tell the difference between a bright and dim light, or mild and hot salsa? The answer has to do with the frequency of the action potentials. As the rate of action potentials increases, we can perceive increases in the intensity of a stimulus.

Just as computers have improved by becoming more energy efficient and faster, the brain has evolved to show improvements in efficiency and speed. Improving energy efficiency is important, because even though the brain represents only 2 percent of your body weight, it accounts for about 20 percent of your energy consumption. Relative to the rest of your body, the brain is an energy hog. Of the energy that the brain uses, over half is used to restore the resting potential along the axon following each action potential (Astrup et al., 1981).

The energy required to restore and maintain the resting potential is reduced considerably by a **myelin sheath**. A myelin sheath is a layer of fatty glial cell that surrounds most axons similar to the way a shirt sleeve encases your arm. Being largely fat, the myelin sheath is a poor conductor of electricity, so it insulates the axon. The myelin that insulates the axon has small gaps along the length of the axon. The resting potential of insulated cells only has to be maintained at these gaps—not at every location of the cell membrane—so energy use is reduced.

● **myelin sheath** A layer of fatty glial cells that encases and insulates most axons.

The myelin sheath also helps with speed. It allows the action potential to travel up to 15 times faster (Whalley, 2015). With the insulation of myelin sheaths, axons transmit electrical impulses and convey information rapidly (Miller et al., 2012). Rather than having action potentials creep along each tiny segment of the axon, the action potentials can move rapidly down the length of the axon by leaping from gap to gap.

Numerous disorders are associated with problems in either the creation or the maintenance of myelin. One of these disorders is multiple sclerosis (MS), which is thought to be an autoimmune disease where a person's immune system attacks their myelin. MS is a degenerative disease of the nervous system in which myelin tissue hardens, disrupting neuronal communication. In MS, scar tissue replaces the myelin sheath. Symptoms of the disease include blurry and double vision, tingling sensations throughout the body, and general weakness. Unfortunately, Canada has one of the world's highest rates of MS (Figure 3.5).

### apply your knowledge

Have you noticed that if you stub your toe or touch a hot stove, there is an immediate, intense, sharp pain, followed a second or two later by a duller, throbbing ache? The immediately felt sharp pain is carried from the injury to the brain very rapidly by myelin insulated axons. The dull pain reaches the brain after a short delay because it is carried to the brain along axons that are much slower because they are not insulated with myelin.

## How Does Information Travel Between Neurons?

The movement of an action potential along the length of an axon may be compared to a crowd doing "the wave" in a stadium. With the wave, there is a problem, however—the aisles. How does the wave get across each aisle? A similar problem arises for neurons, because they do not touch one another directly, and electricity cannot cross the space between them.

Here is where the chemical part of electro*chemical* transmission comes in. Though communication inside neurons is electrical, communication between neurons is chemical. The communication between neurons is one of the most intriguing and highly researched areas of contemporary neuroscience (Herman & Rosenmund, 2015). Figure 3.6 gives an overview of how this communication between neurons takes place.

### HOW DOES SYNAPTIC TRANSMISSION WORK?

Neurons don't actually touch each other. The region defined by the end of one neuron (the presynaptic membrane) and the beginning of the next neuron (the postsynaptic membrane) is called the **synapse**. The synaptic gap is the tiny space between the terminal button of the presynaptic neuron and the receptor site on the dendrite of the postsynaptic neuron (the aisle in our stadium analogy). Most synapses lie between the end of the axon of one neuron and the dendrites or cell body of another neuron

● **synapse** The region defined by the pre-synaptic membrane and the post-synaptic membrane, including the tiny gap between them.

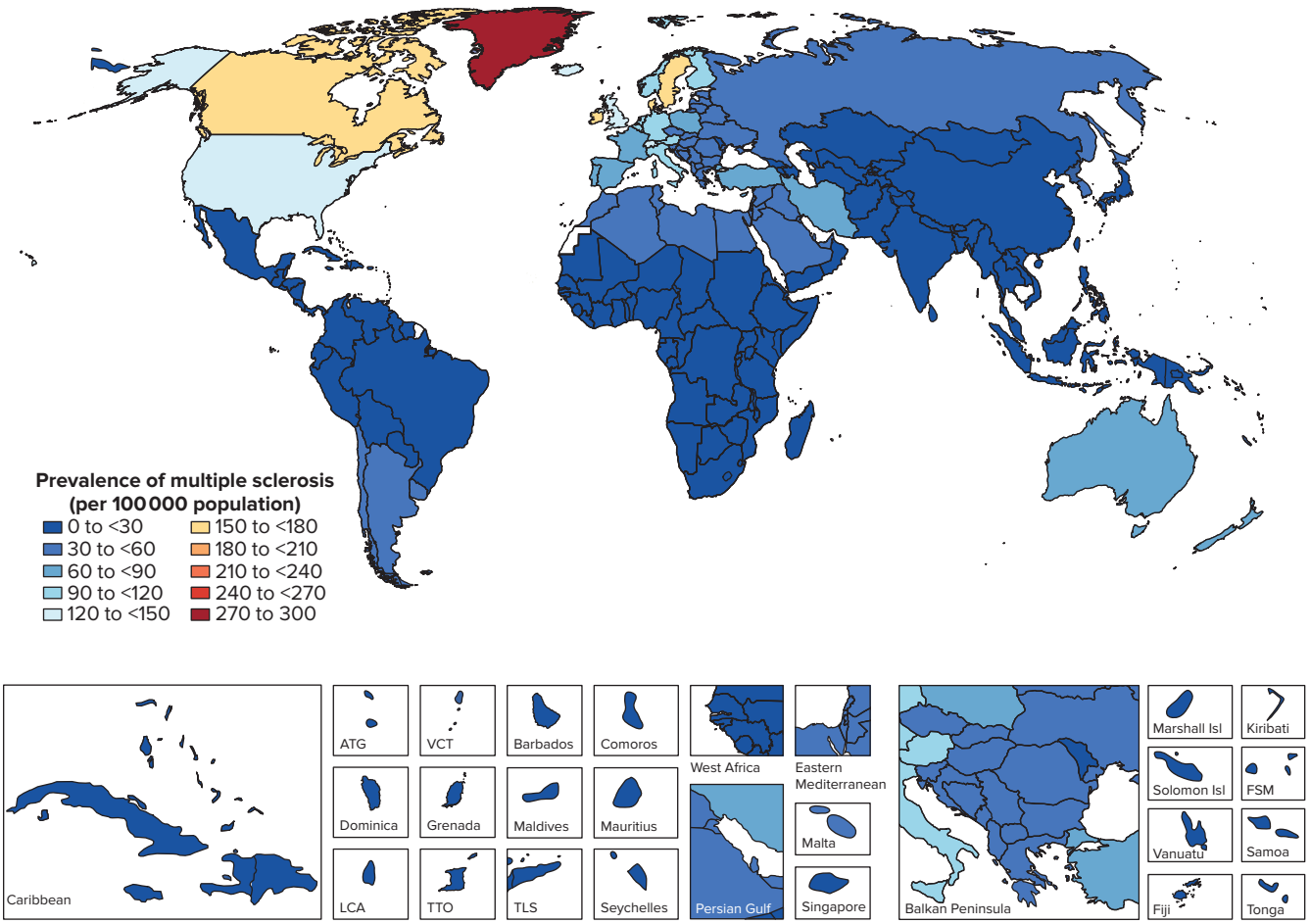



**FIGURE 3.5** **Distribution of Multiple Sclerosis Cases** A world map shows the uneven distribution of cases of multiple sclerosis, with particularly high numbers of cases in northern regions, including Canada.

GBD 2016 Multiple Sclerosis Collaborators. Global, regional, and national burden of multiple sclerosis 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *The Lancet Neurology*. 21 Jan 2019. doi:10.1016/ S1474-4422(18)30443-5.

(Chapeton et al., 2012). Before an impulse can cross the synaptic gap, it must be converted into a chemical signal.

The chemical communication between neurons is called synaptic transmission. There are four steps in this process (Figure 3.7):

1. As we have learned, neurotransmitters are *assembled* in the cell body.
2. The neurotransmitters are *moved to and stored in* very tiny synaptic vesicles (*sacs*) within the terminal buttons.
3. When an action potential reaches the terminal button, it triggers the synaptic vesicles to fuse with the presynaptic membrane, causing the *release* of neurotransmitter molecules into the synaptic gap. The neurotransmitter molecules flood the synaptic gap. Their movements are random, but some of them make their way to receptor sites in the postsynaptic membrane.
4. The neurotransmitter *binds* to the receptor of the next neuron. This binding causes a small shift in the voltage of the next cell. If enough receptors are activated so that the next cell's voltage reaches that critical tipping point, that cell has an action potential.

These four steps—assembling, moving and storing, releasing, and binding—all involve neurotransmitters affecting the probability that the next cell will fire. However, there needs to be ways to stop this process. After all, as much as it is necessary to start a car,

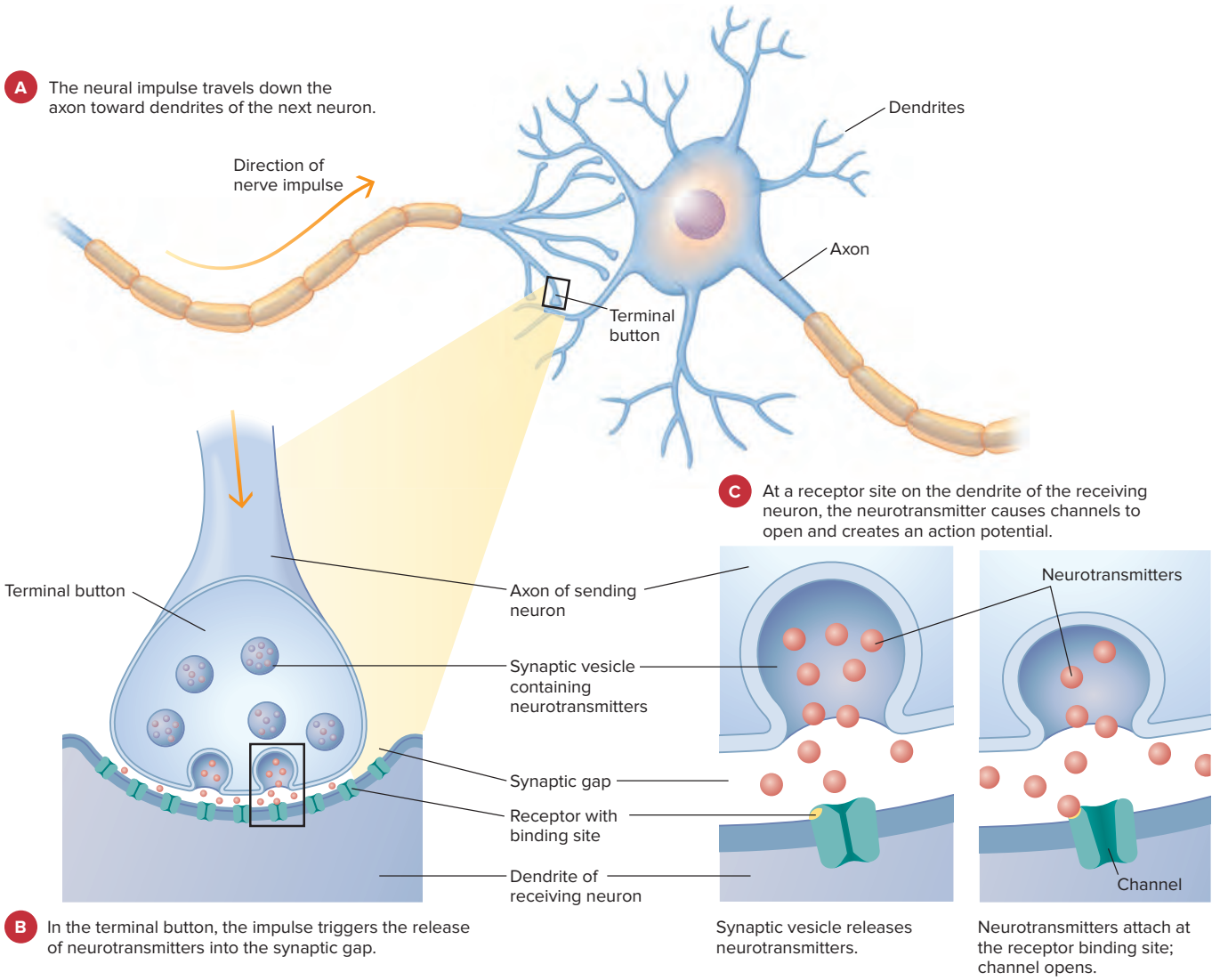



**FIGURE 3.6** **How Synapses and Neurotransmitters Work** (*A*) The axon of the presynaptic (sending) neuron meets dendrites of the postsynaptic (receiving) neuron. (*B*) This is an enlargement of one synapse, showing the synaptic gap between the two neurons, the terminal buttons, and the synaptic vesicles containing a neurotransmitter. (*C*) This is an enlargement of the receptor site. Note how the neurotransmitter opens the channel on the receptor site, triggering the neuron to fire.

it would be impractical to not also have some way of turning off a car's engine. To stop the process of synaptic transmission, there are also four steps (Figure 3.7):

1. Some neurotransmitters bind to receptors on the membrane of the cell they were released from. Stimulation of these receptors, called *autoreceptor activation*, instructs the neuron to stop releasing the neurotransmitter molecules into the synaptic gap.
2. One neurotransmitter (there are about ten neurotransmitters that do the bulk of the communication, and dozens of additional chemical messengers as well) is broken down, or *deactivated*, in the synaptic gap by enzymes.
3. After being released into the synaptic gap, some of the neurotransmitter is reabsorbed by the axon that released it, to await the next neural impulse. This reabsorption, called *reuptake,* is perhaps the original recycling process.
4. If more neurotransmitter is reabsorbed than is needed and can be stored, the excess neurotransmitter is *degraded* by enzymes and discarded.

These four processes, autoreceptor activation, deactivation, reuptake, and degradation, stop the communication between cells until the next action potential occurs.

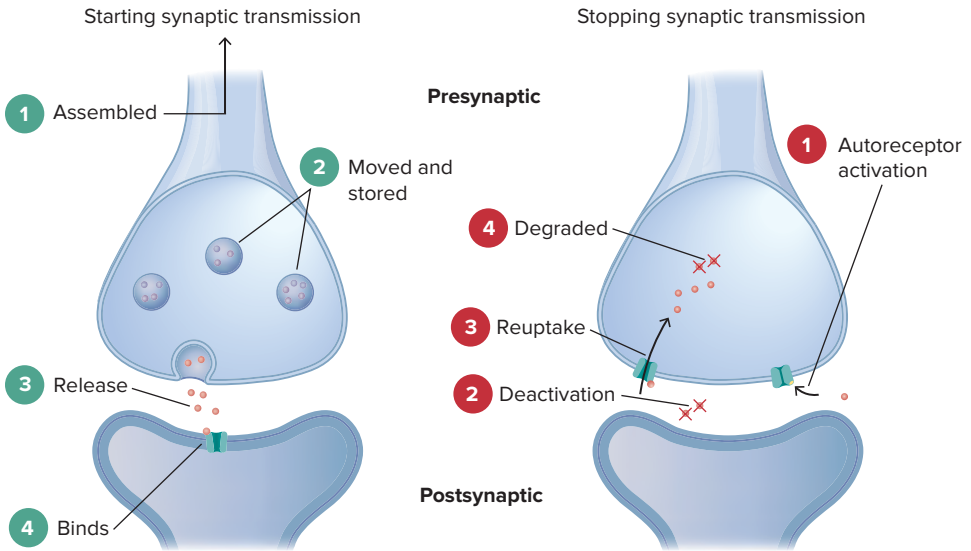



**FIGURE 3.7 Synaptic Transmission** There are four steps involved in starting synaptic transmission (left side of figure) and four steps involved in stopping it (right side of figure). The numbers on this figure correspond to the numbers in the text below where the steps are described.

## WHAT ARE NEUROCHEMICAL MESSENGERS?

Neurotransmitters are like pieces of a puzzle, and the receptor sites on the next neuron are differently shaped spaces. If the shape of a receptor site corresponds to the shape of a neurotransmitter molecule, the neurotransmitter fits into the receptor site, so that the neuron receives the signals coming from the previous neuron. You might think of the receptor site as a keyhole in a lock and the neurotransmitter as the key that fits that lock.

There are many different neurotransmitters. Each plays specific roles and functions in a specific pathway. Some neurotransmitters stimulate or excite neurons to fire—when they bind to receptors they nudge that next cell from –70mV closer to the tipping point of −45mV. Neurotransmitters that increase the chance of a neuron firing are called *excitatory*. Other neurotransmitters inhibit neurons from firing—they make the voltage of the cell even more negative, pushing it away from the tipping point. Neurotransmitters that decrease the chance of a neuron firing are called *inhibitory*. Some neurotransmitters are both excitatory *and* inhibitory.

Most individual neurons secrete only one type of neurotransmitter, but often many different neurons are simultaneously secreting different neurotransmitters into the synaptic gaps of a single neuron. At any given time, a neuron is receiving a mixture of messages from the neurotransmitters. Usually the binding of an excitatory neurotransmitter from one neuron will not be enough to trigger an action potential in the receiving neuron. Triggering an action potential often requires a number of neurons sending excitatory messages simultaneously, or fewer neurons sending inhibitory messages.

Scientists do not know exactly how many neurotransmitters exist, and more are being discovered. In organisms ranging from snails to whales, neuroscientists have found the same neurotransmitter molecules that our own brains use. To get a better sense of what neurotransmitters do, let's consider eight that have major effects on behaviour.

**WHAT IS ACETYLCHOLINE?** *Acetylcholine (ACh)* usually stimulates the firing of neurons and is involved in muscle action, learning, and memory (Ferreira-Vieira et al., 2016). ACh is found throughout the central and peripheral nervous systems. The venom from the bite of the black widow spider causes ACh to gush into the synaptic gaps between the spinal cord and skeletal muscles, producing violent muscle spasms and weakness. Botox treatments for fine lines and wrinkles in the face involve the role of ACh in muscle function. Botox is a brand-name product made from a bacterial

*The neurotransmitter-like venom of the black widow spider does its harm by disturbing neurotransmission.*
Centers for Disease Control

poison called botulin. Botulin destroys ACh so that when someone gets an injection of Botox, their facial muscles—which are activated by ACh—are prevented from moving, with the result that wrinkles do not form.

Individuals with Alzheimer disease, a degenerative brain disorder that gradually destroys memory, have an acetylcholine deficiency (Hachisu et al., 2015). Some of the drugs being developed to alleviate Alzheimer symptoms are designed to compensate for this deficiency.

**WHAT IS GABA?** *GABA (gamma aminobutyric acid)* is found throughout the central nervous system. It is believed to be present in as many as one-third of the brain's synapses. GABA plays a key function in the brain by inhibiting many neurons from firing (Purkayastha et al., 2015); indeed, GABA acts like the brain's brake pedal, helping to regulate neuron firing and control the precision of the signal being carried from one neuron to the next. Low levels of GABA are linked with anxiety (Li et al., 2015). Valium and other antianxiety drugs increase the inhibiting effects of GABA.

**WHAT IS GLUTAMATE?** *Glutamate* is the most prevalent neurotransmitter. If GABA is the brain's brake pedal, glutamate is the accelerator. Glutamate has a key role in exciting many neurons to fire and is especially involved in learning and memory (Purkayastha et al., 2015). Too much glutamate can overstimulate the brain and trigger migraine headaches or even seizures. Glutamate is also thought to be a factor in anxiety, depression, schizophrenia, Alzheimer disease, and Parkinson disease (Volk et al., 2015). Because of the widespread expression of glutamate in the brain, glutamate receptors have increasingly become the targets of drug treatment for a number of neurological and psychological disorders (Bishop et al., 2015).

**WHAT IS NOREPINEPHRINE?** Stress stimulates the release of another neurotransmitter—*norepinephrine* (Sun et al., 2015). When we respond to stress, multiple things must happen at once, and so it is not surprising that norepinephrine (also called *noradrenaline*) has a number of effects on the body. If you think of all the things your body does when you experience extreme fear, for instance, you can guess at some of the ways norepinephrine affects your body. It *inhibits* the firing of neurons in the central nervous system, but it simultaneously *excites* the heart muscle, intestines, and urogenital tract.

This neurotransmitter also helps to control alertness. Too much norepinephrine triggers agitation or jumpiness. For example, amphetamines and cocaine cause hyperactive, manic states of behaviour by rapidly increasing norepinephrine levels in the brain (Shorter et al., 2015). However, too little norepinephrine is associated with depression.

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

**WHAT IS DOPAMINE?** *Dopamine* helps to control voluntary movement and affects sleep, mood, attention, learning, motivation, and the ability to recognize opportunities for rewarding experiences in the environment (Berke, 2018; Meyer, 2012). Stimulant drugs often act by increasing dopamine in the synapse. For example, cocaine and amphetamines produce excitement, alertness, elevated mood, decreased fatigue, and sometimes increased motor activity mainly by activating dopamine receptors (Cheng et al., 2015). Dopamine is related to the personality trait of extroversion (being outgoing and gregarious) (Wacker & Smillie, 2015). Problems in regulating dopamine are associated with a variety of psychological disorders, especially schizophrenia (Whitton et al., 2015), a severe disorder we examine in Chapter 14.

Low levels of dopamine are associated with Parkinson disease, a degenerative neurological disorder in which a person develops jerky physical movements and a tremor, and has difficulty with speech and walking (Fallon et al., 2015). This disease affects over six million people worldwide, including over 100,000 people in Canada (GBD 2015

Neurological Disorders Collaborator Group, 2018); actor Michael J. Fox has been diagnosed with this disease. Parkinson impairs coordinated movement to the point that just walking across a room can be a major ordeal or even impossible.

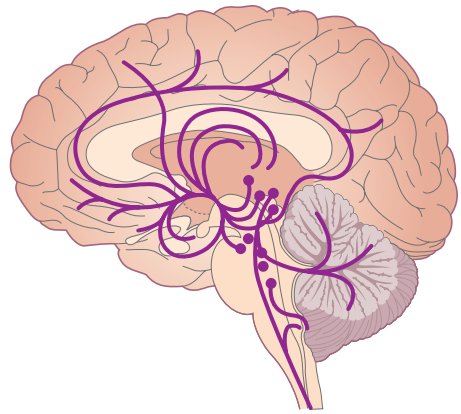


**FIGURE 3.8 Serotonin Pathways** Each of the neurotransmitters in the brain has specific pathways in which it functions. Shown here are the pathways for serotonin.

**WHAT IS SEROTONIN?** *Serotonin* is involved in the regulation of sleep, mood, attention, and learning. In regulating states of sleep and wakefulness, it teams with acetylcholine and norepinephrine. Serotonin plays a role in mood regulation, with low levels of serotonin associated with increased depression (Jenkins et al., 2016).

Medications used to treat depression often act on serotonin, slowing down its reuptake into the terminal buttons and thereby increasing brain levels of serotonin (Little et al., 2006). There are 15 known types of serotonin receptors in the brain (Hoyer et al., 2002), and each type of antidepressant drug affects different receptors. Importantly, some researchers have criticized the view that serotonin is linked to depression (Healy, 2015). In fact, some researchers have concluded that drug treatments that increase the availability of serotonin to the brain have no meaningful effect on depression but do increase the risk of side effects (Katakam et al., 2018). Figure 3.8 shows the brain pathways for serotonin.

**WHAT ARE ENDORPHINS?** *Endorphins* are natural opiates—substances that depress nervous system activity and eliminate pain—that mainly stimulate the firing of neurons. As opiates, endorphins shield the body from pain and elevate feelings of pleasure. A long-distance runner, a woman giving birth, and a person in shock after a car wreck all have elevated levels of endorphins (Bali et al., 2015).

As early as the fourth century BCE, the Greeks used wild poppies to induce euphoria. More than 2,000 years later, the magical formula behind opium's addictive action was finally discovered. In the early 1970s, scientists found that opium plugs into a sophisticated system of natural opiates that lie deep within the brain's pathways (Pert, 1999; Pert & Snyder, 1973). Morphine (the most important narcotic of opium) mimics the action of endorphins by stimulating receptors in the brain involved with pleasure and pain (Navratilova et al., 2015).

**WHAT IS OXYTOCIN?** *Oxytocin* is a hormone and neurotransmitter that plays an important role in the experience of love and social bonding. A powerful surge of oxytocin is released in mothers who have just given birth, and oxytocin is related to the onset of lactation (milk production) and breastfeeding (Vrachnis et al., 2011). Oxytocin, however, is involved in more than a mother's ability to provide nourishment for her baby. It is also involved in making babies more attractive and rewarding, thus contributing to the experience of some parents who find themselves "in love at first sight" with their newborn (Olazábal, 2018).

Oxytocin is released during a sexual orgasm and is thought to play a role in the human tendency to feel pleasure during orgasm and to form emotional bonds with romantic partners (Khajehei & Behroozpour, 2018). Higher levels of oxytocin are present in new lovers and higher levels persist six months later compared to non-attached single young adults (Schneiderman et al., 2012). Higher oxytocin levels are associated with positive affect, affectionate touch, and preoccupation with one's partner and the relationship.

Provocative research also has linked oxytocin to the way that some individuals respond to stress (Neumann & Landgraf, 2012). According to Shelley Taylor (2011a, 2011b), women under stress do not experience the classic "fight or flight" response—rather, the influx of oxytocin they experience suggests that women may seek bonds with others when under stress. This response has been referred to as "tend and befriend" and it more accurately represents the stress response of women (von Dawans et al., 2019).

You would probably not be surprised to hear that oxytocin has fascinated not only scientists but the public as well. It sounds like a natural love potion. Recently, some research on the effects of oxytocin on interpersonal trust has been called into question. To read about that work, see the Critical Controversy.

# critical controversy

## *Does Oxytocin Make People More Trusting?*

Unsurprisingly, oxytocin has been one of the most studied chemicals in all of the behavioural sciences. Imagine: a neurotransmitter that appears to be a kind of natural love potion. Some have called it "liquid trust"! Even better, oxytocin can be administered to people in a simple nasal spray.

Some early experiments involving administering oxytocin produced fascinating results. For instance, one study examined whether oxytocin would lead people to be more trusting of others with their personal information (Mikolajczak et al., 2010). Participants were randomly assigned to one of two groups. One group received a nasal spray containing oxytocin; the other group received a nasal spray containing a placebo. The dependent variable, trust, was operationalized using "the envelope task." For this task, participants completed a questionnaire containing a series of highly personal, intimate questions (for example, preferences for various sexual practices). Participants were then asked to place the questionnaire in an envelope and give it to the experimenter (who assured the participants that they would not look at their responses). Participants were informed that they could seal the envelope and were offered tape for the seal. The key dependent measure was whether (and how) participants sealed the envelope.

Results were dramatic: Over 80 percent of those in the placebo group sealed the envelope with tape, compared to less than 7 percent in the oxytocin group. In addition, 60 percent of those in the oxytocin group did not seal the envelope at all (Mikolajczak et al., 2010). Maybe oxytocin really is liquid trust! Or is it?

Years later, the same team of researchers tried to reproduce their findings, but they couldn't (Lane et al., 2015). In fact, in two studies they found that oxytocin did not affect how individuals treated the envelope at all: Those who received oxytocin were just as protective of their personal information as those in the placebo group. What could explain the difference?

The earlier study and the newer ones differed in one key way: The original study was only "single blind." This means that, although participants did not know whether they received oxytocin or the placebo in the nasal spray, the experimenter interacting with them did. Mikolajczak and colleagues now consider that the experimenter treated participants in subtly different ways, leading the oxytocin group to behave differently (Lane et al., 2015).

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Replication is the foundation of good science. It is important for experimenters to verify their own work, and the work of others, under different conditions. This example shows us that even clever research designs require rigorous standards.

**WHAT DO YOU THINK?**

- If you thought that someone you were interacting with had been given "liquid trust," how might you behave?
- Can you think of a different way to test the hypothesis that oxytocin is liquid trust?

## HOW DO DRUGS AND NEUROTRANSMITTERS INTERACT?

Recall that neurotransmitters fit into the receptor sites like keys in keyholes. Other substances, such as drugs, can sometimes fit into those receptor sites as well, producing a variety of effects. Many animal venoms, such as that of the black widow spider mentioned above, act by disturbing neurotransmission. Similarly, most drugs that influence behaviour do so mainly by influencing the work of neurotransmitters.

Drugs that mimic or increase the effects of a neurotransmitter are called *agonists*. Drugs that block the effects of the neurotransmitter are called *antagonists*. For example, the drug morphine mimics the actions of endorphins by stimulating receptors in the brain and spinal cord associated with pleasure and pain, producing feelings of pleasure. Other drugs, such as naloxone, can block a neurotransmitter's action by preventing it from getting into the receptor site. Drugs used to treat schizophrenia, for example, interfere with the activity of dopamine.

## How Do Groups of Neurons Communicate?

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

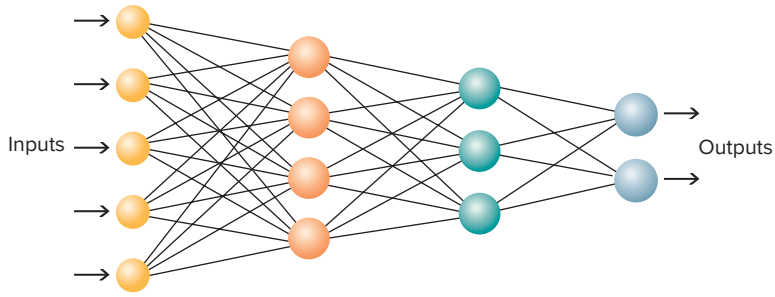



**FIGURE 3.9** **An Example of a Neural Network** *Inputs* (information from the environment and from sensory receptors, such as the details of a person's face) become embedded in extensive connections between neurons in the brain. This embedding process leads to *outputs* such as remembering the person's face.

Most information processing occurs when information moves through **neural networks**—interconnected pathways of nerve cells that integrate sensory input and motor output. For example, as you read this sentence, the input from your eyes is transmitted to your brain and then passed through many neural networks, which translate the characters on the page into neural codes for letters, words, associations, and meanings. Some of the information is stored in the neural networks, and, if you read aloud, some is passed on as messages to your lips and tongue.

● **neural networks** Networks of nerve cells that integrate sensory input and motor output.

Neural networks can take years to develop and make up most of the brain. Working in networks allows neurons to amplify the brain's computing power (Park & Friston, 2013; Wolf et al., 2013). Figure 3.9 shows a simplified drawing of a neural network and gives you an idea of how the activity of one neuron is linked with that of many others.

Some neurons have short axons and communicate with other nearby neurons. Other neurons have long axons and communicate with circuits of neurons some distance away. These neural networks are not static. They can be altered through changes in the strength of synaptic connections.

Any piece of information, such as your friend's name, might be embedded in hundreds or even thousands of connections between neurons. In this way, human activities such as being attentive, memorizing, and thinking are distributed over a wide range of connected neurons. Differences in these neural networks are responsible for the differences observed in those London cab drivers discussed earlier in this chapter.

### apply your knowledge

How do we find a new restaurant or a hotel in an unfamiliar city? We rely far less on paper maps and our internal resources to navigate our world than we did in the past. How might our increased reliance on external technology, such as GPS systems, impact our brains? To study this, researchers assigned healthy participants to two groups (Fajnerová et al., 2018). People in the experimental group spent three months navigating their worlds with augmented-reality glasses equipped with a GPS guidance system. People in the control group spent three months with no special technology. After just three months, the hippocampus, the part of the brain that is essential for navigating the world, showed fewer connections with other brain regions in the experimental group.

Neuroscientists often use the phrase "use it or lose it" in reference to the brain's connections and functions. By reducing the effort required of our brains by using external technologies, we may be reducing the complexity and capacities of our brain. Does knowing this make you want to change your reliance on GPS devices?

# 3. WHAT ARE THE MAJOR PARTS OF THE BRAIN AND HOW DO WE STUDY THEM?

The intricate networks of neurons in the living brain are invisible to the naked eye. Fortunately, technology is available to help neuroscientists form pictures of the structure and organization of neurons and of the larger systems they make up. Some technology goes beyond pictures, and shows movies of the activity of the brain. This section explores

techniques that scientists use in brain research, and what these tools reveal about the brain's structures and functions. We pay special attention to the cerebral cortex, the region of the brain that is most relevant to psychology.

## How Do Researchers Study the Brain and Nervous System?

Early knowledge of the human brain came mostly from studies of individuals who had suffered brain damage from injury or disease or who had brain surgery to relieve another condition. Modern discoveries have relied largely on technology that enables researchers to "look inside" the brain while it is at work. Increasingly, studies combine multiple techniques to more fully capture the brain and its activity (Jorge et al., 2014). Let's examine some of these innovative techniques.

### WHAT IS BRAIN LESIONING?

*Brain lesioning* involves damaging brain tissue, sometimes to alleviate symptoms and sometimes to mimic an injury or disease. In the laboratory, neuroscientists produce lesions in animals and then assess the effects on the animals' behaviour. They create the lesions by surgically removing brain tissue; destroying tissue with a laser, cold, heat, or electricity; or they eliminate the tissue by injecting it with a drug. Examining the person or animal following the lesioning gives researchers a sense of the function of the part of the brain that has been damaged or removed.

Do you know anyone who has experienced a stroke or brain damage from an injury? These events create lesions in the brain. Identifying the areas affected by a stroke or brain injury and then observing the aspects of a person's life that are affected by the injury can help researchers identify the functions associated with specific brain areas (de Guise et al., 2015; Farinelli et al., 2015).

### WHAT IS ELECTRICAL RECORDING?

Why do neuroscientists buy so many bathing caps? They use them, after fitting them with small metal discs called surface electrodes, to view the activity of the brain using an *electroencephalogram (EEG).* An EEG records the electrical activity of thousands of neurons in the brain. Recall that when neurotransmitters bind to a postsynaptic receptor, there are small changes in the voltage of the cell. EEGs record these changes. Electrodes placed on the scalp detect brain-wave activity, which is recorded on a chart known as an *electroencephalograph* (Figure 3.10). This device can assess brain damage, sleep disorders, seizures, and other problems (Gradisnik et al., 2015; Muraja-Murro et al., 2015).

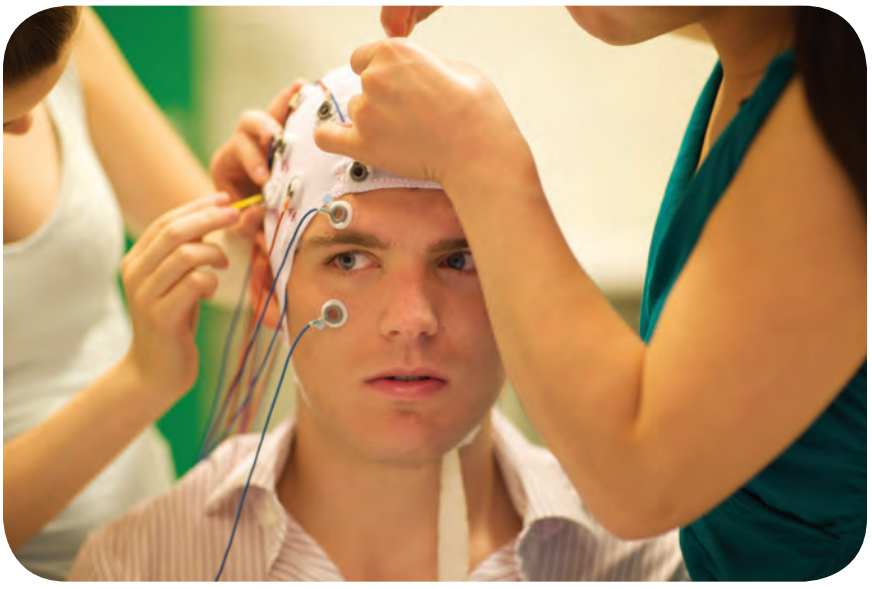


**FIGURE 3.10** **An EEG Recording** The electroencephalogram (EEG) is widely used in sleep research. The device has led to some major breakthroughs in understanding sleep by showing how the brain's electrical activity changes during sleep.


EEGs have been used in research examining the brain and happiness. Ekman, Davidson, and Friesen (1990) measured EEG activity during emotional experiences provoked by watching film clips. Participants watched amusing clips (such as a puppy playing with flowers and monkeys taking a bath) as well as clips likely to provoke fear or discomfort (a leg amputation and a third-degree burn victim). How does the brain respond to such stimuli? EEGs showed that while

watching the amusing clips, people tended to exhibit more left than right prefrontal activity. In contrast, when the participants viewed the unpleasant or fear-provoking films, the right prefrontal area was generally more active than the left.

Do these differences generalize to overall differences in feelings of happiness? They just might. Heather Urry and her colleagues (2004) found that individuals with more left than right prefrontal activity (what is called *prefrontal asymmetry*) tend to rate themselves higher on a number of measures of well-being, including self-acceptance, positive relations with others, purpose in life, and life satisfaction.

EEGs are helpful in a wide range of treatment and diagnosing applications ranging from brain tumours to monitoring patients in medically induced comas to make sure they get the right amount of anaesthesia. However, EEGs are limited in that they can't discriminate the activity of different species. Your EEG recordings are indistinguishable from those of a cockroach.

Not all recordings of electrical brain activity are made with surface electrodes attached to the scalp. *Single-unit recordings* provide information about a single neuron's electrical activity by inserting a thin probe in or near an individual neuron. The probe transmits the neuron's electrical activity to an amplifier so that researchers can "see" the activity (Teleńczuk et al., 2015).

## WHAT IS BRAIN IMAGING?

For decades, X rays have been used to reveal damage inside the body, both in the brain and in other locations. A single X ray of the brain gives limited information, however, because it only shows a two-dimensional image of the three-dimensional interior of the brain. An improved imaging technique called *computerized axial tomography* (*CAT scan* or *CT scan*) produces a three-dimensional image obtained from a series of X rays of the head that are assembled into a composite image by a computer. The CT scan provides valuable information about the location and extent of damage involving stroke, language disorder, or loss of memory (Muschelli et al., 2015). There are concerns that exposing the brain to X rays, especially with CT scans when a series of X rays are taken, may be harmful. Research has associated CT scans during childhood with an increased risk of brain tumours (Meulepas et al., 2019).

Another imaging method, *positron-emission tomography (PET scan),* measures metabolic changes in the brain related to activity. PET measures the amount of glucose in various brain regions and sends this information to a computer for analysis. Most cars use gasoline for fuel, whereas brains primarily use the sugar glucose. As the activity of a neuron increases, it uses more glucose. Tracing the amounts of glucose used by the brain generates a picture of the brain's activity. PET scans have been used in a wide variety of studies (Ossenkoppele et al., 2015; Spadoni et al., 2015). PET scans can be used to examine the amount of neurotransmitters waiting to be released into the synaptic gap in neurons in the brain (Jabbi et al., 2013).

In addition to CT and PET scans, another technique used to image the brain is *magnetic resonance imaging (MRI).* MRI involves creating a magnetic field around a person's body and using radio waves to construct images of the person's tissues and biochemical activities. The magnetic field used to create an MRI image is over 50,000 times more powerful than the earth's magnetic field (Parry & Matthews, 2002). MRI takes advantage of the fact that the human brain contains a great deal of water (like the rest of the body, the brain is 70 percent water). Within each water molecule there are hydrogen atoms (remember, water is $H_2O$). These hydrogen atoms are like tiny magnets. When hydrogen atoms are exposed to a very strong magnetic field, they align themselves with it. Neurons contain more water than other brain tissues, and that difference is what provides the high resolution brain images that MRI produces.

Getting an MRI scan involves lying still inside a large metal tube. MRI scans provide an exquisitely detailed picture of the architecture of the brain and allow researchers to see if and how experience affects brain structure. MRI generates very clear pictures of the brain's interior without injecting the brain with a substance, and (unlike X rays) does

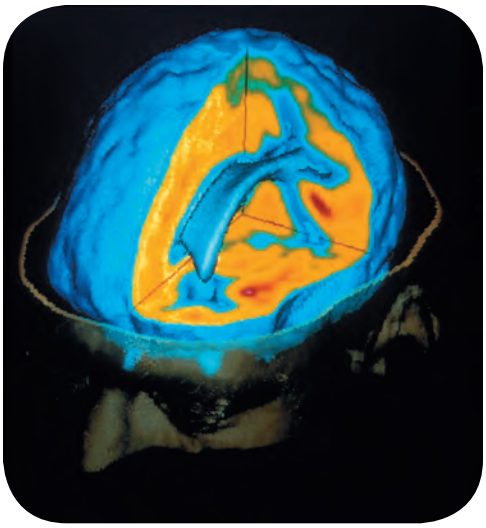


**FIGURE 3.11 Functional Magnetic Resonance Imaging (fMRI)** Through fMRI, scientists can literally see what areas of the brain are active during a task by monitoring oxygenated blood levels.

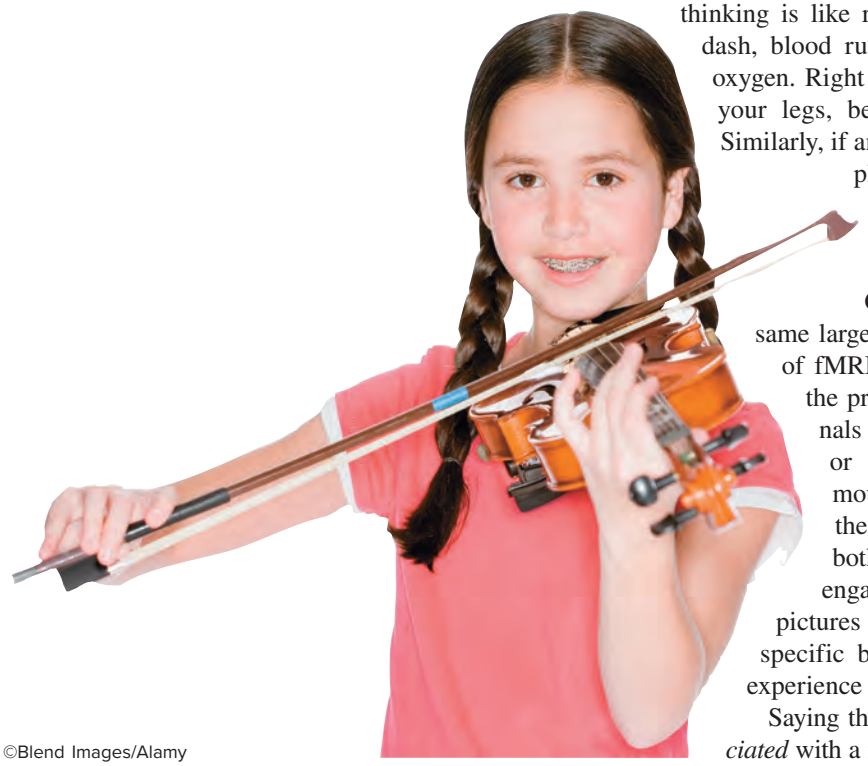


not pose a problem of radiation overexposure. As a result, problems associated with MRIs are rare. For some people, being enclosed in a tight space and being exposed to the loud noise are unwelcome. Given the powerful magnets used in MRI, people with implanted medical devices (e.g. artificial joints, pacemakers, and cochlear implants) are often not given MRIs. Additionally, metal objects including pens and cell phones can become dangerous projectiles if they are mistakenly brought near the equipment. Also, the ink used in some tattoos may contain metals which can distort the image from an MRI and cause skin irritation and swelling (Ibrahim et al., 2020). People with tattoos who are scheduled to have an MRI should be cautious. Most small tattoos (less than 20 cm in length and less than 5 percent of the body covered) are likely safe (Callaghan et al., 2019), but the type of ink in a tattoo will be a factor in deciding whether an MRI is safe (Zanovello et al., 2020).

MRI has been used to document the link between the number of years a person has practised musical skills (playing the piano or violin, for example) and the size of the brain region that is responsible for controlling hand movements (Gärtner et al., 2013). The structure of the brains of those who have practised a musical instrument differ from those who have not. These brain differences illustrate again that behaviour can influence the structure of the brain. Note that these brain changes reflect, as well, the development of neural networks.

Although MRI scans can reveal considerable information about brain *structure,* they cannot portray brain *function.* To portray function, other techniques, such as *functional magnetic resonance imaging,* or *fMRI,* are required. You can think of MRI as providing a detailed photo of the brain and fMRI as providing a movie of the activity of the brain. fMRI allows scientists literally to see what is happening in the brain while it is working (Le Bihan, 2016) (Figure 3.11).

Like the PET scan, fMRI rests on the idea that mental activity is associated with physical changes in the brain. Although PET relies on the use of glucose as fuel for thinking, fMRI exploits changes in blood oxygen that accompany brain activity. When part of the brain is working, oxygenated blood rushes into this part. More oxygen is delivered than is needed. In a sense, fMRI is based on the fact that thinking is like running sprints. When you run a 100-metre dash, blood rushes to the muscles in your legs, carrying oxygen. Right after you stop, you might feel a tightness in your legs, because the oxygen has not all been used. Similarly, if an area of the brain is hard at work—for example, solving a math problem—the increased activity leads to a surplus of oxygenated blood. This "extra" oxygen allows the brain activity to be imaged.





Getting an fMRI involves reclining in the same large metal tube as does an MRI, but in the case of fMRI the person actively does something during the procedure. The person may listen to audio signals sent by the researcher through headphones, or watch visual images on a screen that is mounted overhead, or make decisions. During these procedures, pictures of the brain are taken, both while the brain is resting and while it is engaging in the activity. By comparing the at-rest pictures to the activity pictures, fMRI reveals what specific brain activity is associated with the mental experience being studied.

Saying that fMRI tells us about the brain activity *associated* with a mental experience is a *correlational* statement.

## intersection

### *Environmental Psychology and Neuroscience: How Does Spending Time in Nature Affect the Brain?*

One way that human beings make themselves miserable is by ruminating on negative events. Rumination, or brooding, involves prolonged, self-focused negative thinking. Rumination can involve replaying the same problem or personal mistake over and over.

The remedy for rumination is pretty obvious: Think about something else. But, in order for those other thoughts to truly combat rumination, they must be compelling. Does nature provide an excellent distraction from negative thoughts? A study by Gregory Bratman and his colleagues (2015) sought to answer this question.

The researchers randomly assigned participants to take a 90-minute walk either in an urban setting or in a natural environment. The dependent variables measured the effects of nature in two ways. First, participants rated how much their thoughts involved rumination, before and after the walk. Second, fMRI was used to measure brain activation in a brain region called the subgenual prefrontal cortex. This area of the brain is active during negative emotional states, such as sadness and stress. The results showed that after the nature walk, participants showed declines in rumination and in activation in the subgenual prefrontal cortex. Among those who walked in the urban setting, no differences were found (Bratman et al., 2015).

These results fit with other research demonstrating that spending time in nature enhances well-being (Passmore et al., 2017). Consistent with this idea is research that shows that those who have window views of nature display better memory, greater attention (Taylor et al., 2002), and higher levels of happiness (Kaplan, 2001) than those who don't. Such studies are especially important in today's world. More than half of modern humans live in urban environments, and estimates are that by 2050 over 70 percent of people will live in urban settings (Bratman et al., 2015).

Our brains are marvellously adaptable, but we might want to bear in mind the environments within which our brains evolved. Taking your brain back to nature may be just the remedy for whatever is on your mind.

## apply your knowledge

Where is the brain's funny bone? Many studies have delivered jokes to people during an fMRI to try and identify the regions of the brain that are activated by humour. Recent research suggests the brain regions that show increased activity when hearing a joke depend on the type of joke being told (Chan et al., 2018). For example, when researchers used self deprecating humour ("If each of my admirers were a strand of hair, I would be bald") the brain areas activated were different than when more aggressive humour ("If each of your admirers were a strand of hair, you would be bald") was used.

As we saw in Chapter 2, correlations point to the *association* between variables, not necessarily to the potential causal link between them. For example, although identifying that an image in a picture is a cat may relate to activation in a particular brain area, we do not know if recognizing the cat *caused* the brain activity (Dien, 2009). Still, fMRI is used in experiments in very interesting ways. To read about a fascinating study that tracked the effects of spending time in nature on the brain, see the Intersection above.

Functional MRI is used not only to establish links between brain areas and behaviours, but also to understand the links among different brain areas. *Functional connectivity* refers to the correlation between different brain areas or the degree to which their operation is dependent on each other. Studies of functional connectivity are important because they can tell us about how the brain operates, as a whole, in accomplishing the many complex tasks that it does (Rohr et al., 2015).

An additional method for studying brain functioning, and one that *does* allow for causal inferences, is *transcranial magnetic stimulation (TMS)* (Parkin et al., 2015). First introduced in 1985 (Barker et al., 1985), TMS is often combined with brain-imaging

techniques to establish causal links between brain activity and behaviour, to examine neuronal functioning following brain-injuring events such as accidents and strokes, and even to treat some neurological and psychological disorders.

During TMS, magnetic coils are placed near a person's head and directed at a particular brain area. TMS uses a rapidly changing magnetic field which causes brief electrical pulses in the brain, and these pulses trigger action potentials in neurons (Parkin et al., 2015). Immediately following this burst of action potentials, activity in the targeted brain area is temporarily inhibited, causing what is known as a *virtual lesion*. Completely painless, this technique, when used with brain imaging, allows scientists to examine the role of various brain regions. If a brain region is *associated* with a behaviour, as demonstrated using fMRI or PET, then the temporary disruption of processing in that area should disrupt that behaviour as well.

In order to develop an increasingly comprehensive and accurate understanding of the brain, research relies on the results from multiple studies using different techniques. For example, EEG and fMRI were used to identify that the left pre-supplementary motor cortex was associated with our ability to express and recognize happy and sad facial expressions (Seitz et al., 2008). Then, TMS was used to show that people's ability to recognize happy faces, but not angry or fearful faces, was impaired when the magnetic fields from the TMS disrupted functioning of this brain region (Rochas et al., 2013). The initial correlational findings from the fMRI and EEG studies informed later research that used TMS to identify a function of the pre-supplementary motor cortex.

TMS is not only used in research but also in treatment of a wide range of health challenges. For example, TMS has been used to help people with Alzheimer disease, schizophrenia, nicotine cravings, and depression (Li et al., 2013; Paus & Barrett, 2004).

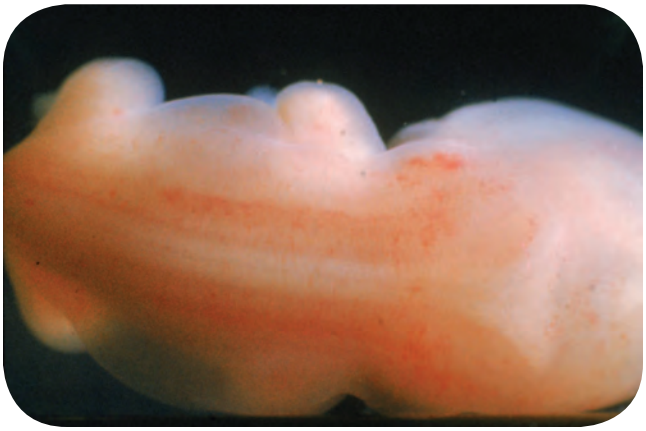


**FIGURE 3.12 Embryological Development of the Nervous System** The photograph shows the primitive tubular appearance of the nervous system at six weeks in the human embryo.


## How Is the Brain Organized?

As a human embryo develops inside its mother's womb, the nervous system begins forming as a long, hollow tube on the embryo's back. About three weeks after conception, cells making up the tube differentiate into a mass of neurons, most of which then develop into three major regions of the brain: the hindbrain, which is adjacent to the top part of the spinal cord; the midbrain, which rises above the hindbrain; and the forebrain, which is the uppermost region of the brain (Figure 3.12).

### WHAT IS THE HINDBRAIN?

The **hindbrain**, located at the skull's rear, is the lowest portion of the brain. The three main parts of the hindbrain are the medulla, cerebellum, and pons. Figure 3.13 illustrates these brain structures.

The *medulla* begins where the spinal cord enters the skull. The medulla controls many vital functions, such as breathing and heart rate. It also regulates our reflexes. The *pons* is a bridge in the hindbrain that connects the cerebellum and the brain stem. It contains several clusters of fibres involved in sleep and arousal (Mijangos-Moreno et al., 2015).

Taken together, the medulla, pons, and much of the hindbrain (as well as the midbrain, discussed below) are called the **brain stem**, which gets its name because it looks like a stem. Embedded deep within the brain, the brain stem connects with the spinal cord at its lower end and then extends upward to encase the reticular formation in the midbrain. The brain stem is the oldest part of the brain, having evolved more than 500 million years ago, when organisms needed to breathe out of water (Hagadorn & Seilacher, 2009). Groups of cells in the brain stem determine alertness and regulate basic survival functions such as breathing, heartbeat, and blood pressure (Chivers et al., 2015; Lee et al., 2015).

- **hindbrain** Located at the skull's rear, the lowest portion of the brain, consisting of the medulla, cerebellum, and pons.

- **brain stem** The stemlike brain area that includes much of the hindbrain (excluding the cerebellum) and the midbrain; it connects with the spinal cord at its lower end and then extends upward to encase the reticular formation in the midbrain.

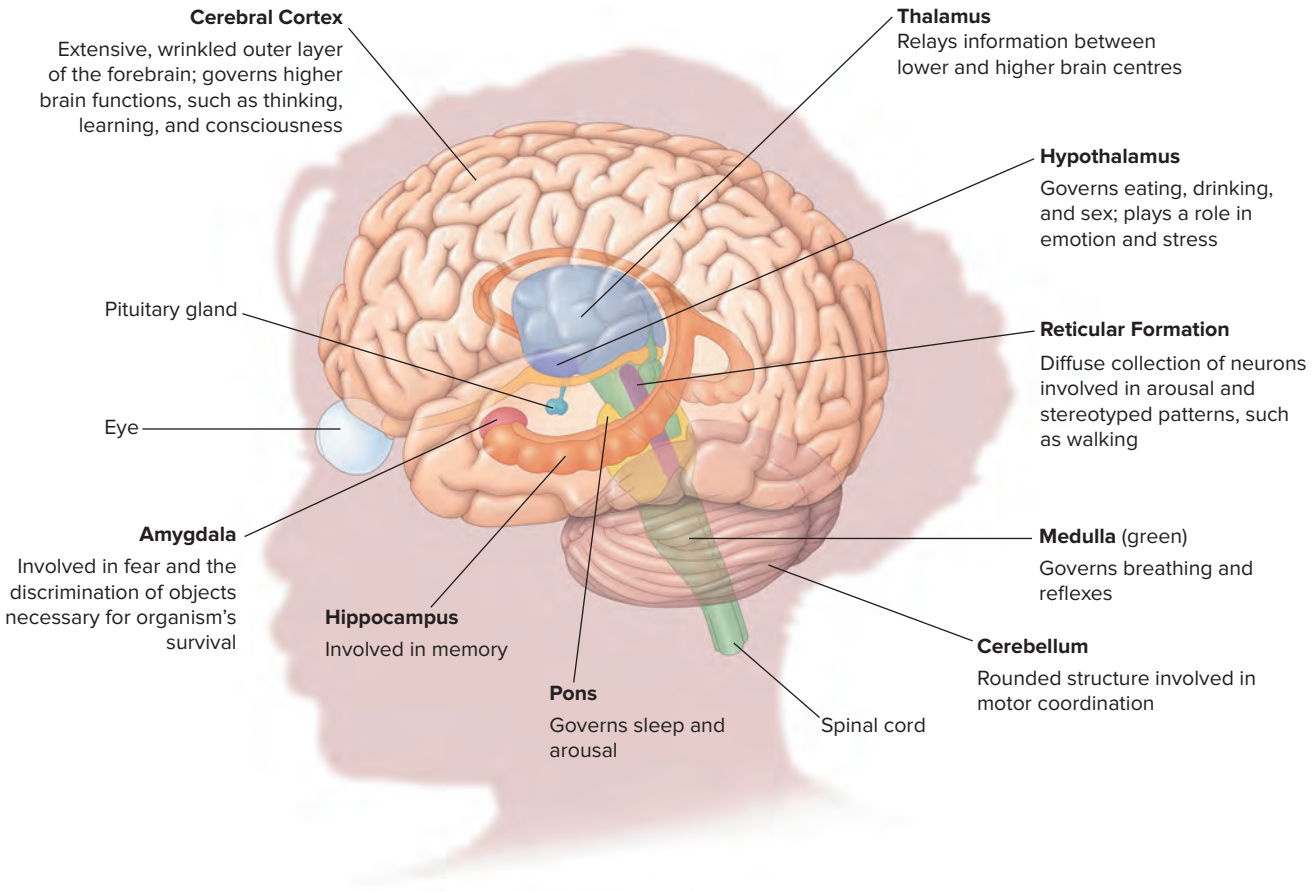



**FIGURE 3.13** **Structure and Regions in the Human Brain** To get a feel for where these structures are in your own brain, use the eye (*pictured on the left of the figure*) as a landmark. Note that structures such as the thalamus, hypothalamus, amygdala, pituitary gland, pons, and reticular formation reside deep within the brain.

Interestingly, just as musical training can influence other areas of the brain, it can affect the brain stem as well (Weiss & Bidelman, 2015).

The *cerebellum* extends from the rear of the hindbrain. It consists of two rounded structures thought to play important roles in motor coordination (Bosch et al., 2015; Hardwick et al., 2013). The cerebellum coordinates leg and arm movements; for example, when we walk, play golf, and practise the piano, the cerebellum is hard at work. When a wide receiver makes an amazing catch, scraping their toes in bounds, or when the centre on your hockey team deflects a puck from their skate to their stick, the cerebellum of each athlete deserves credit. If another portion of the brain commands us to send a quick text message to a friend, it is the cerebellum that integrates the muscular activities required to do so. Damage to the cerebellum impairs the performance of coordinated movements. When this damage occurs, movements become awkward and jerky. Extensive damage to the cerebellum makes it impossible to stand up. Drinking too much alcohol can interfere with the cerebellum's functioning, resulting in poor balance, stumbling, and slurring of words. Exposure to alcohol as a fetus, or long-term alcohol abuse as an adult can result in damage to the cerebellum, resulting in unsteady balance, difficulty coordinating one's arms and legs, and difficulty producing speech (Luo, 2015). When you see these motor challenges in the elderly, problems with the cerebellum often deserve the blame.

## WHAT IS THE MIDBRAIN?

The **midbrain**, located between the hindbrain and forebrain, has many axons that ascend and descend to connect the higher and lower portions of the brain (Watabe-Uchita et al.,

● **midbrain** Located between the hindbrain and forebrain, an area in which many nerve-fibre systems ascend and descend to connect the higher and lower portions of the brain; in particular, the midbrain relays information between the brain and the eyes and ears.

2012). In particular, the midbrain relays information between the brain and the eyes and ears. Your ability to look in the mirror and focus your gaze on a piece of spinach stuck in your teeth is attributed to a bundle of neurons in the midbrain.

Parkinson disease arises from damage near the bottom of the midbrain to an area called the *substantia nigra* (Lenfeldt et al., 2015) which is rich in dopamine-producing neurons. Without sufficient dopamine, there is a deterioration in body movement, rigidity, and tremors. This part of the midbrain feeds dopamine into the *striatum,* the central input station for the basal ganglia, to which we will turn our attention in a moment. The midbrain is rich in dopamine receptors, and therefore is especially involved in reward experiences, pleasure, and addiction (Goertz et al., 2015; Morales et al., 2015).

Another important system in the midbrain is the reticular formation (see Figure 3.13). The **reticular formation** is a diffuse collection of neurons involved in stereotyped patterns of behaviour such as walking, sleeping, and turning to attend to a sudden noise (Jones & Benca, 2013; Nofzinger et al., 2015).

● **reticular formation** A system in the midbrain comprising a diffuse collection of neurons involved in stereotyped patterns of behaviour such as walking, sleeping, and turning to attend to a sudden noise.

## WHAT DOES THE FOREBRAIN DO?

You try to understand what all of these terms and parts of the brain mean. You talk with friends and plan a party for this weekend. You remember that it has been six months since you last visited the dentist. You are confident you will do well on the next exam in this course. All of these experiences and millions more would not be possible without the **forebrain**—the brain's largest division (Nord et al., 2015).

● **forebrain** The brain's largest division and its most forward part.

But before we explore the structures and function of the forebrain, let's stop for a moment and examine how the brain evolved. The brains of the earliest vertebrates were smaller and simpler than those of later animals. Genetic changes during the evolutionary process were responsible for the development of more complex brains with additional parts and interconnections (Broglio et al., 2015; Luzzati, 2015).

In both the chimpanzee's brain and (especially) the human's brain, the hindbrain and midbrain structures are covered by a forebrain structure called the *cerebral cortex.* The human hindbrain and midbrain are similar to those of other animals, so it is the relatively large size of the human forebrain that mainly differentiates the human brain from the brain of other animals. The human forebrain's most important structures are the limbic system, thalamus, basal ganglia, hypothalamus, and cerebral cortex.

### WHAT DOES THE LIMBIC SYSTEM DO?

The **limbic system**, a loosely connected network of structures under the cerebral cortex, is important in both memory and emotion. Its two principal structures are the amygdala and the hippocampus (see Figure 3.13).

● **limbic system** A loosely connected network of structures under the cerebral cortex, important in both memory and emotion. Its two principal structures are the amygdala and the hippocampus.

The **amygdala** is an almond-shaped structure located inside the brain toward the base. There is an amygdala (the plural is *amygdalae*) on each side of the brain. The amygdala is involved in the discrimination of objects that are necessary for an organism's survival, such as appropriate food, mates, and social rivals. Neurons in the amygdala often fire selectively at the sight of such stimuli, and lesions in the amygdala can cause animals to engage in unhelpful behaviour such as attempting to eat, fight with, or even mate with an object like a chair.

● **amygdala** An almond-shaped structure within the base of the temporal lobe that is involved in the discrimination of objects that are necessary for the organism's survival, such as appropriate food, mates, and social rivals. There is one amygdala in each hemisphere of the brain.

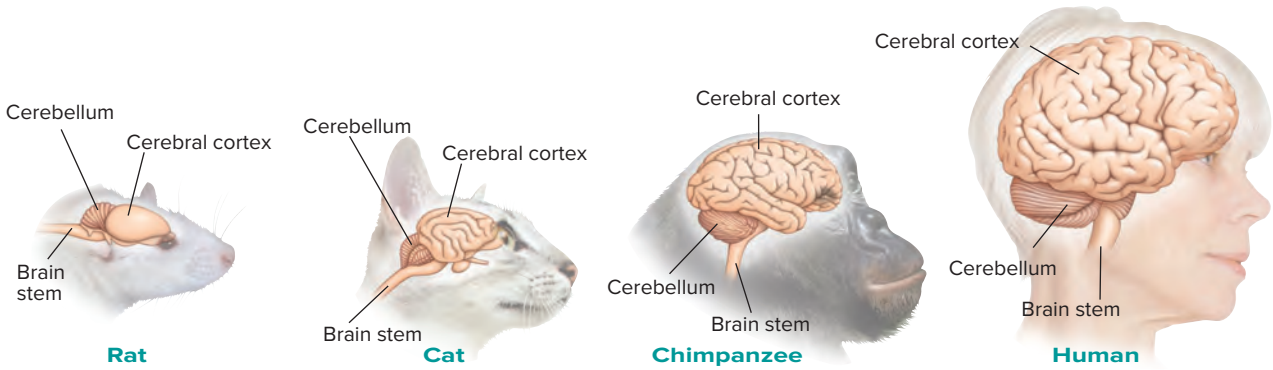
In both humans and animals, the amygdala is active in response to unpredictable stimuli (Herry et al., 2007). In humans, damage to the amygdala can make it impossible to recognize facial expressions of distress (Adolphs, 2009). The amygdala is also involved in your awareness and expression of emotions through its many connections with a variety of brain areas (Whalen et al., 2013). Individuals who are particularly good at regulating their emotions show greater functional connectivity between the amygdalae and the area of the brain that is just behind your forehead (Rohr et al., 2015). This area, called the *prefrontal cortex,* is associated with planning, self-control, and decision making. Interestingly, the size of both the left and right amygdalae is linked to the size of a person's online social network (Facebook) and real-world social network (Von Der Heide et al., 2014). Throughout this book you will encounter the amygdalae whenever we turn to discussions of intense emotions.

# psychological inquiry

### The Brain in Different Species

The below illustration compares the brain of a rat, cat, chimpanzee, and human. In examining the figure, keep in mind that each species is adapted to different environmental challenges.

1. In what ways is each brain well suited to the challenges faced by its particular species?
2. What structures are similar across all the species? Why do you think certain brain structures are common for these various species? What challenges do all of these species face that would account for the common features of their brains?
3. Note how much larger the cerebral cortex becomes as we go from the brain of a rat to the brain of a human. Why don't rats have a large cerebral cortex?
4. We often think of the human brain as an amazing accomplishment of nature. How might life be different for a rat or a cat with a human brain?




(first photo) ©Photodisc/Getty Images; (second photo) ©Stockdisc/Stockbyte/Getty Images; (fourth photo) ©McGraw-Hill Education/JW Ramsey, photographer

The **hippocampus** has a special role in memory (Czerniawski et al., 2015; Schapiro et al., 2016). Individuals who suffer extensive hippocampal damage can no longer retain any new conscious memories. It is fairly certain, though, that memories are not stored "in" the limbic system. Instead, the limbic system seems to determine what parts of the information passing through the cortex should be "printed" into durable, lasting neural traces in the cortex. The hippocampus seems to help us recall things by waking up the areas of the brain that were used when we originally encountered the information (Rugg et al., 2015).

● **hippocampus** The structure in the limbic system that has a special role in the storage of memories.

**WHAT IS THE THALAMUS?** The **thalamus** is a forebrain structure that sits at the top of the brain stem in the central core of the brain (see Figure 3.13). It serves as a very important relay station, functioning much like a server in a computer network. That is, an important function of the thalamus is to sort information and send it to the appropriate places in the forebrain for further integration and interpretation (Makinson & Huguenard, 2015). For example, one area of the thalamus receives information from the cerebellum and sends it to the motor area of the cerebral cortex. Indeed, most neural input to the cerebral cortex goes through the thalamus. Whereas one area of the thalamus works to orient information from the sensory receptors (hearing, seeing, and so on), another region seems to be involved in sleep and wakefulness, having ties with the reticular formation.

● **thalamus** The forebrain structure that sits at the top of the brain stem in the brain's central core and serves as an important relay station.

● **basal ganglia** Large neuron clusters located above the thalamus and under the cerebral cortex that work with the cerebellum and the cerebral cortex to control and coordinate voluntary movements.

**WHAT ARE THE BASAL GANGLIA?** Above the thalamus and under the cerebral cortex lie large clusters, or *ganglia,* of neurons called **basal ganglia**. The basal ganglia work with the cerebellum and the cerebral cortex to control and coordinate voluntary movements (Nambu, 2015). Basal ganglia enable people to engage in habitual activities such as riding a bicycle and vacuuming a carpet. Individuals with damage to basal ganglia suffer from either unwanted movement, such as constant writhing or jerking of limbs, or too little movement, as in the slow and deliberate movements of people with Parkinson disease (Rolinski et al., 2015).

● **hypothalamus** A small forebrain structure, located just below the thalamus, that monitors three pleasurable activities—eating, drinking, and sex—as well as emotion, stress, and reward.

**HOW DOES THE HYPOTHALAMUS FUNCTION?** The **hypothalamus**, a small forebrain structure just below the thalamus, monitors three rewarding activities—eating, drinking, and sex—as well as emotion, stress, and reward (see Figure 3.13 for the location of the hypothalamus). The old joke is that the hypothalamus's functions are sometimes referred to as the 4 F's; feeding, fighting, fleeing, and *mating*.

A good way to describe the function of the hypothalamus is as a regulator of the body's internal state. It responds to changes in blood and neural input by secreting hormones and producing neural outputs. For example, if the temperature of circulating blood near your hypothalamus is increased by just one degree, certain cells in the hypothalamus increase their rate of firing. This starts a chain of events. Circulation through the skin and sweat glands increases immediately to release this heat from the body. The cooled blood returning to the hypothalamus slows the activity of some of the neurons there, stopping the process when the temperature is just right, 37.1 degrees Celsius. These temperature-sensitive neurons function like a finely tuned thermostat to maintain an even state in the body.

The hypothalamus is much more than just a thermostat (Alvarez-Bolado et al., 2015). The hypothalamus is also involved in emotional states and responding to stress, playing an important role as an integrative location for handling stress. Much of this integration is accomplished through the hypothalamus's action on the pituitary gland—an important endocrine gland located just below it.

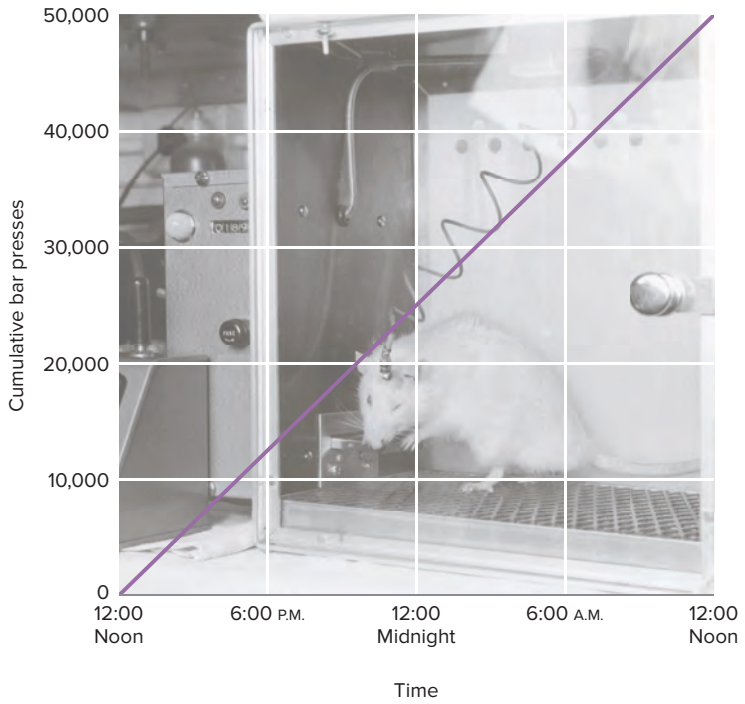



**FIGURE 3.14 Results of the Experiment on the Role of the Hypothalamus in Pleasure** The graphed results for one rat show that it pressed the bar more than 2,000 times an hour for a period of 24 hours to receive stimulation to its hypothalamus (Olds, 1958). A rat is shown here pressing a similar bar.



Artificially stimulating the hypothalamus with electricity can cause intense feelings of pleasure. In a classic experiment, James Olds and Peter Milner (1954) implanted an electrode in the hypothalamus of a rat's brain. When the rat ran to a corner of an enclosed area, a mild electric current was delivered to its hypothalamus. The researchers thought the electric current would cause the rat to avoid the corner. Much to their surprise, the rat kept returning to the corner. Olds and Milner believed they had discovered a pleasure centre in the hypothalamus. Olds (1958) conducted further experiments and found that rats would press bars until they dropped from exhaustion just to continue to receive a mild electric shock to their hypothalamus. One rat pressed a bar more than 2,000 times an hour for a period of 24 hours to receive the stimulation to its hypothalamus (Figure 3.14).

The hypothalamus is not the only brain structure involved in feeling pleasure; other brain areas, such as the limbic system, the nucleus accumbens and the ventral tegmental area, to be discussed in Chapter 5, are also involved in experiencing pleasure (Castro et al., 2015).

The Olds studies have implications for drug addiction (Barson et al., 2015). We will explore the effects of drugs on the reward centres of the brain in Chapter 5.

## What Is the Cerebral Cortex and What Does It Do?

The **cerebral cortex** is part of the forebrain and is the most recently evolved part of the brain. The word *cortex* means "bark" (as in tree bark) in Latin, and the cerebral cortex is the outer layer of the brain. The cerebral cortex is where the most complex mental functions, such as thinking, decision making, planning, producing and comprehending language, and processing emotions, take place. You could say that the cerebral cortex is responsible for what makes us human and what makes you you.

The **neocortex** (or "new bark") is the outermost part of the cerebral cortex. In humans, this area makes up 80 percent of the cortex (compared with just 30 to 40 percent in most other mammals). The size of the neocortex in mammals is strongly related to the size of the social group in which the organisms live. The neocortex is responsible for our high-level thinking, and some researchers theorize that it evolved so that humans could make sense of one another (Dunbar, 2014).

The cerebral cortex covers the lower portions of the brain like a towel that is laid over the brain's surface. In humans, the cerebral cortex is greatly convoluted, as if the towel were loosely folded, and this produces a lot of grooves and bulges. This folding greatly enlarges the surface area (compared to a brain with a smooth surface, as if the towel were pulled tightly to remove the wrinkles). The cerebral cortex is highly connected with other parts of the brain (Bota et al., 2015). Millions of axons connect the neurons of the cerebral cortex with those located elsewhere in the brain.

● **cerebral cortex** Part of the forebrain, the outer layer of the brain, responsible for the most complex mental functions, such as thinking and planning.

● **neocortex** The outermost part of the cerebral cortex, making up 80 percent of the cortex in the human brain.

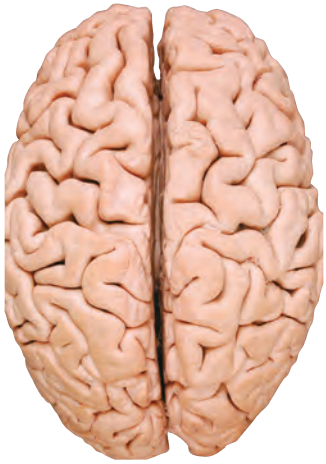


**FIGURE 3.15** **The Hemispheres of the Human Brain** The two halves (hemispheres) of the human brain can be seen clearly in this photograph.
©McGraw-Hill Education/Christine Eckel, photographer

### WHAT ARE THE LOBES OF THE BRAIN?

The wrinkled surface of the cerebral cortex is divided into two halves called *hemispheres* (Figure 3.15). Each hemisphere is subdivided into four regions, or *lobes:* occipital, temporal, frontal, and parietal (Figure 3.16).

The **occipital lobes**, located at the back of the head, respond to visual stimuli. Connections among various areas of the occipital lobes allow for the processing of information about aspects of visual stimuli, such as their colour, shape, and motion (Krigolson et al., 2015). A person can have perfectly functioning eyes, but the eyes only detect changes in light and transport this information as action potentials to the brain. That information must be interpreted in the occipital lobes in order for the viewer to "see it." A stroke or a wound in an occipital lobe can cause total blindness or wipe out a portion of the person's visual field even though the eyes are perfectly intact.

● **occipital lobes** Structures located at the back of the head that respond to visual stimuli.

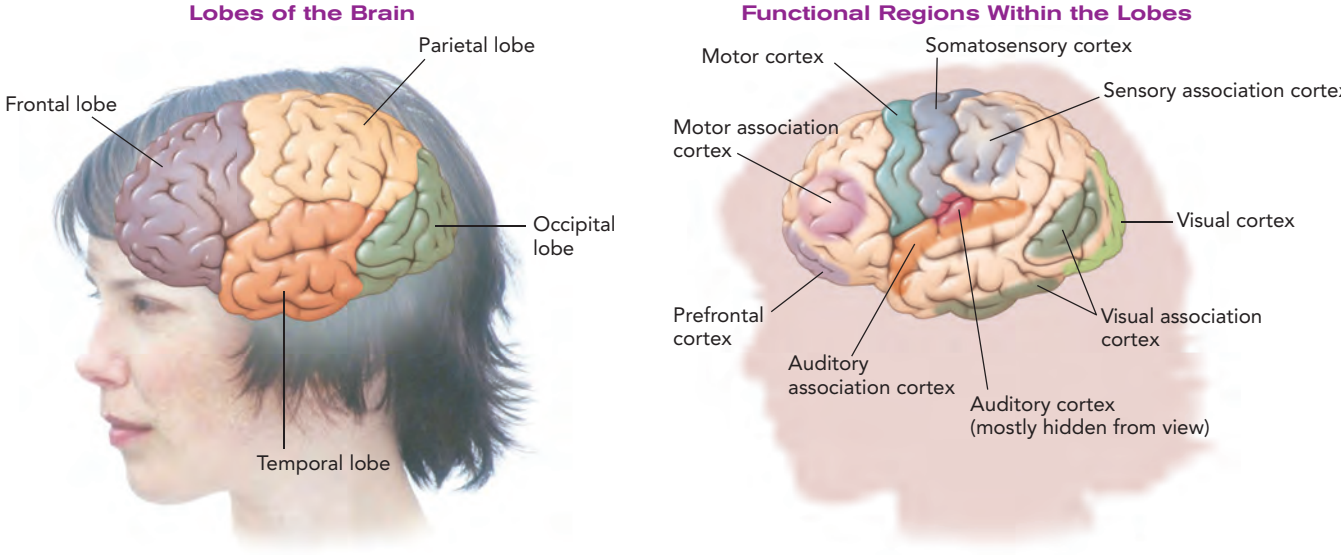



**FIGURE 3.16** **The Lobes and Association Areas of the Cerebral Cortex** The cerebral cortex (*left*) is roughly divided into four lobes: occipital, temporal, frontal, and parietal. The cerebral cortex (*right*) also consists of the motor cortex and somatosensory cortex. The cerebral cortex includes association areas, such as the visual association cortex, auditory association cortex, and sensory association cortex.
(photo) ©ER Productions/Getty Images

● **temporal lobes** Structures in the cerebral cortex that are located just above the ears and are involved in hearing, language processing, and memory.

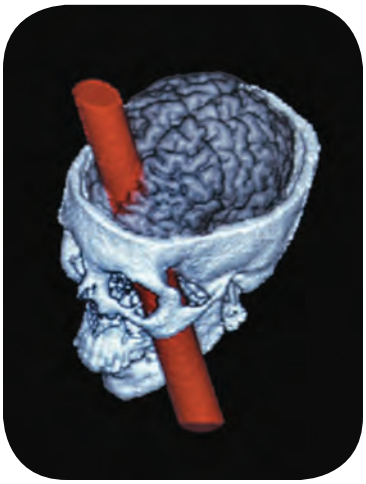
The **temporal lobes**, located just above the ears, are involved in hearing, language processing, and memory. The temporal lobes have a number of connections to the limbic system. For this reason, people with damage to the temporal lobes may not be able to transfer experiences into long-term memory (Voets et al., 2015).

● **frontal lobes** The portions of the cerebral cortex behind the forehead that are involved in personality, intelligence, and the control of voluntary muscles.

The **frontal lobes**, located right behind the forehead, are involved in personality, intelligence, and the control of voluntary muscles. A fascinating case study illustrates how damage to the frontal lobes can profoundly alter personality. Phineas T. Gage, a 25-year-old foreman who worked for the Rutland and Burlington Railroad, was the victim of a terrible accident in 1848. Phineas and several co-workers were using blasting powder to construct a roadbed. The crew drilled holes in the rock and gravel, poured in the blasting powder, and then tamped down the powder with an iron rod. While Phineas was still tamping it down, the powder exploded, driving the iron rod up through the left side of his face and out through the top of his head. Although the wound healed, Phineas was left a different person. Previously he was mild-mannered, hard-working, emotionally calm, and well liked by those who knew him. Afterwards, he was stubborn, hot-tempered, aggressive, and unreliable. Damage to the frontal lobe of his brain had dramatically altered Phineas's personality.

The frontal lobes of humans are especially large when compared with those of other animals. For example, in rats, the frontal cortex barely exists; in cats, it occupies just 3.5 percent of the cerebral cortex; in chimpanzees, 17 percent; and in humans, approximately 30 percent.

An important part of the frontal lobes is the *prefrontal cortex,* which is at the front of the motor cortex (see Figure 3.16). The prefrontal cortex is involved in higher cognitive functions such as planning, reasoning, and self-control (Berridge & Arnsten, 2015; Domenech & Koechlin, 2015).



*A computerized reconstruction of Phineas T. Gage's accident, based on measurements taken of his skull.*


The **parietal lobes**, located at the top and toward the rear of the head, are involved in registering spatial location, attention, and motor control (Bonino et al., 2015). The parietal lobes are at work when you are judging how far you have to throw a ball so someone else can catch it, when you shift your attention from one activity to another (look away from the TV to attend to a noise outside), and when you turn the pages of this book. Parietal lobes are also involved in our perception of numerical information (Eger et al., 2015). The brilliant physicist Albert Einstein said that his reasoning often was best when he imagined objects in space. It turns out that his parietal lobes were 15 percent larger than average (Witelson et al., 1999).

● **parietal lobes** Structures at the top and toward the rear of the head that are involved in registering spatial location, attention, and motor control.

A word of caution—it is easy to go too far in localizing function within a particular lobe. Although this discussion has attributed specific functions to specific lobes (such as vision in the occipital lobe), considerable integration and connection occur between the lobes and between the lobes and other parts of the brain.

## WHAT ARE THE SOMATOSENSORY CORTEX AND MOTOR CORTEX?

Two other important regions of the cerebral cortex are the somatosensory cortex and the motor cortex (see Figure 3.16). The **somatosensory cortex** processes information about body sensations. It is located at the front of the parietal lobes. The **motor cortex**, at the rear of the frontal lobes, processes information about voluntary movement.

● **somatosensory cortex** A region in the cerebral cortex that processes information about body sensations, located at the front of the parietal lobes.

● **motor cortex** A region in the cerebral cortex that processes information about voluntary movement, located just behind the frontal lobes.

The map in Figure 3.17 shows which parts of the somatosensory and motor cortexes are associated with various parts of the body. It is based on research done by Wilder Penfield (1947), a neurosurgeon at the Montreal Neurological Institute. He worked with patients who had severe epilepsy, and he often performed surgery to remove portions of the epileptic patients' brains. However, he was concerned that removing a portion of the brain might impair some of the individuals' functions. Penfield's solution was to map the cortex during surgery by stimulating different cortical areas and observing the responses of the patients, who were given a local anaesthetic so that they could still remain awake during the operation. He found that when he stimulated certain somatosensory and motor areas of the brain, patients reported feeling different sensations, or different parts of the patient's body moved.

Penfield's approach is still used today when neurosurgeons perform certain procedures—for example, the removal of a brain tumour. Keeping the patient awake allows the

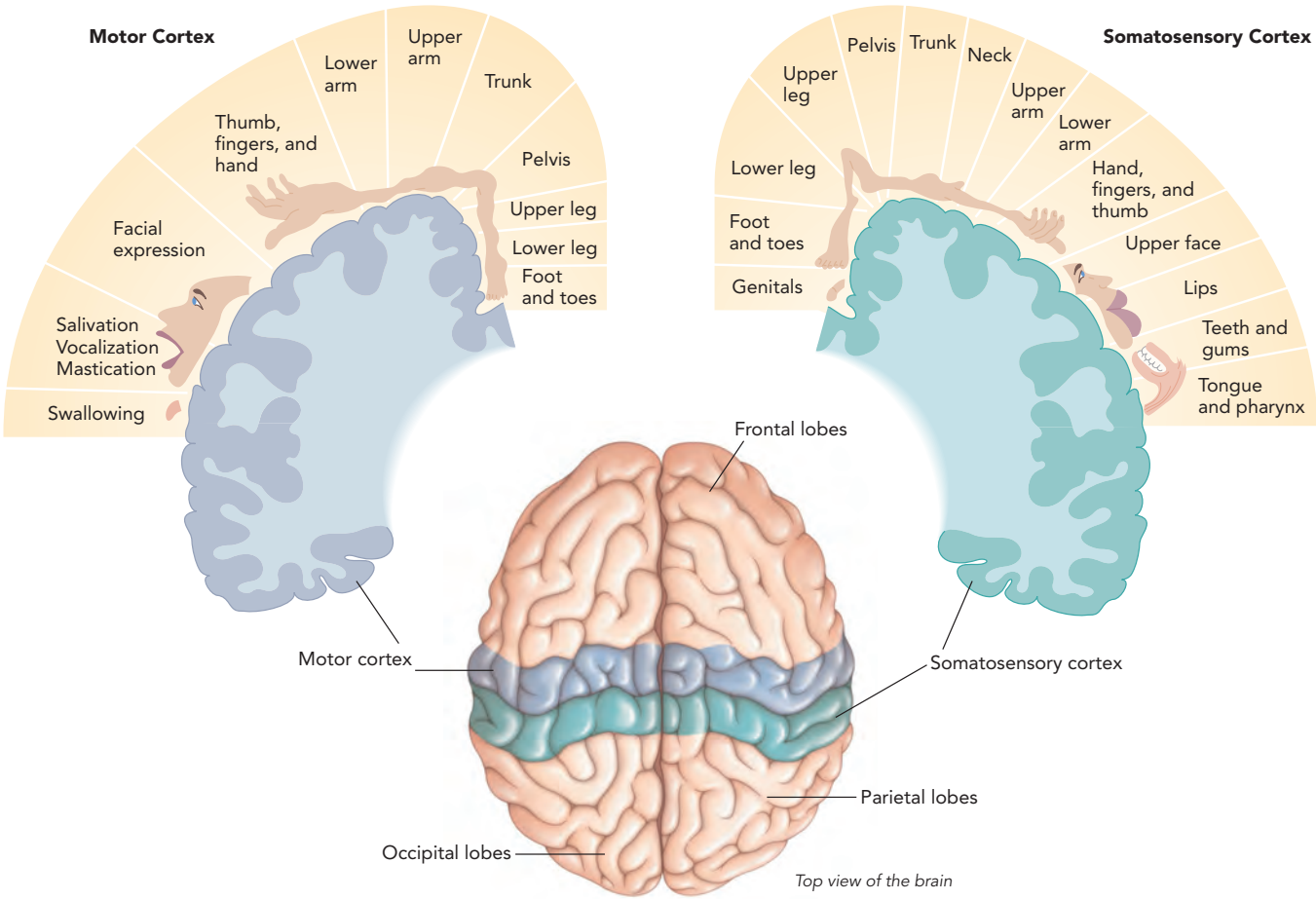



**FIGURE 3.17** **Disproportionate Representation of Body Parts in the Motor and Somatosensory Areas of the Cortex** The amount of cortex allotted to a body part is not proportionate to the body part's size. Instead, the brain has more space for body parts that require precision and control. Thus, the thumb, fingers, and hand require more brain tissue than does the arm.

neurosurgeon to ask patients questions about what they are seeing, hearing, and feeling to be sure that the parts of the brain that are being considered for removal are not essential for consciousness, speech, and other important functions. The extreme precision of brain surgery ensures that life-saving operations do as little harm as possible to the delicate human brain.

For both somatosensory and motor areas, there is a point-to-point relation between a part of the body and a location on the cerebral cortex. In Figure 3.17, the face and hands are given proportionately more space than other body parts because the face and hands are capable of finer perceptions and more intricate movements than are other body areas and therefore need more cerebral cortex representation.

The point-to-point mapping of somatosensory fields onto the cortex's surface is the basis of our orderly and accurate perception of the world (Hsiao & Gomez-Ramirez, 2013). When something touches your lip, for example, your brain knows what body part has been touched because the nerve pathways from your lip are the only pathways that project to the lip region of the somatosensory cortex.

## WHAT IS THE ASSOCIATION CORTEX?

**Association cortex** or **association area** refers to the regions of the cerebral cortex that integrate sensory and motor information. (The term *association cortex* applies to cortical material that is neither somatosensory nor motor cortex—but it is not filler space.) There are association areas throughout the brain, and each sensory system has its own association area in the cerebral cortex. Intellectual functions, such as thinking and problem solving, occur in the association cortex. Embedded in the brain's lobes, association cortex makes up 75 percent of the cerebral cortex (see Figure 3.16).

● **association cortex or association area** The region of the cerebral cortex that is the site of the highest intellectual functions, such as thinking and problem solving.

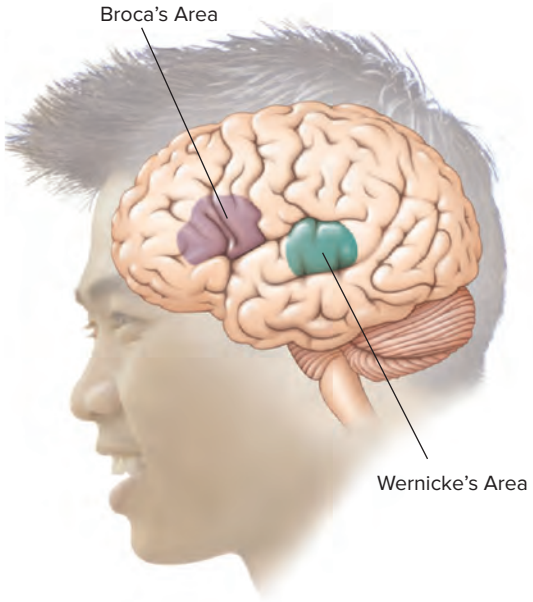



**FIGURE 3.18 Broca's Area and Wernicke's Area**
Broca's area is typically located in the brain's left hemisphere and is involved in the control of speech. Individuals with damage to Broca's area have problems saying words correctly. Also shown is Wernicke's area, the portion of the left hemisphere that is involved in understanding language. Individuals with damage to this area cannot comprehend words; they hear the words but do not know what they mean.

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

The largest portion of association cortex is located in the frontal lobes, directly behind the forehead. Damage to this area does not lead to somatosensory or motor loss but rather to problems in planning and problem solving, or what are called *executive functions* (Carlson et al., 2013). Personality also may be linked to the frontal lobes. Recall the misfortune of Phineas Gage, whose personality radically changed after he experienced frontal lobe damage.

## What Is the Difference Between the Two Cerebral Hemispheres and How Does Split-Brain Research Help Us Understand This Difference?

Recall that the cerebral cortex consists of two halves—left and right (see Figure 3.15). Do these hemispheres have different functions? A discovery by French surgeon Paul Broca provided early evidence that they do.

In 1861 Broca saw a patient who had injured the left side of his brain about 30 years earlier. The patient became known as Tan because *tan* was the only word he could speak. Tan suffered from *expressive aphasia* (also called *Broca's aphasia*), a language disorder that involves the inability to produce language. Tan died several days after Broca evaluated him (and no, there is no evidence that Broca killed him to examine his brain), and an autopsy revealed that the injury was to a precise area of the left hemisphere. Today we refer to this area of the brain as *Broca's area,* and we know that it plays an important role in the production of speech.

A similar story exists for an area of the left hemisphere known as *Wernicke's area,* named for Carl Wernicke, a German neurologist who, in 1874, noticed that individuals with injuries to this area had difficulties understanding language. People with damage to Wernike's area have problems comprehending what others are saying, but they can produce words. Figure 3.18 shows the locations of Broca's area and Wernicke's area. It is easy to confuse Broca's area (associated with speech production) and Wernicke's area (associated with language comprehension). You might remember that Broca's famous patient was called Tan because that was the only word he could produce, so Broca's area is about speech production.

## apply your knowledge

In general, people with left hemisphere damage are more likely to display language problems than people with similar damage to the right hemisphere. This is further evidence that that two hemispheres have different functional strengths, especially related to language skills. But what about people who are left handed or ambidextrous?

Only about 5 percent of right-handed people process and produce complex language in their right hemisphere. This is generally the case for non-right-handed people (left-handed and ambidextrous people) as well. However, atypical language organization (having complex language processed in the right hemisphere) was found in 8 percent of non-right-handed people (Szaflarski et al., 2002). And 14 percent of non-right-handed people show complex language processing in both the right and left hemisphere.

Are you right handed, left handed, or ambidextrous? What does your handedness tell you about the organization of your brain?

Researchers continue to be interested in differences between the brain's left and right hemispheres in terms of their involvement in thinking, feeling, and behaviour (Falasca et al., 2015; Ruiz & Hupé, 2015; Takamiya et al., 2015).

For many years, scientists speculated that the **corpus callosum**, the large bundle of axons that connects the brain's two hemispheres, has something to do with relaying information between the two sides (Figure 3.19). Roger Sperry (1974) confirmed this in an experiment in which he cut the corpus callosum in cats. He also severed certain nerves leading from the eyes to the brain. After the operation, Sperry trained the cats to solve a series of visual problems with one eye blindfolded. After a cat learned the task—say, with only its left eye uncovered—its other eye was blindfolded, and the animal was tested again. The "split-brain" cat behaved as if it had never learned the task. In these cats, memory was stored only in the one hemisphere, which could no longer directly communicate with the other hemisphere.

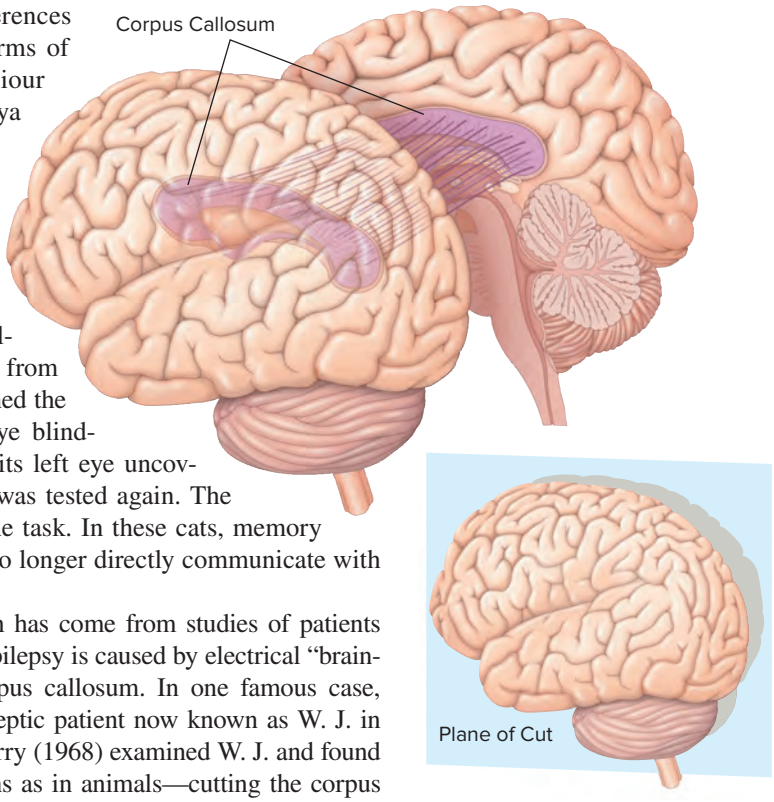



**FIGURE 3.19 The Corpus Callosum** The corpus callosum is a thick bundle of fibres (essentially axons) that connects the brain cells in one hemisphere to those in the other. In healthy brains, the two sides engage in a continuous flow of information via this neural bridge.

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

The right hemisphere receives information directly mostly from the left side of the body, and the left hemisphere receives information directly mostly from the right side of the body. When you hold an object in your left hand, for example, the sensory message from the touch only goes directly to the right hemisphere. When you hold an object in your right hand, the sensory message from the touch only goes directly to the left hemisphere (Figure 3.20). Most of us have a functioning corpus callosum, so information that is transmitted directly to one hemisphere is also available to the other hemisphere. For example, if you hold a pen in your right hand, the left hemisphere receives direct sensory messages that the pen is in your right hand. The right hemisphere is also aware of this because messages from the left hemisphere are transmitted to the right hemispheres via the corpus callosum. Although we might have two minds, we usually use them in tandem because of the cross communication between the hemispheres.

● **corpus callosum** The large bundle of axons that connects the brain's two hemispheres, responsible for relaying information between the two sides.

You can appreciate how well the corpus callosum rapidly integrates your experience by considering how hard it is to do two things at once (Stirling, 2002). Try to pat your head with one hand and rub your stomach with the other hand at the same time. Even with two separate hands controlled by two separate hemispheres, doing two different things at once is difficult.

In people with intact brains, hemispheric specialization of function occurs. Researchers have uncovered evidence for hemispheric differences in function by sending different information to each ear. Though not complete, information to the right ear is mostly sent to the left hemisphere and information to the left ear is mostly sent to the right hemisphere. This research has shown that the brain tends to divide its functioning into one hemisphere or the other, as we will now consider.

## WHAT IS THE FUNCTION OF THE LEFT HEMISPHERE?

The most extensive research on the differences in functioning of the brain's two hemispheres has focused on language. Much, though certainly not all, complex

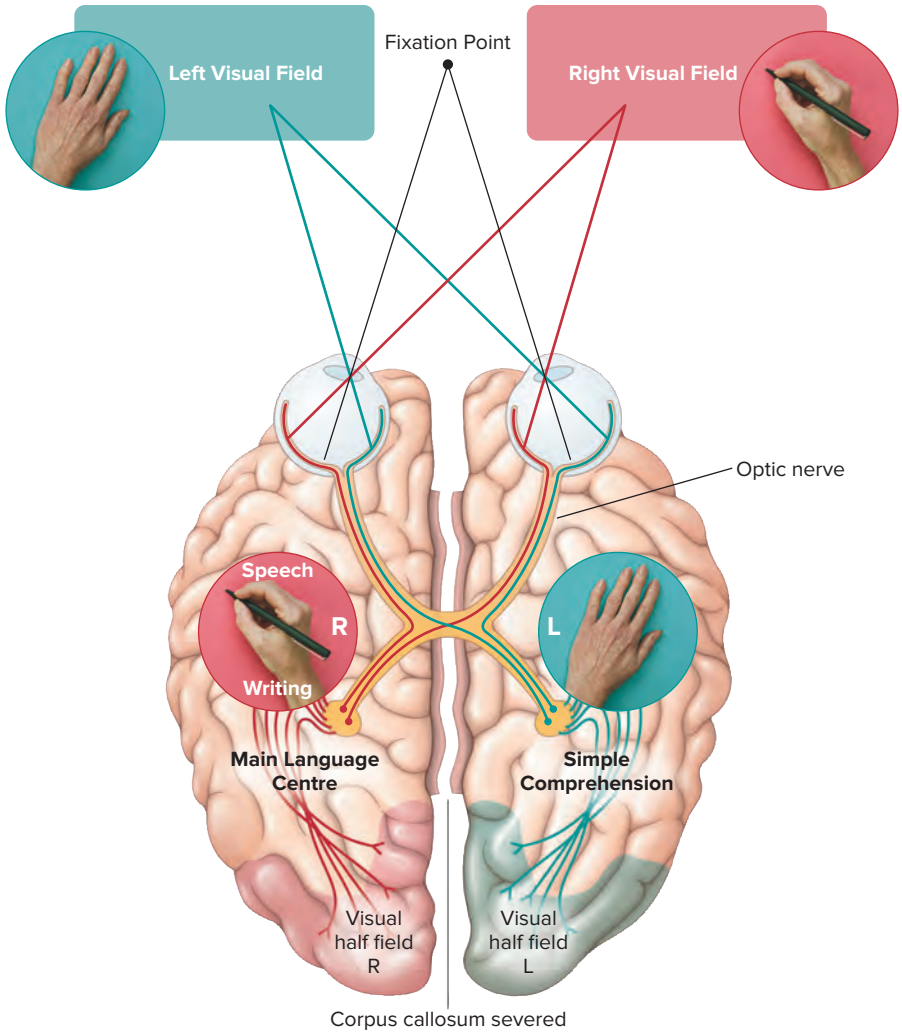



**FIGURE 3.20 Information Pathways from the Eyes to the Brain** Each of our eyes receives sensory input from both our left and our right field of vision. Information from the left half of our visual field goes to the brain's right hemisphere (which is typically responsible for simple comprehension), and information from the right half of our visual field goes to the brain's left hemisphere (which is typically where the brain's main language centres are located to control speech and writing). The input received in either hemisphere passes quickly to the other hemisphere across the corpus callosum. When the corpus callosum is severed, however, this transmission of information cannot occur.

language processing and production is done by the left (Prat, 2013; Wu et al., 2015). For example, as you read this sentence, the left hemisphere recognizes words and numbers and comprehends syntax (rules for forming phrases and sentences) and grammar (Skeide et al., 2015), but the right hemisphere does not. The left hemisphere is also keenly involved when we sing the words of a song. In addition, although not generally associated with spatial perception, the left hemisphere can direct us in solving some basic spatial puzzles, such as identifying whether an object is inside or outside a box.

## WHAT IS THE FUNCTION OF THE RIGHT HEMISPHERE?

Though less so than the left hemisphere, the right hemisphere does play a role in understanding and producing language. The right hemisphere is adept at picking up the meaning of stories and the intonations of voices, and it excels at catching on to song melodies (Bidelman & Chung, 2015; Qi et al., 2015). Furthermore, the right hemisphere is involved in conversation processing (Holtgraves, 2012). Researchers have found increasing evidence that following damage to the left hemisphere, especially early in development, the right hemisphere can take over some language functions (de Bode et al., 2015; Staudt, 2010).

The real strength of the right hemisphere, however, appears to be the processing of nonverbal information such as spatial perception, visual recognition, and emotion

(Kensinger & Choi, 2009). With respect to interpreting spatial information, the right hemisphere is involved in our ability to tell if something is on top of something else, how far apart two objects are, and whether two objects moving in space might crash into each other. Without the right hemisphere, you would be lousy at many video games.

The right hemisphere has a major role in processing information about people's faces (Caspers et al., 2015; Kanwisher, 2006). How do we know? One way we know is that researchers have asked people to watch images on a computer screen and to press a button with either their right or left hand if they recognize a face. Even right-handed people respond faster with their left hands because when people see a face, the right hemisphere (which controls the left hand) processes this information and allows for a faster reaction time than when the processed information must be transferred to the left hemisphere so the person can respond with their right hand (Gillihan & Farah, 2005).

There is a specialized area in the right hemisphere for processing faces (Kanwisher & Yovel, 2010; McKone et al., 2010; Pitcher et al., 2012). This area, located in the fusiform gyrus in the right temporal lobe, is called the *fusiform face area (FFA).* The FFA is a dime-size area just behind your right ear. Using fMRI, researchers have shown that the FFA is especially active when a person is viewing a face—a human face, a cat's face, or a cartoon face—but not cars, butterflies, or other objects (Tong et al., 2000).

Additionally, the right hemisphere may be more involved than the left hemisphere in processing emotions—both when we express emotions ourselves and when we interpret others' emotions (Carmona et al., 2009). People are more likely to remember emotion words if they hear them in the left ear. As well, much of our sense of humour resides in the right hemisphere (Bartolo et al., 2006; Coulson & Wu, 2005). If you want to be sure that someone laughs at your joke, tell it to the person's left ear!

### ARE YOU A RIGHT-BRAINED OR A LEFT-BRAINED PERSON?

People commonly use the terms *left-brained* (meaning logical and rational) and *right-brained* (meaning creative or artistic) as a way of categorizing different brain functioning in themselves and others. Such generalizations have little scientific basis. We have both hemispheres for a reason: We use them both. For most complex human activities, there is interplay between the brain's two hemispheres (Hinkley et al., 2012).

## How Do the Different Parts of the Brain Work Together?

How do we coordinate all of the regions of the brain to produce the wondrous complexity of thoughts, feelings, and behaviours that we experience? Neuroscience still does not have complete answers to questions such as how the brain solves a murder mystery or composes an essay. Even so, we can get a sense of integrative brain function by using a real-world scenario, such as the act of escaping from a burning building.

Imagine that you are texting a friend when a fire breaks out behind you. The sound of crackling flames is relayed from your ears through the thalamus, to the auditory cortex, and on to the auditory association cortex. At each stage, the stimulus is processed to extract information, and at some stage, probably at the association cortex level, the sounds are matched with something like a neural memory representing sounds of fires you have heard previously.

Your attention (guided in part by the reticular formation) shifts to the auditory signal being held in your association cortex and on to your auditory association cortex, and simultaneously (again guided by reticular systems) your head turns toward the noise.

The perception of "fire" sets new machinery in motion. Now your visual association cortex reports in: "Objects matching flames are present." In other regions of the association cortex, the visual and auditory reports are synthesized ("We have things that look and sound like fire"), and neural associations representing potential actions ("flee") are

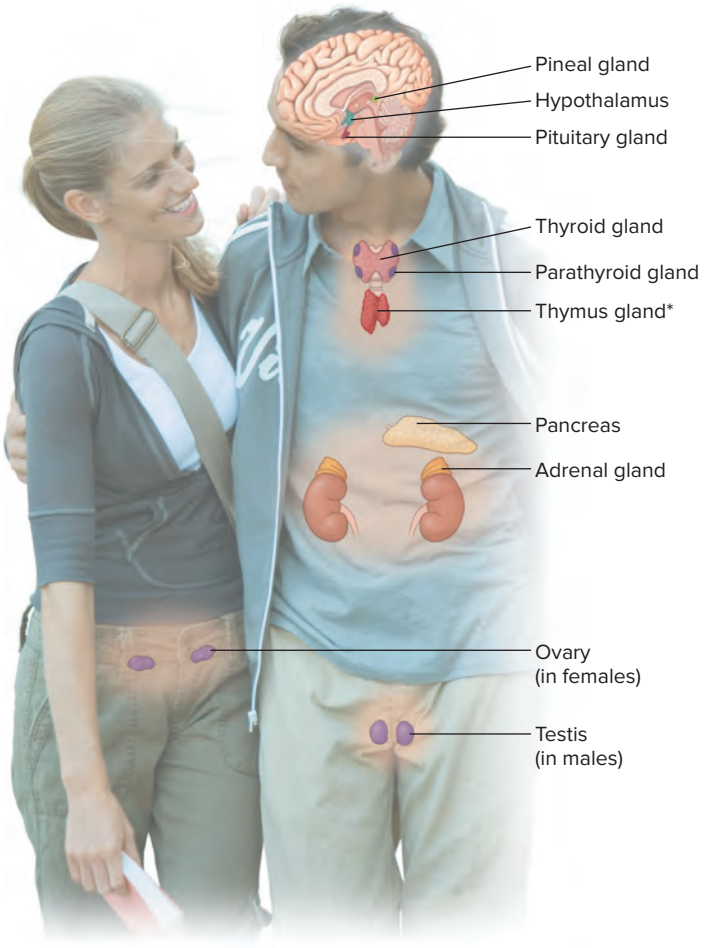



**FIGURE 3.21** **The Major Endocrine Glands** The pituitary gland releases hormones that regulate the hormone secretions of the other glands. The pituitary gland is regulated by the hypothalamus.

*Location of the thymus is shown above, but this gland is largely replaced by fat in adults.

(photo) ©PhotoAlto/PunchStock

activated. However, firing neurons that code the plan to flee will not get you out of the chair. For that task, the basal ganglia must become engaged, and from there the commands will arise to set the brain stem, motor cortex, and cerebellum to the work of transporting you out of the room. All of this happens in mere seconds.

So, which part of your brain did you use to escape? Virtually all systems had a role. By the way, you would probably remember this event because your limbic circuitry would likely have started memory formation when the association "fire" was triggered. The next time the sounds of crackling flames reach your auditory association cortex, the associations triggered would include this most recent escape. In sum, considerable integration of function takes place in the brain. All of the parts of the nervous system work together as a team to keep you safe and sound.

## 4. WHAT IS THE ENDOCRINE SYSTEM?

The nervous system works closely with another bodily system—the endocrine system. The **endocrine system** consists of glands that regulate the activities of certain organs by releasing their chemical products into the bloodstream. **Glands** are organs or tissues in the body that produce chemicals that control many bodily functions. The endocrine glands include the pituitary, pineal, thyroid, parathyroid, thymus, adrenals, pancreas, ovaries (in females), and testes (in males) (Figure 3.21). The chemical messengers produced by these glands are called **hormones**. The bloodstream carries hormones to all parts of the body, and the membrane of every cell has receptors for one or more hormones. Let's take a closer look at the function of some of the main endocrine glands.

- **endocrine system** The body system consisting of a set of glands that regulate the activities of certain organs by releasing their chemical products into the bloodstream.
- **glands** Organs or tissues in the body that create chemicals that control many bodily functions.
- **hormones** Chemical messengers that are produced by the endocrine glands and carried by the bloodstream to all parts of the body.

The **pituitary gland**, a pea-sized gland just beneath the hypothalamus, controls growth and regulates other glands (Figure 3.22). The anterior (front) part of the pituitary is called the *master gland*, because almost all of its hormones direct the activity of target glands elsewhere in the body. The anterior pituitary gland is controlled by the hypothalamus.

The **pineal gland** is less than a centimetre long and is located near the centre of the brain. It gets its name because neuroanatomists thought it was shaped like a pine cone (frankly, this author lacks this imagination and doesn't see the resemblance). The pineal gland secretes a single hormone, melatonin, which helps to control your circadian rhythms and regulate some of your reproductive hormones.

### apply your knowledge

Do you know people, perhaps your grandparents, who struggle to have a good night's sleep and don't wake up feeling rested? The pineal gland, and in particular its inability to secrete adequate amounts of melatonin, may be to blame. Calcification of the pineal gland is linked to sleep problems in the elderly and in people with Alzheimer disease, but it is not a necessary consequence of aging (Mutalik & Tadinada, 2017).

The **thyroid gland** is shaped like a small butterfly with a 5-centimetre wingspan. It is located in your neck just below your Adam's apple. Have you ever wondered why iodine is added to salt? The thyroid uses iodine from your diet to produce hormones that help regulate your metabolism. If you have unexplained weight gain, changes in your resting heart rate, sensitivity to cold, and increased anxiety and irritability, then your doctor may order a blood test to make sure that your thyroid is working properly.

Behind the thyroid is the **parathyroid**, which consists of four glands, each the size of a grain of rice. The parathyroid is important in regulating the levels of calcium in your body.

The **thymus** is located between your lungs and behind your sternum (your breastbone). Its main role is to produce white blood cells to help fight infection (Zdrojewicz et al., 2016). The thymus is particularly important in the immune system of infants and children. Following puberty, the thymus performs a magic trick—it disappears. After puberty the thymus is largely replaced with fat. Thus, removing it in adults has little consequence.

The **adrenal glands**, located at the top of each kidney, regulate mood, energy levels, and the ability to cope with stress. Each adrenal gland secretes epinephrine (also called *adrenaline*) and norepinephrine (also called *noradrenaline*). Unlike most hormones, epinephrine and norepinephrine act quickly. Epinephrine helps a person prepare for an emergency by acting on smooth muscles, the heart, stomach, intestines, and sweat glands. In addition, epinephrine stimulates the reticular formation, which in turn arouses the sympathetic nervous system, and this system subsequently excites the adrenal glands to produce more epinephrine.

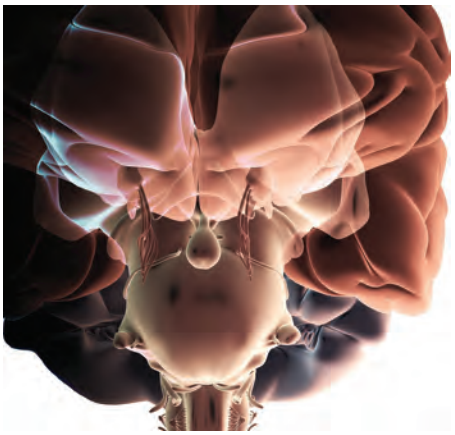


**FIGURE 3.22** **The Pituitary Gland** The pituitary gland, which hangs by a short stalk from the hypothalamus, regulates the hormone production of many of the body's endocrine glands. Here it is enlarged 30 times.


Norepinephrine also alerts the individual to emergency situations by interacting with the pituitary and the liver. You may remember that norepinephrine functions as a neurotransmitter when it is released by neurons. In the adrenal glands, norepinephrine is released as a hormone. In both instances, norepinephrine conveys information—in the first case, to neurons; in the second case, to glands (Nicolaides et al., 2015). The activation of the adrenal glands plays an important role in stress and physical health, as we will see at the end of this chapter.

The **pancreas**, located under the stomach, is a dual-purpose gland that performs both digestive and endocrine functions. The part of the pancreas that serves endocrine functions produces a number of hormones, including insulin. This part of the pancreas, the *islets of Langerhans,* busily turns out hormones like a little factory. Insulin is an essential hormone that controls glucose (blood sugar) levels in the body and is related to metabolism, body weight, and obesity. People whose pancreas has been infiltrated with fat have an increased risk for diabetes and obesity, which are risk factors for pancreatic cancer (Eibl et al., 2018). Type II diabetes has traditionally been described as a life-long disease. However, recent research has found that giving people with diabetes an intensive therapy including diet, exercise, and drugs can lead to normal blood sugar levels, sustained weight loss, and a drug-free life (McInnes et al., 2017).

The **ovaries**, located in the pelvis on either sides of the uterus in females, and **testes**, located in the scrotum in males, are the sex-related endocrine glands. These glands produce hormones involved in sexual development and reproduction. These glands and the hormones they produce play important roles in developing sexual characteristics. They are also involved in other characteristics and behaviours, as we will see throughout this book.

Neuroscientists have discovered that the nervous and endocrine systems are intricately interconnected. The brain's hypothalamus connects these systems and the two systems work together to control the body's activities. Recall from earlier in this chapter that the autonomic nervous system regulates processes such as respiration, heart rate, and digestion. The autonomic nervous system acts on the endocrine glands to produce a number of important physiological reactions to strong emotions, such as rage and fear.

The endocrine system differs from the nervous system in a variety of ways. For one thing, as you saw in Figure 3.21, the parts of the endocrine system are not all connected in the way that the parts of the nervous system are. For another, the endocrine system

- **pituitary gland** A pea-sized gland just beneath the hypothalamus that controls growth and regulates other glands.
- **pineal gland** The gland near the centre of the brain that secretes melatonin to regulate sleep and some reproductive organs.
- **thyroid gland** A butterfly-shaped gland in the neck that is involved in metabolism.
- **parathyroid** Four small glands in the neck that control the body's calcium levels.
- **thymus** A gland located between the lungs that is critical to the immune system of infants and children.
- **adrenal glands** Glands at the top of each kidney that are responsible for regulating mood, energy level, and the ability to cope with stress.
- **pancreas** A dual-purpose gland under the stomach that performs both digestive and endocrine functions.
- **ovaries** Sex-related endocrine glands that produce hormones involved in female sexual development and reproduction.
- **testes** Sex-related endocrine glands in the scrotum that produce hormones involved in male sexual development and reproduction.

works more slowly than the nervous system, because hormones are transported in our blood through the circulatory system. Our hearts do a mind-boggling job of pumping blood throughout the body, but blood moves far more slowly than the neural impulses do in the nervous system's superhighway.

# 5. HOW CAN WE RECOVER FROM BRAIN DAMAGE?

A critical property of the brain is its ability to change, especially following brain damage. Researchers have investigated the brain's ability to adapt and repair itself following injury. For example, blindness, especially occurring early in life, can cause remarkable changes in the brain's occipital lobe (Fine & Park, 2018). Though changes in the anatomy of the occipital lobe related to blindness are quite minor, changes in the neurochemistry and metabolism of the brain region can be striking. As a result, the occipital lobe, which normally responds to visual input, may respond to inputs from touch, hearing, and even thinking.

Brain damage can produce horrific effects, including paralysis, sensory loss, memory loss, and personality changes. However, depending on the age of the individual and the extent of the damage, the brain can adapt and functions can be recovered (Kolb & Teskey, 2012). How much recovery takes place following the damage depends in part on the amount and type of stimulation from the environment (Sale, 2018).

## What Is Brain Plasticity and the Brain's Capacity for Repair?

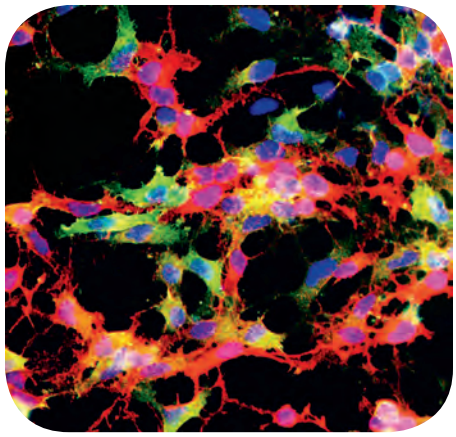
The human brain shows the most plasticity in young children, before the functions of the cortical regions become relatively fixed (Spencer-Smith & Anderson, 2011). For example, if the speech areas in an infant's left hemisphere are damaged, the right hemisphere assumes much of this language function. However, after age 5, damage to the left hemisphere can permanently disrupt language ability. Nonetheless, even the adult brain shows plasticity resulting in cognitive and behavioural recovery following brain damage (Guyer et al., 2018).

A key factor in recovery is whether some or all of the neurons in an affected area are just damaged or completely destroyed (Huang & Chang, 2009). If just damaged, brain function is often restored over time. There are three processes that allow the damaged brain to be repaired:

- *Collateral sprouting,* the process by which axons of some healthy neurons adjacent to damaged cells grow new branches.
- *Substitution of function,* the process by which the damaged region's function is taken over by another area or areas of the brain.
- *Neurogenesis,* the process by which new neurons are generated.

Neurogenesis occurs in mammals, including mice. In mice, exercise increases neurogenesis whereas social isolation decreases it (Clemenson et al., 2015; Gil-Mohapel et al., 2011; Leasure & Decker, 2009). It is now accepted that neurogenesis can occur in humans (Göritz & Frisén, 2012; Inta & Gass, 2015; Sun, 2016). However, to date, the presence of new neurons has been documented only in the hippocampus, which is involved in memory, and the olfactory bulb, which is involved in the sense of smell (Anacker et al., 2015; Xu et al., 2013). Researchers are exploring how the grafting of neural stem cells to various regions of the brain, such as the hypothalamus, might increase neurogenesis (Dadwal et al., 2015; Decimo et al., 2012). If researchers can discover how new neurons are generated, this may provide clues to how to fight degenerative diseases of the brain such as Alzheimer disease and Parkinson disease.

## What Are Brain Tissue Implants?



*This fluorescent micrograph shows glial stem cells. Like other stem cells, these have the capacity to develop into a wide range of other cells.*



To address brain damage, research has generated excitement about *brain grafts*—implants of healthy tissue into damaged brains (Hattiangady & Shetty, 2012). Brain grafts have greater potential success when the brain tissue used is from the fetal stage—an early stage in prenatal development (Thomas et al., 2009). The reason for this advantage is that the fetal neurons are still growing and have a much higher probability of making connections with other neurons than does mature brain tissue.

In several studies, researchers damaged part of an adult rat's brain, waited until the animal recovered as much as possible by itself, and assessed its behavioural deficits. They then took the corresponding area of a fetal rat's brain and transplanted it into the damaged brain of the adult rat. In these studies, the rats that received the brain transplants demonstrated considerable behavioural recovery (Reyes et al., 2015; Shetty et al., 2008). Though we use the term "brain transplants," keep in mind that only a small piece of brain material, perhaps the size of the lead tip of a pencil, is transplanted.

Might such implants be successful in humans suffering from brain damage? The research results hold promise (Moriarty et al., 2018), with new research focused on modifying the neural environment so the implants are better able to survive, mature, and integrate with the host brain (Tsai, 2018). However, finding donor material is a concern (Glaw et al., 2009). Although using brain tissue from aborted fetuses is a possibility, there are ethical concerns about that practice.

Perhaps one of the most heated debates in recent years has concerned the use of human embryonic stem cells in research and treatment. The human body contains more than 220 different types of cells, but **stem cells** are unique because they are primitive cells that have the capacity to develop into most types of human cells.

● **stem cells** Unique primitive cells that have the capacity to develop into most types of human cells.

Because of their amazing plasticity, stem cells might potentially replace damaged cells in the human body, including cells involved in spinal cord injury and brain damage (Rosser & Bachoud-Lévi, 2012; Yoo et al., 2013).

Typically, researchers have harvested the stem cells from frozen embryos left over from *in vitro fertilization* procedures. In these procedures, a number of eggs, or *ova,* are collected from a woman's ovaries in order to be fertilized in a lab. In vitro fertilization attempts to bring together the ova with sperm, producing human embryos. Because the procedure is difficult and delicate, doctors typically fertilize a large number of eggs hoping that some will survive when implanted in the woman's uterus. In the typical procedure, there are leftover embryos. These embryos are in the *blastocyst* stage, which occurs five days after conception. At this stage the embryo has not yet attached to the uterus and has no brain, no central nervous system, and no mouth—it is an undifferentiated ball of cells.

Some supporters of stem cell technology emphasize that using these cells for research and treatment might relieve a great deal of human suffering. Opponents may disapprove of the use of stem cells in research or treatment because the embryos die when the stem cells are removed. (In fact, leftover embryos are likely to be destroyed in any case.) In 2009, American President Barack Obama removed restrictions on stem cell research. The Government of Canada continues to support and fund stem cell research. The promise of stem cell research must be considered alongside concern for people with serious health challenges who seek treatment before such research has been thoroughly evaluated. For example, the media have reported that a patient had cells from his nose begin to grow in his spine following a stem cell treatment (Crowe, 2019).

A complementary line of research sounds like a futuristic episode of Star Trek. Researchers have designed probes that mimic the size, shape, and flexibility of actual neurons (Yang et al., 2019). They do such a good job of mimicking neurons that the brain does not seem to detect them, so there is little immune response. Because these probes can monitor the activity of brain regions they could help us understand health challenges such as depression and schizophrenia. Interestingly, when implanted in the

hypothalamus of mice, the probes seemed to recruit the mice's own neurons and may provide a platform to encourage cell migration and tissue regeneration. If successful, these probes could allow for regenerative medicine without fetal tissue or stem cells.

# 6. WHAT DOES GENETICS HAVE TO DO WITH PSYCHOLOGY AND BEHAVIOUR?

In addition to the brain and nervous system, other aspects of our physiology affect our psychological processes. Genes, a focal point of this section, are an essential contributor to these processes (Bishop, 2015; Pluess, 2015). As noted in Chapter 1, the influence of nature (our internal genetic endowment) and nurture (our external experience) on psychological characteristics has long fascinated psychologists. A recent reconsideration of these two forces suggests that psychologists, at least when it comes to factors that contribute to our success, may have exaggerated the influence of nature (Moreau et al., 2019).

## What Are Chromosomes, Genes, and DNA?

- **chromosomes** In the human cell, threadlike structures that come in 23 pairs, one member of each pair originating from each parent, and that contain the remarkable substance DNA.

- **deoxyribonucleic acid (DNA)** A complex molecule in the cell's chromosomes that carries genetic information.

- **genes** The units of hereditary information, consisting of short segments of chromosomes composed of DNA.

Within the human body are literally trillions of cells. The nucleus of each human cell contains 46 **chromosomes**, threadlike structures that come in 23 pairs, with one member of each pair originating from each biological parent. Chromosomes contain the remarkable substance **deoxyribonucleic acid (DNA)**, a complex molecule that carries genetic information. **Genes**, the units of hereditary information, are short chromosome segments composed of DNA. The relationship among cells, chromosomes, genes, and DNA is illustrated in Figure 3.23.

Genes hold the code for creating proteins out of amino acids, forming the bases for everything our bodies do. Specifically, many genes direct and regulate the production of these proteins. Although every cell in our body contains a full complement of our genes, different genes are active in each cell. Many genes encode proteins that are unique to a particular cell and give the cell its identity. Will it be a neuron or a bone cell? The activation

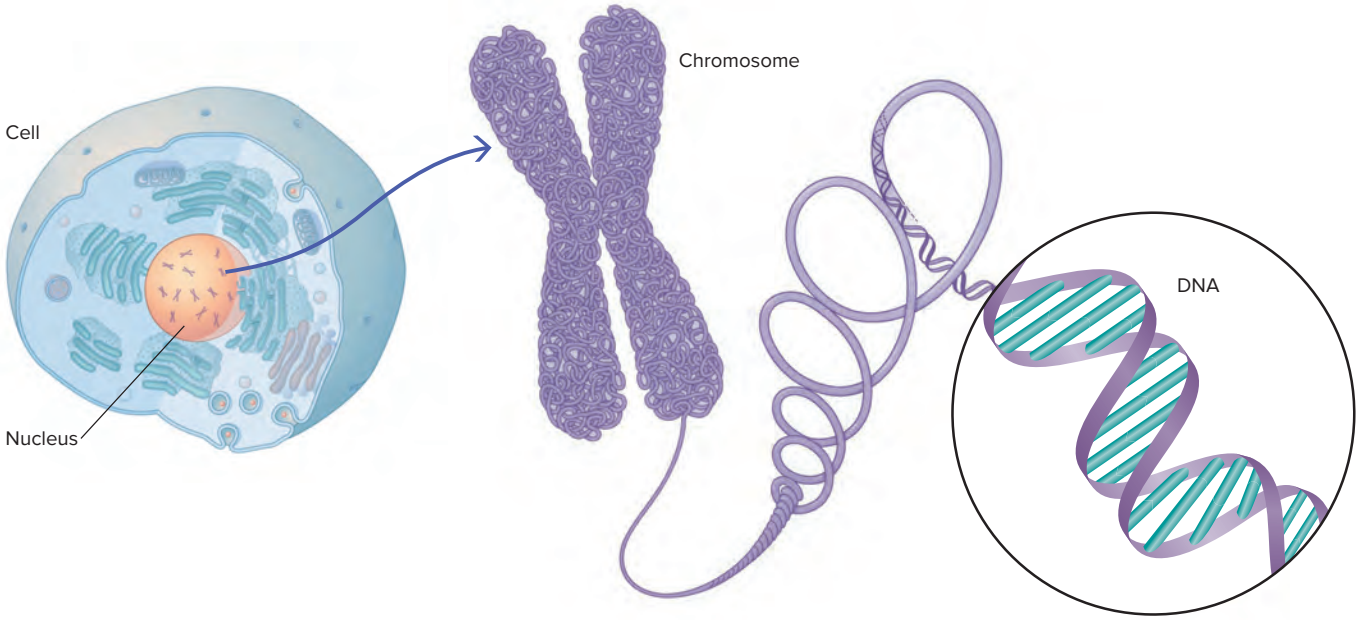



**FIGURE 3.23** **Cells, Chromosomes, Genes, and DNA** (*Left*) The body houses trillions of cells, which are the basic structural units of life. Each cell contains a central structure, the nucleus. (*Middle*) Chromosomes and genes are located in the nucleus of the cell. Chromosomes are made up of threadlike structures composed mainly of DNA molecules. Note that inside the chromosome are the genes. (*Right*) A gene is a segment of DNA that contains the hereditary code. The structure of DNA resembles a spiral ladder.

of our genes determines the answer to this question. Some genes are involved in the development of the embryo and then are turned off for the rest of life. Genes do not operate independently but work with one another and in collaboration with hormones and the environment to direct the body's functions (Goossens et al., 2015; Moore, 2013).

An international research program called the Human Genome Project (*genome* refers to an organism's complete genetic material, as discussed below) documented the human genome. However, it still is not known how many genes humans have and even the definition of the word "gene" is being reconsidered (Salzberg, 2018). Current guesses for the number of genes that code for proteins range from 20,000 to 30,000. When genes from one parent combine at conception with the same number of genes from the other parent, the number of possibilities is staggering. Although scientists are still a long way from unravelling all the mysteries about how genes work, some aspects of this process are well understood, starting with the fact that multiple genes interact to give rise to observable characteristics.

*A positive result from the Human Genome Project. Shortly after Andrew Gobea was born, his cells were genetically altered to prevent his immune system from failing.*
©Mark J. Terrill/AP Images

## How Is Genetics Studied?

Historically speaking, genetics is a relatively young science. Its origins go back to the mid-nineteenth century, when an Austrian monk, Gregor Mendel, studied heredity in generations of pea plants. By crossbreeding plants with different characteristics and noting the characteristics of the offspring, Mendel discovered predictable patterns of heredity and thereby laid the foundation for modern genetics.

Mendel noticed that some genes seem to be more likely than others to determine the physical characteristics of an organism. In some gene pairs, one gene is dominant over the other. If one gene of a pair is dominant and one is recessive, the **dominant-recessive genes principle** applies, meaning that the dominant gene overrides the recessive gene—that is, it prevents the recessive gene from expressing its instructions. The recessive gene exerts its influence only if *both* genes of a pair are recessive. If you inherit a recessive gene from only one biological parent, you may never know you carry the gene.

● **dominant-recessive genes principle** The principle that, if one gene of a pair is dominant and one is recessive, the dominant gene overrides the recessive gene. A recessive gene exerts its influence only if both genes of a pair are recessive.

In the world of dominant-recessive genes, brown eyes, farsightedness, and dimples rule over blue eyes, nearsightedness, and freckles. If, however, you inherit a recessive gene for a trait from *both* of your biological parents, you will show the trait. That is why two brown-haired parents can have a child with red hair: Each parent would have dominant genes for brown hair and recessive genes for red hair. Because dominant genes override recessive genes, the parents have brown hair. However, the child can inherit recessive genes for red hair from each biological parent. With no dominant genes to override them, the recessive genes would make the child's hair red.

Yet, the relationship between genes and characteristics is complex. Even simple traits such as eye colour and hair colour are likely the product of *multiple* genes. Moreover, many different genes probably influence complex human characteristics such as personality and intelligence (Plomin & von Stumm, 2018). Scientists use the term *polygenic inheritance* to describe the influences of multiple genes on behaviour.

Given the staggering importance of Mendel's work, you might be surprised to learn that the scientific community pretty much ignored his work for decades. Scientists didn't initially appreciate the significance of his insights.

Present-day researchers continue to apply Mendel's methods, as well as the latest technology, in their quest to expand our knowledge of genetics. We next consider four ways in which scientists investigate our genetic heritage: molecular genetics, genome-wide association method, selective breeding, and behaviour genetics.

### WHAT IS MOLECULAR GENETICS?

The field of *molecular genetics* involves the manipulation of genes using technology to determine their effect on behaviour. There is currently a great deal of enthusiasm about the use of molecular genetics to discover the specific locations on genes that determine susceptibility to many diseases and other aspects of health and well-being (Bartels & Baselmans, 2015; Kendler et al., 2012; Li et al., 2015; Polfus et al., 2015).

## WHAT IS THE GENOME-WIDE ASSOCIATION METHOD?

The completion of the Human Genome Project in 2003 has allowed for the use of the *genome-wide association method* to identify genetic variations linked to a particular disease, such as cancer, cardiovascular disease, or Alzheimer disease (National Human Genome Research Institute, 2015). To conduct a genome-wide association study, researchers obtain DNA from individuals who have a disease of interest and from those who do not. Then, each participant's complete set of DNA, or genome, is purified from their blood or cells and scanned on machines to determine markers of genetic variation. If the genetic variations occur more frequently in people who have the disease, the variations suggest the region in the human genome where the disease-causing problem exists. Genome-wide association studies have been conducted for a variety of diseases and disorders, including Alzheimer disease (Raj et al., 2012) and depression (Major Depressive Disorder Working Group, 2013).

Genes that are close to one another in our DNA are more likely to be inherited together. This link between neighbouring genes is used in *linkage analysis*. This genome analysis may help identify the location of certain genes by referring to other genes whose position is already known, which is a strategy often used to search for genes associated with a disease (Ott et al., 2015). Gene linkage studies are now being conducted on a wide variety of disorders and health issues.

A key challenge in genome-wide association studies, as well as genetic linkage studies, is replication. Recall that replicating a research finding means repeating it. If a genetic characteristic is associated with a particular disorder, disease, or characteristic in one sample of participants, this association should emerge as well in another sample. Unfortunately, many early findings using genome-wide analyses did not replicate; that is, genes that were associated with a particular characteristic in one sample did not show the same association in later studies. As a result, scientists who use these tools have become increasingly cautious about drawing conclusions (Jannot et al., 2015).

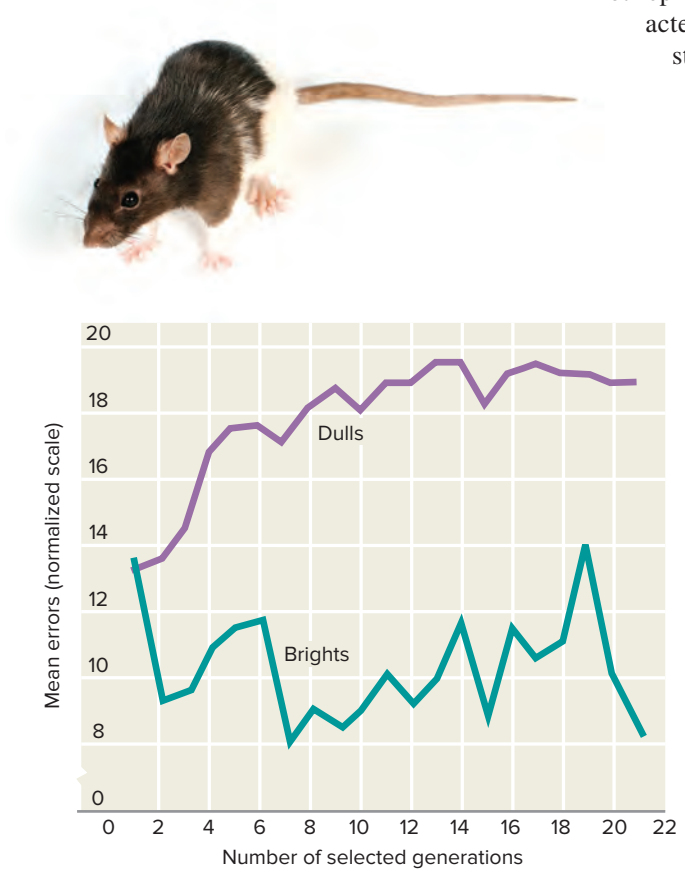



FIGURE 3.24 **Results of Tryon's Selective Breeding Experiment with Maze-Bright and Maze-Dull Rats** These results demonstrate genetic influences on behaviour.



## WHAT IS SELECTIVE BREEDING?

*Selective breeding* is a genetic method in which organisms are chosen for reproduction based on how much of a particular trait they display. Mendel developed this technique in his studies of pea plants. A more recent example involving behaviour is the classic selective breeding study conducted by Robert Tryon (1940). He studied maze-running ability in rats. After he trained a large number of rats to run a complex maze, he then mated the rats that were the best at maze running ("maze bright'') with each other and the ones that were the worst ("maze dull'') with each other. He continued this process for 21 generations of rats. As Figure 3.24 shows, after several generations, the maze-bright rats significantly outperformed the maze-dull rats.

Selective breeding studies demonstrate that genes are an important influence on behaviour, but so is experience. For example, in another study, maze-bright and maze-dull rats were reared in one of two environments: (1) an impoverished environment that consisted of a barren wire-mesh group cage, or (2) an enriched environment that contained tunnels, ramps, visual displays, and other stimulating objects (Cooper & Zubeck, 1958). When they reached maturity, only the maze-dull rats that had been reared in an impoverished environment made more maze-learning errors than the maze-bright rats.

It is unethical to conduct selective breeding studies with human beings. (*Eugenics* refers to the application of selective breeding to humans; Adolf Hitler tragically and notoriously espoused this practice in Nazi Germany.) In humans, researchers generally examine the influence of genetics on psychological characteristics by using behaviour genetics.

## WHAT IS BEHAVIOUR GENETICS?

*Behaviour genetics* is the study of the nature and degree of heredity's influence on behaviour. Behaviour genetics is less invasive than the other types of genetic investigation. Using methods such as the *twin study,* behaviour geneticists examine the extent to which individuals are shaped by their heredity and their environmental experiences (Ilies & Dimotakis, 2015; Knopik et al., 2015; South, 2015).

In the most common type of twin study, researchers compare the behavioural similarity of identical twins with the behavioural similarity of fraternal twins (Bell & Saffery, 2012). *Identical twins* develop from a single fertilized egg that splits into two genetically identical embryos, each of which becomes a person. *Fraternal twins* develop from separate eggs and separate sperm, and so they are genetically no more similar than non-twin siblings. They may even be of different sexes.

By comparing groups of identical and fraternal twins, behaviour geneticists capitalize on the fact that identical twins are more similar genetically than are fraternal twins. In one study, 428 identical and fraternal twin pairs in Italy were compared with respect to their levels of self-esteem, life satisfaction, and optimism for the future (Caprara et al., 2009). The identical twins were much more similar than the fraternal twins on these measures.

In another type of twin study, researchers evaluate identical twins who were reared in separate environments. If their behaviour is similar, the assumption is that heredity has played an important role in shaping their behaviour. This strategy is the basis for the Minnesota Study of Twins Reared Apart, directed by Thomas Bouchard and his colleagues (1996). The researchers bring identical twins who have been reared apart to Minneapolis from all over the world to study their behaviour. They ask thousands of questions about their family, childhood, interests, and values. Researchers obtain detailed medical histories with information about diet, smoking, and exercise habits.

Drawing strong conclusions about genetics from twins reared apart has been criticized for various reasons. First, some of the separated twins in the Minnesota study had been together several months prior to their adoption and some had been reunited prior to testing (in certain cases, for a number of years). Second, adoption agencies often put identical twins in similar homes. Third, identical twins typically look very similar and our looks influence how the world treats us. The critical point is that identical twins not only share more genes, they also share a more common environment than fraternal twins. Additionally, though it is frequently reported that identical twins share 100 percent of their genes, the actual genetic relatedness of twins is less than this (Bruder et al., 2008). Therefore, it is difficult to determine if the psychological and behavioural similarities between identical twins are attributable to their similar (but not identical) genes or their similar environment. Finally, even strangers (of the exact same age) are likely to have some coincidental similarities (Joseph, 2006).

One additional recently discovered finding further shows that genetics alone do not account for why identical twins share more similarities. Our characteristics, including psychological ones, depend on the genes we inherit from our parents *and* on epigenetics. Epigenetics are the molecular mechanisms that control which genes are turned on or off. Epigenetics are more similar in identical twins than fraternal twins, and this nongenetic factor explains why identical twins share similar factors, such as the risk of cancer (Van Baak et al., 2018).

You have probably heard of instances of twins who were separated at birth and who, upon being reunited later in life, found themselves strikingly similar to each other. To think critically about such cases, consider the Psychological Inquiry.

### apply your knowledge

A review of epigenetic studies concluded that wireless technologies, including cell phones, may contribute to some neurodevelopmental and neurobehavioural alterations (Sage & Burgio, 2018). Wireless technologies emit electromagnetic fields and pulsed radiofrequency radiation. These emissions have been linked to poorer performance in memory, learning, cognition and attention tasks, and problems including autism and attention deficit hyperactivity disorders. Until more research is complete, you may want to limit your use of wireless technologies.

# psychological inquiry

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### *Identical Twins*

We've all heard stories about identical twins who were separated at birth. When these twins meet up in adulthood, people often find the similarities between them to be uncanny. Are these similarities evidence of the extraordinary power of genes? Let's take a closer look.

1. Imagine that you were asked how similar two people of the same gender, ethnicity, and age might be. In what ways might such people be alike?
2. How might such individuals, even growing up in very different environments, evoke similar responses from others?
3. Do you think that people of this same gender, age, and ethnicity might enjoy similar hobbies? Have similar jobs?
4. What does this Psychological Inquiry tell you about the power of vivid and unusual cases in the conclusions we reach?

*Our height depends significantly on the genes we inherit. However, even if we have genes that call for the stature of a basketball centre, we may not reach that "genetically programmed" height if we lack good nutrition, adequate shelter, and medical care.*

©Leon Bennett/Getty Images

## Are We a Product of Genes or the Environment?

So far, we have focused a lot on genes, and you are probably getting the picture that genes are a powerful force in shaping an organism. The role of genetics in some characteristics may seem obvious; for instance, how tall you are depends to a large degree on how tall your biological parents are. However, imagine a person growing up in an environment with poor nutrition, inadequate shelter, little or no medical care, and a mother who had received no prenatal care. This individual may have genes that call for the height of an NBA or a WNBA centre, but without environmental support for this genetic capacity, they may never reach that genetically programmed height.

The relationship between an individual's genes and the actual person we see before us is not a perfect one-to-one correspondence. Even for a characteristic such as height, genes do not fully determine where a person will stand on this variable. We need to account for the role of nurture, or environmental factors, in the characteristics we see in a person.

If the environment matters for an apparently simple characteristic such as height, imagine the role it might play in a complex psychological characteristic such as being outgoing or intelligent. For such a trait, genes are, again, not directly reflected in the characteristics of the person. Indeed, genes do not tell us exactly what a person will be like. Genes are simply related to some of the characteristics we see in a person.

To account for this gap between genes and actual observable characteristics, scientists distinguish between a genotype and a phenotype. A **genotype** is an individual's genetic heritage, the actual genetic material present in every cell in the person's body. A **phenotype** is the individual's observable characteristics. The relationship between a genotype and phenotype is not always obvious. Recall that some genetic characteristics are dominant and others are recessive. Seeing that a person has brown eyes (their phenotype) does not tell us whether the person might also have a gene for blue eyes

- **genotype** An individual's genetic heritage; one's actual genetic material.

- **phenotype** An individual's observable characteristics.

(their genotype) hiding out as well. The phenotype is influenced both by the genotype and by environmental factors.

The word *phenotype* applies to both physical *and* psychological characteristics. Consider a trait such as extroversion—the tendency to be outgoing and sociable. Even if we knew the exact genetic recipe for extroversion, we still could not perfectly predict a person's level of (phenotypic) extroversion from their genes, because at least some of this trait is influenced by the person's experience. We will revisit the concepts of genotype and phenotype throughout this book—for example, when we examine intelligence, human development, and personality.

Whether a gene is "turned on"—that is, directing cells to assemble proteins—is a matter of collaboration between hereditary and environmental factors. *Genetic expression,* a term that refers to gene activity that affects the body's cells, is influenced by the genes' environment (Gottlieb, 2007). For example, hormones that circulate in the blood make their way into the cell, where they can turn genes on and off. This flow of hormones can be affected by external environmental conditions, such as the amount of light, the length of the day, nutrition, pollutants, and behaviour. Another factor that can influence DNA synthesis is stress, a powerful factor in health and wellness that we consider at the end of this chapter.

## HOW DO WE ALTER GENES, AND WHAT IS CRISPR?

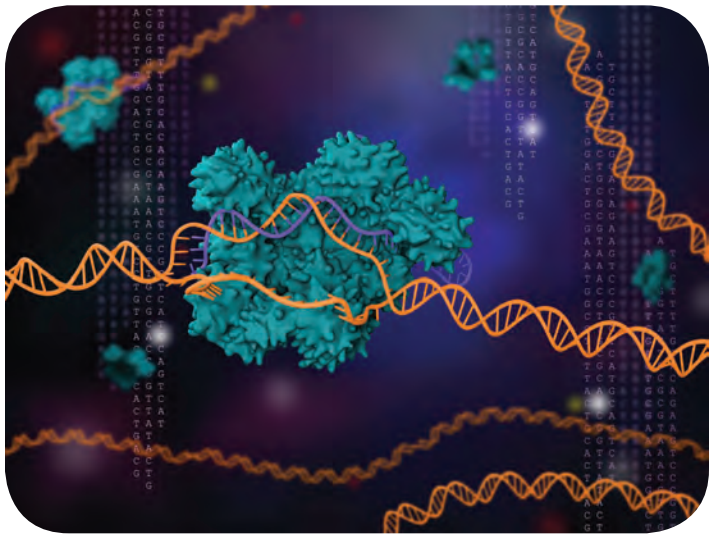
A new technique that allows researchers to alter genes has simultaneously excited and concerned the scientific community. The technique's full name is "clustered regularly interspaced short palindromic repeats"—thankfully scientists shorten this mouthful to "CRISPR" (pronounced *crisper*). CRISPR is part of your natural defence systems that fight viruses. CRISPR maintains a warehouse of snippets of harmful viruses. When CRISPR detects a match between a virus in your body and a sequence in its warehouse, CRISPR can snip the DNA of the invading virus with great precision, preventing it from replicating.

Using CRISPR, scientists have developed techniques to modify the genomes of animals including humans by introducing altered DNA sequences. You can think of this as akin to using the cut and paste function in your word processor. Though similar techniques have been available for a long time, CRISPR-based technology is revolutionary because it is much faster, easier, and exact than previous techniques, at only a fraction of their cost.

The goals of CRISPR technology are to modify the genes of people with diseases such Alzheimer disease, cystic fibrosis, and Huntington disease, and to create genetic resistance to viruses such as HIV. These modifications would be inherited by future generations, so children of those with modified genes would also be free of the diseases.

So, what are the many serious concerns of researchers regarding the application of CRISPR technology? Concerns include that the technology could turn off essential genes, activate cancer-causing genes, and create unintended consequences resulting from rearranging chromosomes (Baylis, 2018). Furthermore, the concerns are not limited to medical issues. The technology presents challenging social issues, including fear that gene-editing technology could intensify already troubling inequalities, leading to human rights concerns and a new round of eugenics.

These concerns are underscored by two recent studies. One study, conducted in China, has not been published in the scientific literature. The lead researcher, He Jiankui, reported that he had used CRISPR technology to alter the genomes of two human babies so that they would be protected against the HIV virus (Normile, 2018). A second study examined the genetics and mortality of over 400,000 people who naturally had the gene



*CRISPR technology allows researchers to alter genes by snipping DNA (depicted in orange) with your immune system (depicted in blue).*
Shutterstock/Meletios Verras

configuration that Jiankui's study created using CRISPR technology (Wei & Nielsen, 2019). Though these people were highly resistant to HIV, they also had a shortened life span. Independent analyses of Jiankui's work has criticized his research, including the ethical practice of this research, and raised doubts as to whether the babies are, in fact, immune to HIV (Regalado, 2019). In December of 2019, Jiankui was convicted of conducting "illegal medical practices," sentenced to three years in prison, and fined $560,000.

## 7. HOW DOES STRESS IMPACT OUR HEALTH AND WELLNESS?

The nervous system plays an essential role in our health and wellness.

- **stress** The responses of individuals to environmental stressors.
- **stressors** Circumstances and events that threaten individuals and tax their coping abilities and that cause physiological changes to ready the body to handle the assault of stress.

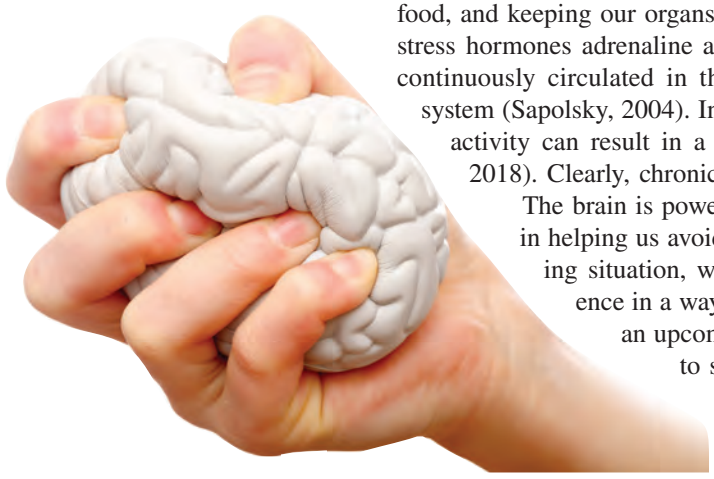
**Stress** is the response of individuals to **stressors**, which are the circumstances and events that threaten individuals and tax their coping abilities. Recall that the sympathetic nervous system jumps into action when we encounter a threat in the environment. When we experience stress, our body readies itself to handle the assault.

You certainly know what stress feels like. Imagine showing up for class and being surprised that there is a test that you were not aware of. Or consider how you would respond to having to give an impromptu speech in front of hundreds of critics. In these situations you would likely sweat, your heart would start thumping quickly, your mouth would be dry, and your pupils would get big. In short, your sympathetic nervous system would be activated.

As we have seen, stress can begin with a "fight or flight" response sparked by the sympathetic nervous system. This reaction quickly mobilizes the body's physiological resources to prepare us to deal with threats to survival. An unexpected exam or having to deliver a speech are not a threat to your survival, but the human stress response can occur to *anything* that threatens personally important motives (Sapolsky, 2004).

*Acute stress* is the stress that occurs in response to an immediate temporary perceived threat. When the stressful situation ends, so does acute stress. Acute stress is adaptive, because it allows us to do the things we need to do in an emergency. Once the danger passes, the parasympathetic nervous system can calm us down and focus on body maintenance. However, we are not in a live-or-die situation most of the time when we experience stress. Indeed, we can "stress ourselves out" just by thinking.

*Chronic stress*—stress that goes on continuously—may lead to persistent autonomic nervous system arousal (Morey et al., 2015). When the sympathetic nervous system is working to meet the demands of whatever is stressing us out, the parasympathetic nervous system does not have a chance to do its job of maintenance and repair, digesting food, and keeping our organs in good working order. Furthermore, in chronic stress, the stress hormones adrenaline and norepinephrine, produced by the endocrine system, are continuously circulated in the body, eventually causing a breakdown of the immune system (Sapolsky, 2004). In other words, over time, chronic autonomic nervous system activity can result in a wide range of serious health challenges (Stefanaki et al., 2018). Clearly, chronic stress is best avoided.



*Though short-term stress helps us deal with our environment, long-term stress can cause serious health problems.*
Ocskay Bence/Shutterstock.com

The brain is powerfully affected by chronic stress, but it can also be our ally in helping us avoid continuous stress. Consider that when we face a challenging situation, we can exploit the brain's abilities and interpret the experience in a way that is less stressful. For example, maybe we can approach an upcoming speech not so much as a stressor but as an opportunity to shine. Changing the way people think about their life challenges and experiences can help them live less stressfully and maintain good health (McGregor et al., 2015; Sannes et al., 2015).

At the beginning of this chapter, we considered how changing the way we think leads to physical changes in the brain and its operations. In light of this remarkable

capacity, we can potentially use our brains' powers to change how we look at life experiences—and maybe even to deploy the brain as a defence against stress.

The biological foundations of psychology are in evidence across the entire nervous system, including the brain, the intricately working neurotransmitters, the endocrine system, and our genes. These physical realities of our body work in concert to produce our behaviour, thoughts, and feelings. The activities you perform every day are all signs of the success of this physical system. Your mastery of the material in this chapter is only one reflection of the extraordinary capabilities of this biological achievement.

## apply your knowledge

Given the negative impact that stress can have on our health and well-being, we would be wise to utilize tools and skills to reduce it. Here are a few ideas to help you through stressful times:

1. *Distraction*. Those online cat videos may have value. Distraction, such as being with friends or watching stand-up comedy, helps with stress.
2. *Perspective*. Remember the Rule of 6. Will the issue giving you stress matter in 6 hours, 6 days or 6 months? Asking this question can provide perspective so that the stressor is less daunting.
3. *Write*. Telling people about what you find stressful may lead you to think about it more. But writing about the stress may take it from your mind onto the paper, so it will not be continually "looped" in your thinking.
4. *Exercise*. Physical activity, particularly in nature, can decrease stress and increase your well-being.

# summary

### 1. WHAT IS THE NERVOUS SYSTEM?

The nervous system is the body's electrochemical communication circuitry. It includes the brain. Four important characteristics of the nervous system are complexity, integration, adaptability, and electrochemical transmission. The brain's special ability to adapt and change is called plasticity.

Decision making in the nervous system occurs in specialized pathways of nerve cells. Three of these pathways involve sensory input, motor output, and neural networks.

The nervous system is divided into two main parts: central (CNS) and peripheral (PNS). The CNS consists of the brain and spinal cord. The PNS has two major divisions: somatic and autonomic. The autonomic nervous system consists of two main divisions: sympathetic and parasympathetic. The sympathetic nervous system drives our body's response to threatening circumstances, while the parasympathetic nervous system is involved in maintaining the body, digesting food, and healing wounds.

### 2. WHAT ARE NEURONS AND GLIAL CELLS?

Neurons are cells that specialize in processing information. They make up the communication network of the nervous system. The five main parts of the neuron are the cell body, dendrite (receiving part), axon (sending part), axon terminal, and cell membrane. A myelin sheath encases and insulates most axons, which speeds up transmission of neural impulses and saves energy.

Impulses are sent from a neuron along its axon in the form of brief electrical impulses. Resting potential is the stable, slightly negative charge of a neuron that is not firing. The brief wave of electrical charge that sweeps down the axon, called the action potential, is an all-or-nothing response. The synapse is the space between neurons. At the synapse, neurotransmitters are released from the sending neuron, and some of these attach to receptor sites on the receiving neuron, where they may stimulate another electrical impulse. Several steps are involved in stopping synaptic transmission, including deactivation, autoreceptor binding, reuptake, and degradation. Neurotransmitters include acetylcholine, GABA, glutamate, norepinephrine, dopamine, serotonin, endorphins, and oxytocin. Neural networks are clusters of neurons that are interconnected and that develop through experience.

### 3. WHAT ARE THE MAJOR PARTS OF THE BRAIN AND HOW DO WE STUDY THEM?

The main techniques used to study the brain are brain lesioning, electrical recording, and brain imaging. These methods have revealed a great deal about the three major divisions of the brain—the hindbrain, midbrain, and forebrain.

The cerebral cortex makes up most of the outer layer of the brain, and it is where higher mental functions such as thinking and planning take place. The wrinkled surface of the cerebral cortex is divided into hemispheres, each with four lobes: occipital, temporal, frontal, and parietal. There is considerable integration and connection among the brain's lobes.

The brain has two hemispheres. Two areas in the left hemisphere that involve specific language functions are Broca's area (producing speech) and Wernicke's area (understanding language). The corpus callosum is a large bundle of fibres that connects the two

hemispheres. Research suggests that the left brain is typically more dominant in processing verbal information (such as language) and the right brain in processing nonverbal information (such as spatial perception, visual recognition, faces, and emotion). Nonetheless, in a person whose corpus callosum is intact, both hemispheres of the cerebral cortex are involved in most complex human functioning.

## 4. WHAT IS THE ENDOCRINE SYSTEM?

The endocrine glands release hormones directly into the bloodstream for distribution throughout the body. The pituitary gland is the master endocrine gland. The adrenal glands play important roles in moods, energy level, and ability to cope with stress. Other parts of the endocrine system include the thyroid, parathyroid, thymus, pancreas (which produces insulin), and the ovaries and testes (which produce sex hormones).

## 5. HOW CAN WE RECOVER FROM BRAIN DAMAGE?

The human brain has considerable plasticity, although this ability to adapt and change is greater in young children than later in development. Three ways in which a damaged brain might repair itself are collateral sprouting, substitution of function, and neurogenesis. Brain grafts are implants of healthy tissue into damaged brains. Brain grafts are more successful when fetal tissue is used. Stem cell research is a controversial area of science that may allow for novel treatments for damaged nervous systems.

## 6. WHAT DO GENETICS HAVE TO DO WITH PSYCHOLOGY AND BEHAVIOUR?

Chromosomes are threadlike structures that occur in 23 pairs, with one member of each pair coming from each parent. Chromosomes contain the genetic substance deoxyribonucleic acid (DNA). Genes, the units of hereditary information, are short segments of chromosomes composed of DNA. According to the dominant-recessive genes principle, if one gene of a pair is dominant and one is recessive, the dominant gene overrides the recessive gene.

Two important concepts in the study of genetics are the genotype and phenotype. The genotype is an individual's actual genetic material. The phenotype is the observable characteristics of the person.

Different ways of studying heredity's influence are molecular genetics, selective breeding, genome-wide association method, and behaviour genetics. CRISPR is a potentially revolutionary technology that allows researchers to alter our genes. This technology holds great promise, and great concern, for researchers.

Both genes and environment play a role in determining the phenotype of an individual. Even for characteristics in which genes play a large role (such as height and eye colour), the environment is also a factor.

## 7. HOW DOES STRESS IMPACT OUR HEALTH AND WELLNESS?

Stress is the body's response to changes in the environment. Stressors are the agents of these changes—that is, the circumstances and events that threaten the organism. The body's stress response is largely a function of sympathetic nervous system activation that prepares us for action in the face of a threat. The stress response involves slowing down or putting aside maintenance processes (such as immune function and digestion) in favour of rapid action.

Acute stress is an adaptive response, but chronic stress can have negative consequences for our health. Although stress may be inevitable, our reaction to a stressful event is largely a function of how we think about it.

# key *terms*

action potential
adrenal glands
afferent nerves or sensory nerves
all-or-nothing principle
amygdala
association cortex or association area
autonomic nervous system
axon
basal ganglia
brain stem
cell body
central nervous system (CNS)
cerebral cortex
chromosomes
corpus callosum
dendrites
deoxyribonucleic acid (DNA)
dominant-recessive genes principle
efferent nerves or motor nerves
endocrine system
forebrain
frontal lobes
genes
genotype
glands
glial cells or glia
hindbrain
hippocampus
hormones
hypothalamus
limbic system
midbrain
mirror neurons
motor cortex
myelin sheath
neocortex
nervous system
neural networks
neurons
neurotransmitters
occipital lobes
ovaries
pancreas
parasympathetic nervous system
parathyroid
parietal lobes
peripheral nervous system (PNS)
phenotype
pineal gland
pituitary gland
plasticity
resting potential
reticular formation
somatic nervous system
somatosensory cortex
stem cells
stress
stressors
sympathetic nervous system
synapses
temporal lobes
testes
thalamus
thymus
thyroid gland