4.2 Our Brains Control Our Thoughts, Feelings, and Behaviour

Learning Objectives

1. Describe the structures and function of the "old brain" and its influence on behaviour.
2. Explain the structure of the cerebral cortex (its hemispheres and lobes) and the function of each area of the cortex.
3. Define the concepts of brain plasticity, neurogenesis, and brain lateralization.

If you were someone who understood brain anatomy and were to look at the brain of an animal that you had never seen before, you would nevertheless be able to deduce the likely capacities of the animal. This is because the brains of all animals are very similar in overall form. In each animal the brain is layered, and the basic structures of the brain are similar (see Figure 4.5, "The Major Structures in the Human Brain"). The innermost structures of the brain — the parts nearest the spinal cord — are the oldest part of the brain, and these areas carry out the same functions they did for our distant ancestors. The "old brain" regulates basic survival functions, such as breathing, moving, resting, and feeding, and creates our experiences of emotion. Mammals, including humans, have developed further brain layers that provide more advanced functions — for instance, better memory, more sophisticated social interactions, and the ability to experience emotions. Humans have a very large and highly developed outer layer known as the *cerebral cortex* (see Figure 4.6, "Cerebral Cortex"), which makes us particularly adept at these processes.

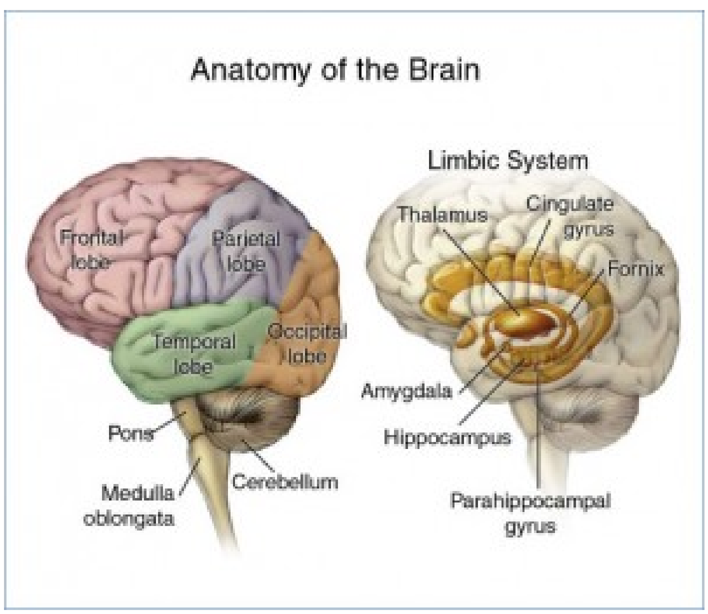

Figure 4.5 The Major Structures in the Human Brain.

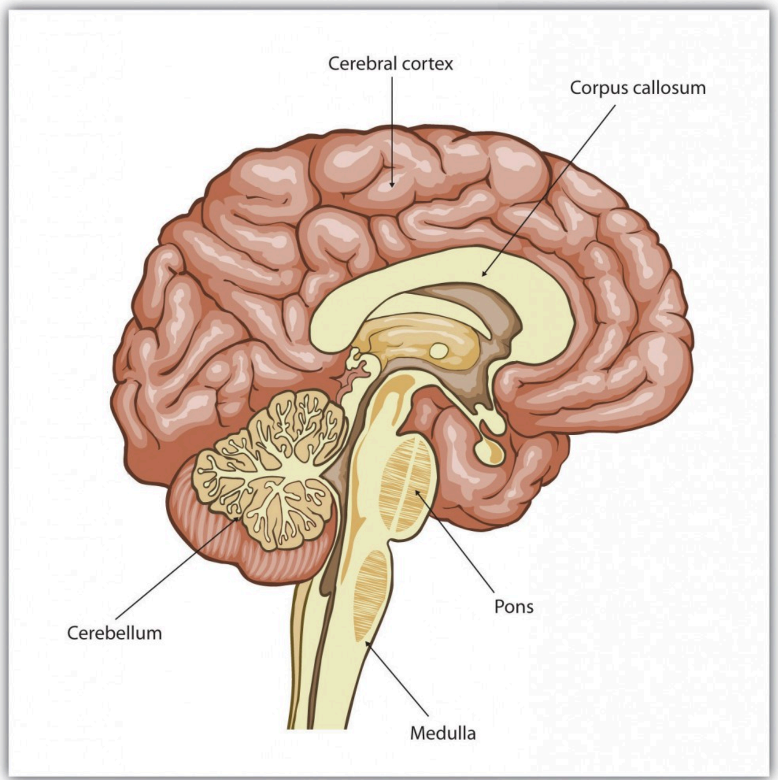

Figure 4.6 Cerebral Cortex. Humans have a very large and highly developed outer brain layer known as the cerebral cortex. The cortex provides humans with excellent memory, outstanding cognitive skills, and the ability to experience complex emotions.

The Old Brain: Wired for Survival

The **brain stem** is *the oldest and innermost region of the brain*. It's designed to control the most basic functions of life, including breathing, attention, and motor responses (Figure 4.7, "The Brain Stem and the Thalamus"). The brain stem begins where the spinal cord enters the skull and forms the **medulla**, *the area of the brain stem that controls heart rate and breathing*. In many cases the medulla alone is sufficient to maintain life — animals that have the remainder of their brains above the medulla severed are still able to eat, breathe, and even move. The spherical shape above the medulla is the **pons**, *a structure in the brain stem that helps control the movements of the body, playing a particularly important role in balance and walking*.

Running through the medulla and the pons is a long, narrow network of neurons known as the **reticular formation**. The job of the reticular formation is to filter out some of the stimuli that are coming into the brain from the spinal cord and to relay the remainder of the signals to other areas of the brain. The reticular formation also plays important roles in walking, eating, sexual activity, and sleeping. When electrical stimulation is applied to the reticular formation of an animal, it immediately becomes fully awake, and when the reticular formation is severed from the higher brain regions, the animal falls into a deep coma.

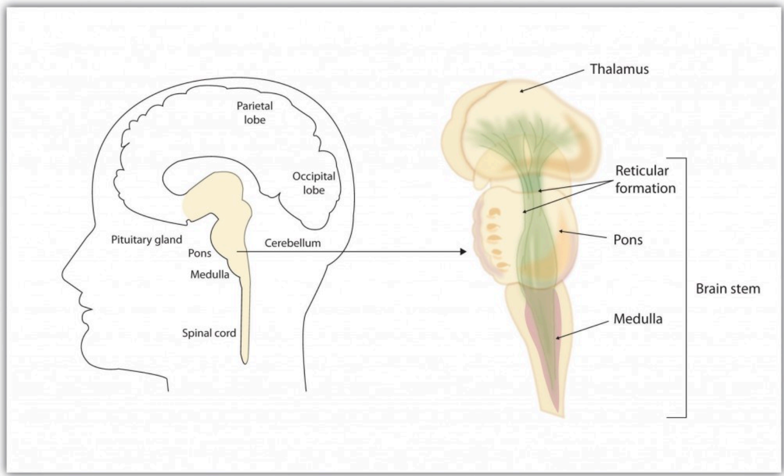

Figure 4.7 The Brain Stem and the Thalamus. The brain stem is an extension of the spinal cord, including the medulla, the pons, the thalamus, and the reticular formation.

Above the brain stem are other parts of the old brain that also are involved in the processing of behaviour and emotions (see Figure 4.8, "The Limbic System"). The **thalamus** is *the egg-shaped structure above the brain stem that applies still more filtering to the sensory information that is coming up from the spinal cord and through the reticular formation, and it relays some of these remaining signals to the higher brain levels* (Sherman & Guillery, 2006). The thalamus also receives some of the higher brain's replies, forwarding them to the medulla and the cerebellum. The thalamus is also important in sleep because it shuts off incoming signals from the senses, allowing us to rest.

The **cerebellum** (literally, "little brain") *consists of two wrinkled ovals behind the brain stem. It functions to coordinate voluntary movement*. People who have damage to the cerebellum have difficulty walking, keeping their balance, and holding their hands steady. Consuming alcohol influences the cerebellum, which is why people who are drunk have more difficulty walking in a straight line. Also, the cerebellum contributes to emotional responses, helps us discriminate between different sounds and textures, and is important in learning (Bower & Parsons, 2003).

Whereas the primary function of the brain stem is to regulate the most basic aspects of life, including motor functions, the *limbic system* is largely responsible for memory and emotions, including our responses to reward and punishment. The **limbic system** is *a brain area, located between the brain stem and the two cerebral hemispheres, that governs emotion and memory*. *It includes the amygdala, the hypothalamus, and the hippocampus*.

The **amygdala** *consists of two "almond-shaped" clusters (amygdala comes from the Latin word for "almond") and is primarily responsible for regulating our perceptions of, and reactions to, aggression and fear*. The amygdala has connections to other bodily systems related to fear, including the sympathetic nervous system (which we will see later is important in fear responses), facial responses (which perceive and express emotions), the processing of smells, and the release of neurotransmitters related to stress and aggression (Best, 2009). In one early study, Klüver and Bucy (1939) damaged the amygdala of an aggressive rhesus monkey. They found that the once angry animal immediately became passive and no longer responded to fearful situations with aggressive behaviour. Electrical stimulation of the amygdala in other animals also influences aggression. In addition to helping us experience fear, the amygdala also helps us learn from situations that create fear. When we experience events that are dangerous,

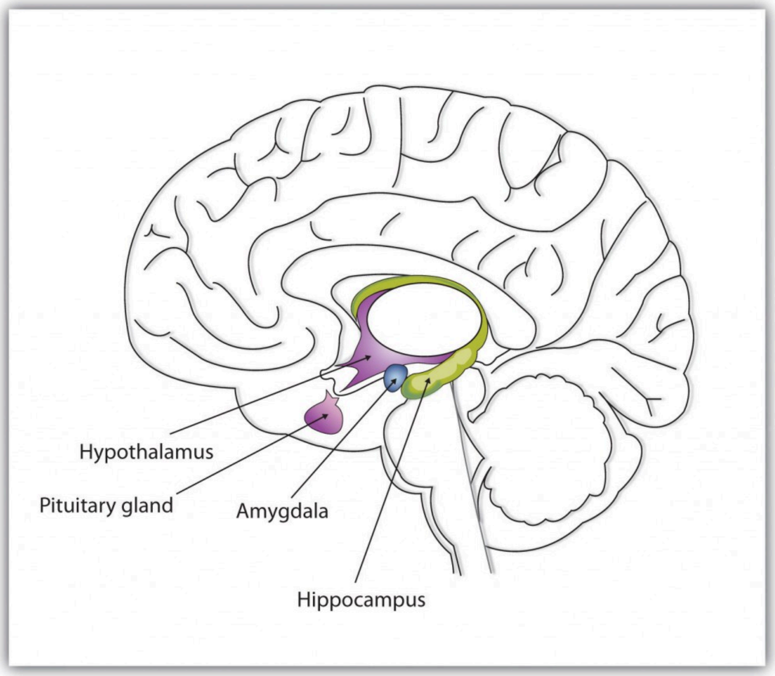

Figure 4.8 The Limbic System. This diagram shows the major parts of the limbic system, as well as the pituitary gland, which is controlled by it.

the amygdala stimulates the brain to remember the details of the situation so that we learn to avoid it in the future (Sigurdsson, Doyère, Cain, & LeDoux, 2007).

Located just under the thalamus (hence its name), the **hypothalamus** is *a brain structure that contains a number of small areas that perform a variety of functions, including the regulation of hunger and sexual behaviour, as well as linking the nervous system to the endocrine system via the pituitary gland.* Through its many interactions with other parts of the brain, the hypothalamus helps regulate body temperature, hunger, thirst, and sex, and responds to the satisfaction of these needs by creating feelings of pleasure. Olds and Milner (1954) discovered these reward centres accidentally after they had momentarily stimulated the hypothalamus of a rat. The researchers noticed that after being stimulated, the rat continued to move to the exact spot in its cage where the stimulation had occurred, as if it were trying to re-create the circumstances surrounding its original experience. Upon further research into these reward centres, Olds (1958) discovered that animals would do almost anything to re-create enjoyable stimulation, including crossing a painful electrified grid to receive it. In one experiment a rat was given the opportunity to electrically stimulate its own hypothalamus by pressing a pedal. The rat enjoyed the experience so much that it pressed the pedal more than 7,000 times per hour until it collapsed from sheer exhaustion.

The **hippocampus** consists of *two "horns" that curve back from the amygdala*. The hippocampus is important in *storing information in long-term memory*. If the hippocampus is damaged, a person cannot build new memories, living instead in a strange world where everything he or she experiences just fades away, even while older memories from the time before the damage are untouched.

The Cerebral Cortex Creates Consciousness and Thinking

All animals have adapted to their environments by developing abilities that help them survive. Some animals have hard shells, others run extremely fast, and some have acute hearing. Human beings do not have any of these particular characteristics, but we do have one big advantage over other animals — we are very, very smart.

You might think that we should be able to determine the intelligence of an animal by looking at the ratio of the animal's brain weight to the weight of its entire body. But this does not really work. The elephant's brain is one-thousandth of its weight, but the whale's brain is only one ten-thousandth of its body weight. On the other hand, although the human brain is one-sixtieth of its body weight, the mouse's brain represents one-fortieth of its body weight. Despite these comparisons, elephants do not seem 10 times smarter than whales, and humans definitely seem smarter than mice.

The key to the advanced intelligence of humans is not found in the size of our brains. What sets humans apart from other animals is our larger **cerebral cortex** — *the outer bark-like layer of our brain that allows us to so successfully use language, acquire complex skills, create tools, and live in social groups* (Gibson, 2002). In humans, the cerebral cortex is wrinkled and folded, rather than smooth as it is in most other animals. This creates a much greater surface area and size, and allows increased capacities for learning, remembering, and thinking. The folding of the cerebral cortex is referred to as *corticalization*.

Although the cortex is only about one-tenth of an inch thick, it makes up more than 80% of the brain's weight. The cortex contains about 20 billion nerve cells and 300 trillion synaptic connections (de Courten-Myers, 1999). Supporting all these neurons are billions more **glial cells** (glia), *cells that surround and link to the neurons, protecting them, providing them with nutrients, and absorbing unused neurotransmitters*. The glia come in different forms and have different functions. For instance, the myelin sheath surrounding the axon of many neurons is a type of glial cell. The glia are essential partners of neurons, without which the neurons could not survive or function (Miller, 2005).

The cerebral cortex is divided into two *hemispheres*, and each hemisphere is divided into four *lobes*, each separated by folds known as *fissures*. If we look at the cortex starting at the front of the brain and moving over the top (see Figure 4.9, "The Two Hemispheres"), we see first the **frontal lobe** (behind the forehead), *which is responsible primarily for thinking, planning, memory, and judgment*. Following the frontal lobe is the **parietal lobe,** *which extends from the middle to the back of the skull and which is responsible primarily for processing information about touch*. Then comes the **occipital lobe** *at the very back of the skull, which processes visual information*. Finally, in front of the occipital lobe (pretty much between the ears) is the **temporal lobe**, *responsible primarily for hearing and language*.

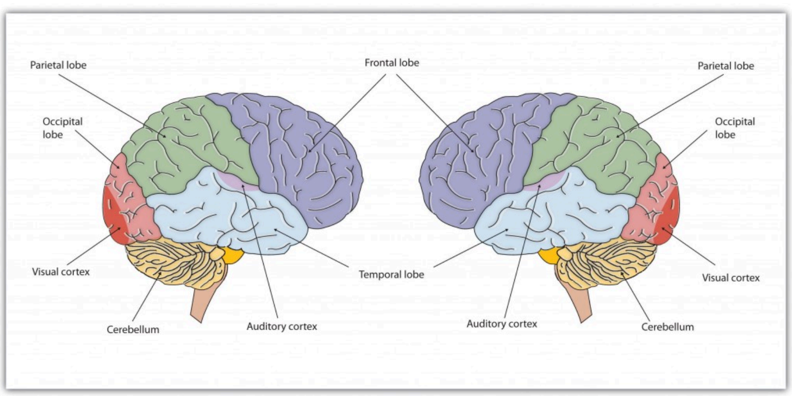

Figure 4.9 The Two Hemispheres. The brain is divided into two hemispheres (left and right), each of which has four lobes (temporal, frontal, occipital, and parietal). Furthermore, there are specific cortical areas that control different processes.

Functions of the Cortex

When the German physicists Gustav Fritsch and Eduard Hitzig (1870/2009) applied mild electric stimulation to different parts of a dog's cortex, they discovered that they could make different parts of the dog's body move. Furthermore, they discovered an important and unexpected principle of brain activity. They found that stimulating the right side of the brain produced movement in the left side of the dog's body, and vice versa. This finding follows from a general principle about how the brain is structured, called **contralateral control,** meaning *the brain is wired such that in most cases the left hemisphere receives sensations from and controls the right side of the body, and vice versa*.

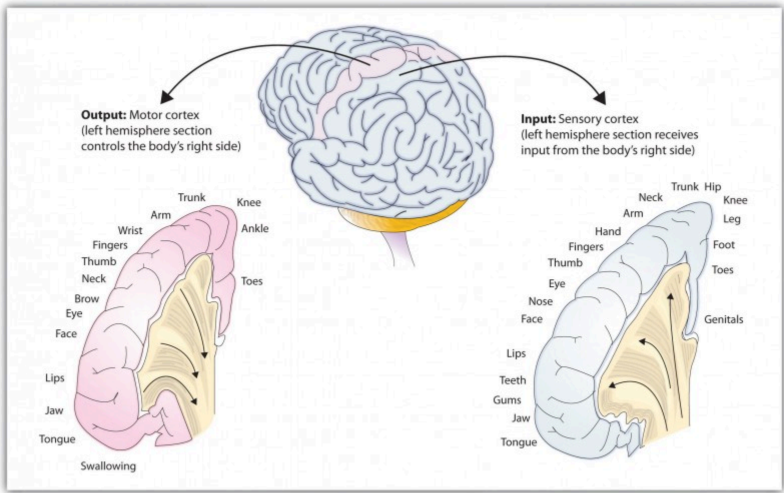

Figure 4.10 The Sensory Cortex and the Motor Cortex. The portion of the sensory and motor cortex devoted to receiving messages that control specific regions of the body is determined by the amount of fine movement that area is capable of performing. Thus the hand and fingers have as much area in the cerebral cortex as does the entire trunk of the body.

Fritsch and Hitzig also found that the movement that followed the brain stimulation only occurred when they stimulated a specific arch-shaped region that runs across the top of the brain from ear to ear, just at the front of the parietal lobe (see Figure 4.10, "The Sensory Cortex and the Motor Cortex"). Fritsch and Hitzig had discovered the **motor cortex**, *the part of the cortex that controls and executes movements of the body by sending signals to the cerebellum and the spinal cord*. More recent research has mapped the motor cortex even more fully, by providing mild electronic stimulation to different areas of the motor cortex in fully conscious patients while observing their bodily responses (because the brain has no sensory receptors, these patients feel no pain). As you can see in Figure 4.10, "The Sensory Cortex and the Motor Cortex," this research has revealed that the motor cortex is specialized for providing control over the body, in the sense that the parts of the body that require more precise and finer movements, such as the face and the hands, also are allotted the greatest amount of cortical space.

Just as the motor cortex sends out messages to the specific parts of the body, the **somatosensory cortex**, *an area just behind and parallel to the motor cortex at the back of the frontal lobe, receives information from the skin's sensory receptors and the movements of different body parts*. Again, the more sensitive the body region, the more area is dedicated to it in the sensory cortex. Our sensitive lips, for example, occupy a large area in the sensory cortex, as do our fingers and genitals.

Other areas of the cortex process other types of sensory information. The **visual cortex** is *the area located in the occipital lobe (at the very back of the brain) that processes visual information*. If you were stimulated in the visual cortex, you would see flashes of light or colour, and perhaps you remember having had the experience of "seeing stars" when you were hit in, or fell on, the back of your head. The temporal lobe, located on the lower side of each hemisphere, contains the **auditory cortex**, *which is responsible for hearing and language*. The temporal lobe also processes some visual information, providing us with the ability to name the objects around us (Martin, 2007).

The motor and sensory areas of the cortex account for a relatively small part of the total cortex. The remainder of the cortex is made up of **association areas** *in which sensory and motor information is combined and associated with our stored knowledge*. These association areas are the places in the brain that are responsible for most of the things that make human beings seem human. The association areas are involved in higher mental functions, such as learning, thinking, planning, judging, moral reflecting, figuring, and spatial reasoning.

The Brain Is Flexible: Neuroplasticity

The control of some specific bodily functions, such as movement, vision, and hearing, is performed in specified areas of the cortex, and if these areas are damaged, the individual will likely lose the ability to perform the corresponding function. For instance, if an infant suffers damage to facial recognition areas in the temporal lobe, it is likely that he or she will never be able to recognize faces (Farah, Rabinowitz, Quinn, & Liu, 2000). On the other hand, the brain is not divided up in an entirely rigid way. The brain's neurons have a remarkable capacity to reorganize and extend themselves to carry out particular functions in response to the needs of the organism and to repair damage. As a result, the brain constantly creates new neural communication routes and rewires existing ones. **Neuroplasticity** refers to *the brain's ability to change its structure and function in response to experience or damage*. Neuroplasticity enables us to learn and remember new things and adjust to new experiences.

Our brains are the most "plastic" when we are young children, as it is during this time that we learn the most about our environment. On the other hand, neuroplasticity continues to be observed even in adults (Kolb & Fantie, 1989). The principles of neuroplasticity help us understand how our brains develop to reflect our experiences. For instance, accomplished musicians have a larger auditory cortex compared with the general population (Bengtsson et al., 2005) and also require less neural activity to move their fingers over the keys than do novices (Münte, Altenmüller, & Jäncke, 2002). These observations reflect the changes in the brain that follow our experiences.

Plasticity is also observed when there is damage to the brain or to parts of the body that are represented in the motor and sensory cortexes. When a tumour in the left hemisphere of the brain impairs language, the right hemisphere will begin to compensate to help the person recover the ability to speak (Thiel et al., 2006). And if a person loses a finger, the area of the sensory cortex that previously received information from the missing finger will begin to receive input from adjacent fingers, causing the remaining digits to become more sensitive to touch (Fox, 1984).

Although neurons cannot repair or regenerate themselves as skin or blood vessels can, new evidence suggests that the brain can engage in **neurogenesis**, *the forming of new neurons* (Van Praag, Zhao, Gage, & Gazzaniga, 2004). These new neurons originate deep in the brain and may then migrate to other brain areas, where they form new connections with other neurons (Gould, 2007). This leaves open the possibility that someday scientists might be able to "rebuild" damaged brains by creating drugs that help grow neurons.

Research Focus: Identifying the Unique Functions of the Left and Right Hemispheres Using Split-Brain Patients

We have seen that the left hemisphere of the brain primarily senses and controls the motor movements on the right side of the body, and vice versa. This fact provides an interesting way to study **brain lateralization**

— *the idea that the left and the right hemispheres of the brain are specialized to perform different functions*. Gazzaniga, Bogen, and Sperry (1965) studied a patient, known as W. J., who had undergone an operation to relieve severe seizures. In this surgery, *the region that normally connects the two halves of the brain and supports communication between the hemispheres*, known as the **corpus callosum**, is severed. As a result, the patient essentially becomes a person with two separate brains. Because the left and right hemispheres are separated, each hemisphere develops a mind of its own, with its own sensations, concepts, and motivations (Gazzaniga, 2005).

In their research, Gazzaniga and his colleagues tested the ability of W. J. to recognize and respond to objects and written passages that were presented to only the left or to only the right brain hemispheres (see Figure 4.11, "Visual and Verbal Processing in the Split-Brain Patient"). The researchers had W. J. look straight ahead and then flashed, for a fraction of a second, a picture of a geometrical shape to the left of where he was looking. By doing so, they ensured that — because the two hemispheres had been separated — the image of the shape was experienced only in the right brain hemisphere (remember that sensory input from the left side of the body is sent to the right side of the brain). Gazzaniga and his colleagues found that W. J. was able to identify what he had been shown when he was asked to pick the object from a series of shapes, using his left hand, but that he could not do this when the object was shown in the right visual field. On the other hand, W. J. could easily read written material presented in the right visual field (and thus experienced in the left hemisphere) but not when it was presented in the left visual field.

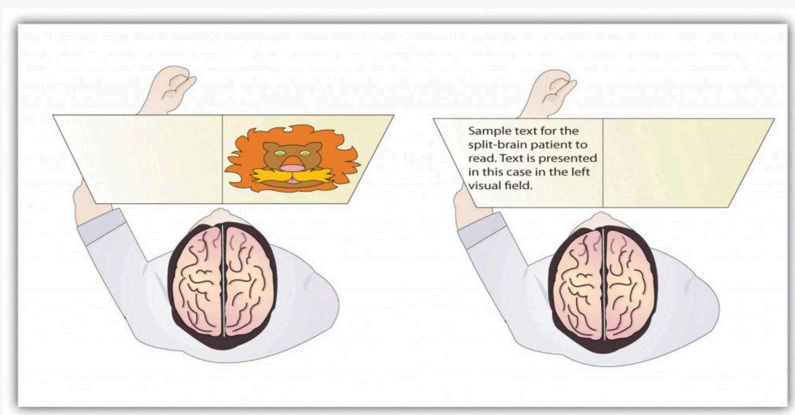

Figure 4.11 Visual and Verbal Processing in the Split-Brain Patient. The information that is presented on the left side of our field of vision is transmitted to the right brain hemisphere, and vice versa. In split-brain patients, the severed corpus callosum does not permit information to be transferred between hemispheres, which allows researchers to learn about the functions of each hemisphere. In the sample on the left, the split-brain patient could not choose which image had been presented because the left hemisphere cannot process visual information. In the sample on the right the patient could not read the passage because the right brain hemisphere cannot process language.

This research, and many other studies following it, has demonstrated that the two brain hemispheres specialize in different abilities. In most people the ability to speak, write, and understand language is located in the left hemisphere. This is why W. J. could read passages that were presented on the right side and thus transmitted to the left hemisphere, but could not read passages that were only experienced in the right brain hemisphere. The left hemisphere is also better at math and at judging time and rhythm. It is also superior in coordinating the order of complex movements — for example, lip movements needed for speech. The right hemisphere, on the other hand, has only very limited verbal abilities, and yet it excels in perceptual skills. The right hemisphere is able to recognize objects, including faces, patterns, and melodies, and it can put a puzzle together or draw a picture. This is why W. J. could pick out the image when he saw it on the left, but not the right, visual field.

Although Gazzaniga’s research demonstrated that the brain is in fact lateralized, such that the two hemispheres specialize in different activities, this does not mean that when people behave in a certain way or perform a certain activity they are only using one hemisphere of their brains at a time. That would be drastically oversimplifying the concept of brain differences. We normally use both hemispheres at the same time, and the difference between the abilities of the two hemispheres is not absolute (Soroker et al., 2005).

Psychology in Everyday Life: Why Are Some People Left-Handed?

Across cultures and ethnic groups, about 90% of people are mainly right-handed, whereas only 10% are primarily left-handed (Peters, Reimers, & Manning, 2006). This fact is puzzling, in part because the number of left-handers is so low, and in part because other animals, including our closest primate relatives, do not show any type of handedness. The existence of right-handers and left-handers provides an interesting example of the relationship among evolution, biology, and social factors and how the same phenomenon can be understood at different levels of analysis (Harris, 1990; McManus, 2002).

At least some handedness is determined by genetics. Ultrasound scans show that nine out of 10 fetuses suck the thumb of their right hand, suggesting that the preference is determined before birth (Hepper, Wells, & Lynch, 2005), and the mechanism of transmission has been linked to a gene on the X chromosome (Jones & Martin, 2000). It has also been observed that left-handed people are likely to have fewer children, and this may be in part because the mothers of left-handers are more prone to miscarriages and other prenatal problems (McKeever, Cerone, Suter, & Wu, 2000).

But culture also plays a role. In the past, left-handed children were forced to write with their right hands in many countries, and this practice continues, particularly in collectivistic cultures, such as India and Japan, where left-handedness is viewed negatively as compared with individualistic societies, such as Canada and the United States. For example, India has about half as many left-handers as the United States (Ida & Mandal, 2003).

There are both advantages and disadvantages to being left-handed in a world where most people are right-handed. One problem for lefties is that the world is designed for right-handers. Automatic teller machines (ATMs), classroom desks, scissors, microscopes, drill presses, and table saws are just some examples of everyday machinery designed with the most important controls on the right side. This may explain in part why left-handers suffer somewhat more accidents than do right-handers (Dutta & Mandal, 2006).

Despite the potential difficulty living and working in a world designed for right-handers, there seem to be some advantages to being left-handed. Throughout history, a number of prominent artists have been left-handed, including Leonardo da Vinci, Michelangelo, Pablo Picasso, and Max Escher. Because the right hemisphere is superior in imaging and visual abilities, there may be some advantage to using the left hand for drawing or painting (Springer & Deutsch, 1998). Left-handed people are also better at envisioning three-dimensional objects, which may explain why there is such a high number of left-handed architects, artists, and chess players in proportion to their numbers (Coren, 1992). However, there are also more left-handers among those with reading disabilities, allergies, and migraine headaches (Geschwind & Behan, 2007), perhaps due to the fact that a small minority of left-handers owe their handedness to a birth trauma, such as being born prematurely (Betancur, Vélez, Cabanieu, & le Moal, 1990).

In sports in which handedness may matter, such as tennis, boxing, fencing, or judo, left-handers may have an advantage. They play many games against right-handers and learn how to best handle their styles. Right-handers, however, play very few games against left-handers, which may make them more vulnerable. This explains why a disproportionately high number of left-handers are found in sports where direct one-on-one action predominates. In other sports, such as golf, there are fewer left-handed players because the handedness of one player has no effect on the competition.

The fact that left-handers excel in some sports suggests the possibility that they may have also had an evolutionary advantage because their ancestors may have been more successful in important skills such as hand-to-hand combat (Bodmer & McKie, 1994). At this point, however, this idea remains only a hypothesis, and determinants of human handedness are yet to be fully understood.

Key Takeaways

- The old brain — including the brain stem, medulla, pons, reticular formation, thalamus, cerebellum, amygdala, hypothalamus, and hippocampus — regulates basic survival functions, such as breathing, moving, resting, feeding, emotions, and memory.
- The cerebral cortex, made up of billions of neurons and glial cells, is divided into the right and left hemispheres and into four lobes.
- The frontal lobe is primarily responsible for thinking, planning, memory, and judgment. The parietal lobe is primarily responsible for bodily sensations and touch. The temporal lobe is primarily responsible for hearing and language. The occipital lobe is primarily responsible for vision. Other areas of the cortex act as association areas, responsible for integrating information.
- The brain changes as a function of experience and potential damage in a process known as plasticity. The brain can generate new neurons through neurogenesis.
- The motor cortex controls voluntary movements. Body parts requiring the most control and dexterity take up the most space in the motor cortex.
- The sensory cortex receives and processes bodily sensations. Body parts that are the most sensitive occupy the greatest amount of space in the sensory cortex.
- The left cerebral hemisphere is primarily responsible for language and speech in most people, whereas the right hemisphere specializes in spatial and perceptual skills, visualization, and the recognition of patterns, faces, and melodies.
- The severing of the corpus callosum, which connects the two hemispheres, creates a “split-brain patient,” with the effect of creating two separate minds operating in one person.

- Studies with split-brain patients as research participants have been used to study brain lateralization.
- Neuroplasticity allows the brain to adapt and change as a function of experience or damage.

Exercises and Critical Thinking

1. Do you think that animals experience emotion? What aspects of brain structure might lead you to believe that they do or do not?
2. Consider your own experiences and speculate on which parts of your brain might be particularly well developed as a result of these experiences.
3. Which brain hemisphere are you likely to be using when you search for a fork in the silverware drawer? Which brain hemisphere are you most likely to be using when you struggle to remember the name of an old friend?
4. Do you think that encouraging left-handed children to use their right hands is a good idea? Why or why not?

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Image Attributions

Figure 4.5: Anatomy of the Brain by artlessstacey (http://commons.wikimedia.org/wiki/File:Brain_headBorder.jpg) is in the public domain.

Figure 4.6: Adapted from Wikia Education. (n.d.). Cerebral cortex. Retrieved from http://psychology.wikia.com/wiki/Cerebral_cortex

4.3 Psychologists Study the Brain Using Many Different Methods

Learning Objective

1. Compare and contrast the techniques that scientists use to view and understand brain structures and functions.

One problem in understanding the brain is that it is difficult to get a good picture of what is going on inside it. But there are a variety of empirical methods that allow scientists to look at brains in action, and the number of possibilities has increased dramatically in recent years with the introduction of new *neuroimaging* techniques. In this section we will consider the various techniques that psychologists use to learn about the brain. Each of the different techniques has some advantages, and when we put them together, we begin to get a relatively good picture of how the brain functions and which brain structures control which activities. Perhaps the most immediate approach to visualizing and understanding the structure of the brain is to directly analyze the brains of human cadavers. When Albert Einstein died in 1955, his brain was removed and stored for later analysis. Researcher Marian Diamond (1999) later analyzed a section of Einstein's cortex to investigate its characteristics. Diamond was interested in the role of glia, and she hypothesized that the ratio of glial cells to neurons was an important determinant of intelligence. To test this hypothesis, she compared the ratio of glia to neurons in Einstein's brain with the ratio in the preserved brains of 11 other more "ordinary" men. However, Diamond was able to find support for only part of her research hypothesis. Although she found that Einstein's brain had relatively more glia in all the areas that she studied than did the control group, the difference was only statistically significant in one of the areas she tested. Diamond admits a limitation in her study is that she had only one Einstein to compare with 11 ordinary men.

Lesions Provide a Picture of What Is Missing

An advantage of the cadaver approach is that the brains can be fully studied, but an obvious disadvantage is that the brains are no longer active. In other cases, however, we can study living brains. The brains of living human beings may be damaged — as a result of strokes, falls, automobile accidents, gunshots, or tumours, for instance. These *damages* are called **lesions**. In rare occasions, brain lesions may be created intentionally through surgery, such as that designed to remove brain tumours or (as in split-brain patients) reduce the effects of epilepsy. Psychologists also sometimes intentionally create lesions in animals to study the effects on their behaviour. In so doing, they hope to be able to draw inferences about the likely functions of human brains from the effects of the lesions in animals. Lesions allow the scientist to observe any loss of brain function that may occur. For instance, when an individual suffers a stroke, a blood clot deprives part of the brain of oxygen, killing the neurons in the area and rendering that area unable to process information. In some cases, the result of the stroke is a specific lack of ability. For instance, if the stroke influences the occipital lobe, then vision may suffer, and if the stroke influences the areas associated with language or speech, these functions will suffer. In fact, our earliest understanding of the specific areas involved in speech and language were gained by studying patients who had experienced strokes.

It is now known that a good part of our moral reasoning abilities is located in the frontal lobe, and at least some of

Figure 4.12 Phineas Gage. Areas in the frontal lobe of Phineas Gage were damaged when a metal rod blasted through it.

this understanding comes from lesion studies. For instance, consider the well-known case of Phineas Gage (Figure 4.12) , a 25-year-old railroad worker who, as a result of an explosion, had an iron rod driven into his cheek and out through the top of his skull, causing major damage to his frontal lobe (Macmillan, 2000). Although, remarkably, Gage was able to return to work after the wounds healed, he no longer seemed to be the same person to those who knew him. The amiable, soft-spoken Gage had become irritable, rude, irresponsible, and dishonest. Although there are questions about the interpretation of this case study (Kotowicz, 2007), it did provide early evidence that the frontal lobe is involved in emotion and morality (Damasio et al., 2005). More recent and more controlled research has also used patients with lesions to investigate the source of moral reasoning. Michael Koenigs and his colleagues (Koenigs et al., 2007) asked groups of normal persons, individuals with lesions in the frontal lobes, and individuals with lesions in other places in the brain to respond to scenarios that involved doing harm to a person, even though the harm ultimately saved the lives of other people (Miller, 2008). In one of the scenarios the participants were asked if they would be willing to kill one person in order to prevent five other people from being killed. As you can see in Figure 4.13, "The Frontal Lobe and Moral Judgment," they found that the individuals with lesions in the frontal lobe were significantly more likely to agree to do the harm than were individuals from the two other groups.

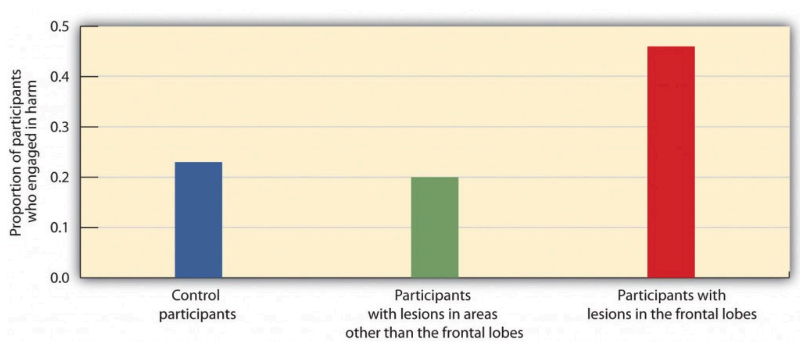

Figure 4.13 The Frontal Lobe and Moral Judgment. Koenigs and his colleagues (2007) found that the frontal lobe is important in moral judgment. Persons with lesions in the frontal lobe were more likely to be willing to harm one person in order to save the lives of five others than were control participants or those with lesions in other parts of the brain. [Long Description]

Recording Electrical Activity in the Brain

In addition to lesion approaches, it is also possible to learn about the brain by studying the electrical activity created by the firing of its neurons. One approach, primarily used with animals, is to place detectors in the brain to study the responses of specific neurons. Research using these techniques has found, for instance, that there are *specific neurons*, known as **feature detectors**, *in the visual cortex that detect movement, lines and edges, and even face*s (Kanwisher, 2000).

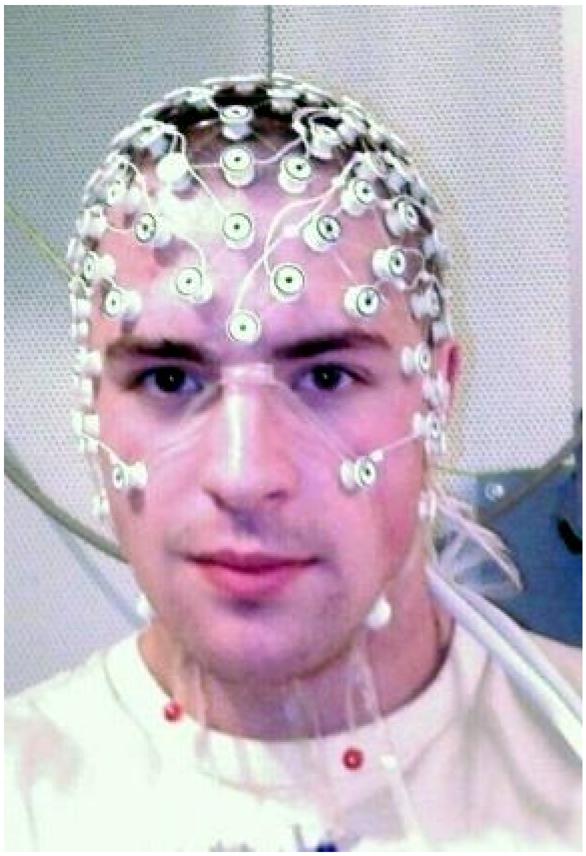

Figure 4.14 EEG Study. A participant in an EEG study with a number of electrodes placed around his head.

A less invasive approach, and one that can be used on living humans, is *electroencephalography (EEG),* as shown in Figure 4.14. The **EEG** is *a technique that records the electrical activity produced by the brain's neurons through the use of electrodes that are placed around the research participant's head.* An EEG can show if a person is asleep, awake, or anesthetized because the brainwave patterns are known to differ during each state. EEGs can also track the waves that are produced when a person is reading, writing, and speaking, and are useful for understanding brain abnormalities, such as epilepsy. A particular advantage of EEG is that the participant can move around while the recordings are being taken, which is useful when measuring brain activity in children, who often have difficulty keeping still. Furthermore, by following electrical impulses across the surface of the brain, researchers can observe changes over very fast time periods.

Peeking inside the Brain: Neuroimaging

Although the EEG can provide information about the general patterns of electrical activity within the brain, and although the EEG allows the researcher to see these changes quickly as they occur in real time, the electrodes must be placed on the surface of the skull, and each electrode measures brainwaves from large areas of the brain. As a result, EEGs do not provide a very clear picture of the structure of the brain. But techniques exist to provide more specific brain images. **Functional magnetic resonance imaging** (fMRI) is *a type of brain scan that uses a magnetic field to create images of brain activity in each brain area*. The patient lies on a bed within a large cylindrical structure containing a very strong magnet. Neurons that are firing use more oxygen, and the need for oxygen increases blood flow to the area. The fMRI detects the amount of blood flow in each brain region, and thus is an indicator of neural activity. Very clear and detailed pictures of brain structures can be produced via fMRI (see Figure 4.15, "fMRI Image"). Often, the images take the form of cross-sectional "slices" that are obtained as the magnetic field is passed across the brain. The images of these slices are taken repeatedly and are superimposed on images of the brain structure itself to show how activity changes in different brain structures over time. When the research participant is asked to engage in tasks while in the scanner (e.g., by playing a game with another person), the images can show which parts of the brain are associated with which types of tasks. Another advantage of the fMRI is that it is noninvasive. The research participant simply enters the machine and the scans begin. Although the scanners themselves are expensive, the advantages of fMRIs are substantial, and they are now available in many university and hospital settings. The fMRI is now the most commonly used method of learning about brain structure.

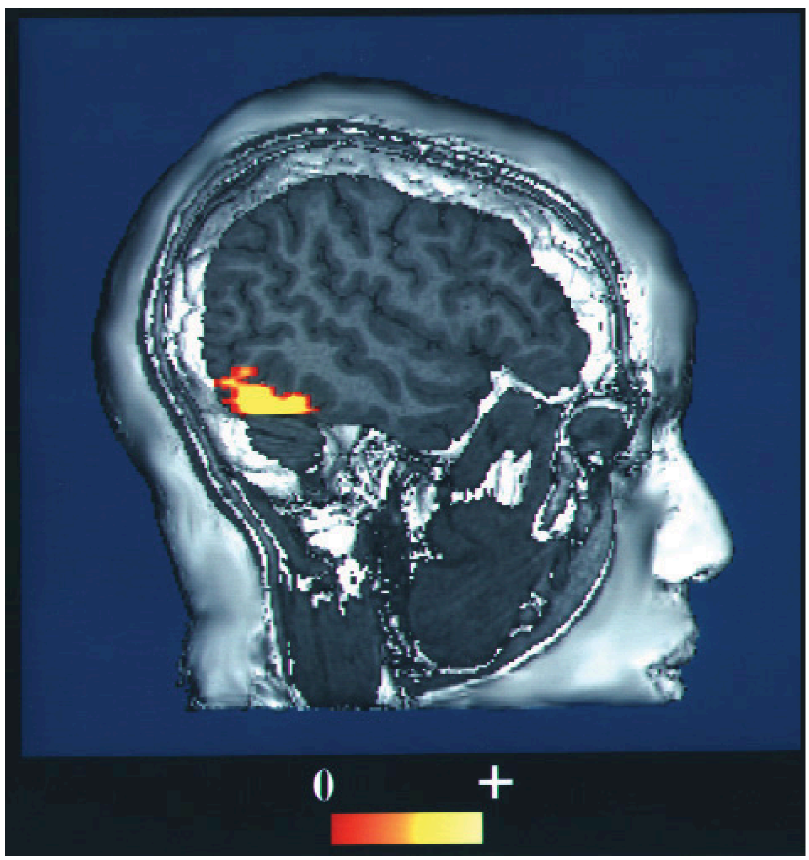

Figure 4.15 fMRI Image. The fMRI creates images of brain structure and activity. The red and yellow areas represent increased blood flow and thus increased activity.

There is still one more approach that is being more frequently implemented to understand brain function, and although it is new, it may turn out to be the most useful of all. **Transcranial magnetic stimulation** (TMS) is *a procedure in which magnetic pulses are applied to the brain of a living person with the goal of temporarily and safely deactivating a small brain region*. In TMS studies the research participant is first scanned in an fMRI machine to determine the exact location of the brain area to be tested. Then the electrical stimulation is provided to the brain before or while the participant is working on a cognitive task, and the effects of the stimulation on performance are assessed. If the participant's ability to perform the task is influenced by the presence of the stimulation, the researchers can conclude that this particular area of the brain is important to carrying out the task. The primary advantage of TMS is that it allows the researcher to draw causal conclusions about the influence of brain structures on thoughts, feelings, and behaviours. When the TMS pulses are applied, the brain region becomes less active, and this deactivation is expected to influence the research participant's responses. Current research has used TMS to study the brain areas responsible for emotion and cognition and their roles in how people perceive intention and approach moral reasoning (Kalbe et al., 2010; Van den Eynde et al., 2010; Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). TMS is also used as a treatment for a variety of psychological conditions, including migraine, Parkinson's disease, and major depressive disorder.

Research Focus: Cyberostracism

Neuroimaging techniques have important implications for understanding our behaviour, including our responses to those around us. Naomi Eisenberger and her colleagues (2003) tested the hypothesis that people who were excluded by others would report emotional distress and that images of their brains would show that they experienced pain in the same part of the brain where physical pain is normally experienced. In the experiment, 13 participants were each placed into an fMRI brain-imaging machine. The participants were told that they would be playing a computer "Cyberball" game with two other players who were also in fMRI machines (the two opponents did not actually exist, and their responses were controlled by the computer). Each of the participants was measured under three different conditions. In the first part of the experiment, the participants were told that as a result of technical difficulties, the link to the other two scanners could not yet be made, and thus at first they could not engage in, but only watch, the game play. This allowed the researchers to take a baseline fMRI reading. Then, during a second, inclusion, scan, the participants played the game, supposedly with the two other players. During this time, the other players threw the ball to the participants. In the third, exclusion, scan, however, the participants initially received seven throws from the other two players but were then excluded from the game because the two players stopped throwing the ball to the participants for the remainder of the scan (45 throws). The results of the analyses showed that activity in two areas of the frontal lobe was significantly greater during the exclusion scan than during the inclusion scan. Because these brain regions are known from prior research to be active for individuals who are experiencing physical pain, the authors concluded that these results show that the physiological brain responses associated with being socially excluded by others are similar to brain responses experienced upon physical injury. Further research (Chen, Williams, Fitness, & Newton, 2008; Wesselmann, Bagg, & Williams, 2009) has documented that people react to being excluded in a variety of situations with a variety of emotions and behaviours. People who feel that they are excluded, or even those who observe other people being excluded, not only experience pain, but feel worse about themselves and their relationships with people more generally, and they may work harder to try to restore their connections with others.

Key Takeaways

- Studying the brains of cadavers can lead to discoveries about brain structure, but these studies are limited because the brain is no longer active.
- Lesion studies are informative about the effects of lesions on different brain regions.
- Electrophysiological recording may be used in animals to directly measure brain activity.
- Measures of electrical activity in the brain, such as electroencephalography (EEG), are used to assess brainwave patterns and activity.
- Functional magnetic resonance imaging (fMRI) measures blood flow in the brain during different activities, providing information about the activity of neurons and thus the functions of brain regions.
- Transcranial magnetic stimulation (TMS) is used to temporarily and safely deactivate a small brain region, with the goal of testing the causal effects of the deactivation on behaviour.

Exercise and Critical Thinking

1. Consider the different ways that psychologists study the brain, and think of a psychological characteristic or behaviour that could be studied using each of the different techniques.

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Image Attributions

Figure 4.12: "Phineas gage – 1868 skull diagram" by John M. Harlow, M.D. (http://it.wikipedia.org/wiki/File:Phineas_gage_-_1868_skull_diagram.jpg) is in the public domain.

Figure 4.14: "EEG cap" by Thuglas (http://commons.wikimedia.org/wiki/File:EEG_cap.jpg) is in the public domain.

Figure 4.15: Face recognition by National Institutes of Health (http://commons.wikimedia.org/wiki/File:Face_recognition.jpg) is in public domain.

Long Descriptions

Figure 4.13 long description: The Frontal Lobe and Moral Judgement

	Control Participants	Participants with lesions in areas other than the frontal lobes	Participants with lesions in the frontal lobes
Proportion of participants who engaged in harm	0.23	0.20	0.46

[Return to Figure 4.13]

4.4 Putting It All Together: The Nervous System and the Endocrine System

Learning Objectives

1. Summarize the primary functions of the CNS and of the subsystems of the PNS.
2. Explain how the electrical components of the nervous system and the chemical components of the endocrine system work together to influence behaviour.

Now that we have considered how individual neurons operate and the roles of the different brain areas, it is time to ask how the body manages to put it all together. How do the complex activities in the various parts of the brain, the simple all-or-nothing firings of billions of interconnected neurons, and the various chemical systems within the body work together to allow the body to respond to the social environment and engage in everyday behaviours? In this section we will see that the complexities of human behaviour are accomplished through the joint actions of electrical and chemical processes in the nervous system and the endocrine system.

Electrical Control of Behaviour: The Nervous System

The nervous system (see Figure 4.16, "The Functional Divisions of the Nervous System"), the electrical information highway of the body, is made up of **nerves** — *bundles of interconnected neurons that fire in synchrony to carry messages*. The **central nervous system** (CNS), *made up of the brain and spinal cord, is the major controller of the body's functions, charged with interpreting sensory information and responding to it* with its own directives. The CNS interprets information coming in from the senses, formulates an appropriate reaction, and sends responses to the appropriate system to respond accordingly. Everything that we see, hear, smell, touch, and taste is conveyed to us from our sensory organs as neural impulses, and each of the commands that the brain sends to the body, both consciously and unconsciously, travels through this system as well.

Nerves are differentiated according to their function. A **sensory (or afferent) neuron** *carries information from the sensory receptors*, whereas a **motor (or efferent) neuron** *transmits information to the muscles and glands*. An **interneuron**, which is by far the most common type of neuron, is located primarily within the CNS and is *responsible for communicating among the neurons*. Interneurons allow the brain to combine the multiple sources of available information to create a coherent picture of the sensory information being conveyed.

The **spinal cord** is *the long, thin, tubular bundle of nerves and supporting cells that extends down from the brain*. It is the central throughway of information for the body. Within the spinal cord, ascending tracts of sensory neurons relay sensory information from the sense organs to the brain while descending tracts of motor neurons relay motor commands back to the body. When a quicker-than-usual response is required, the spinal cord can do its own processing, bypassing the brain altogether. A **reflex** is *an involuntary and nearly instantaneous movement in response to a stimulus*. Reflexes are triggered when sensory information is powerful enough to reach a given threshold and the interneurons in the spinal cord act to send a message back through the motor neurons without relaying the information to the brain (see Figure 4.17, "The Reflex"). When you touch a hot stove and immediately

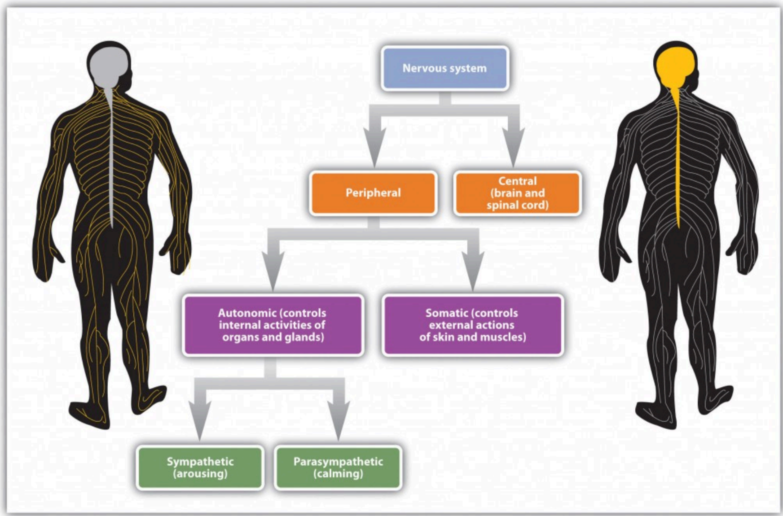

Figure 4.16 The Functional Divisions of the Nervous System. [Long Description]

pull your hand back, or when you fumble your cell phone and instinctively reach to catch it before it falls, reflexes in your spinal cord order the appropriate responses before your brain even knows what is happening.

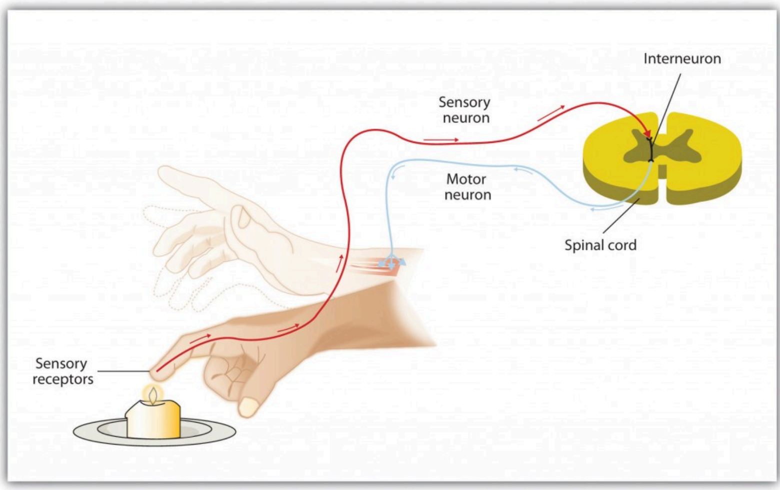

Figure 4.17 The Reflex. The central nervous system can interpret signals from sensory neurons and respond to them extremely quickly via the motor neurons without any need for the brain to be involved. These quick responses, known as reflexes, can reduce the damage that we might experience as a result of, for instance, touching a hot stove.

If the central nervous system is the command centre of the body, the *peripheral nervous system (PNS)* represents the front line. The **PNS** *links the CNS to the body's sense receptors, muscles, and glands*. As you can see in Figure 4.18, "The Autonomic Nervous System," the peripheral nervous system is itself divided into two subsystems, one controlling internal responses and one controlling external responses.

The **autonomic nervous system** (ANS) is *the division of the PNS that governs the internal activities of the human body, including heart rate, breathing, digestion, salivation, perspiration, urination, and sexual arousal*. Many of