11.3 The Central Nervous System

When you hear the term "nervous system," do you think of the brain and the spinal cord? While the central nervous system is the core of the nervous system, the nervous system is actually much more extensive. In vertebrates, the nervous system is made up of the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS consists of the brain and spinal cord, and the PNS consists of the nerves that connect the brain and spinal cord to the rest of the body (**Figure 1**).

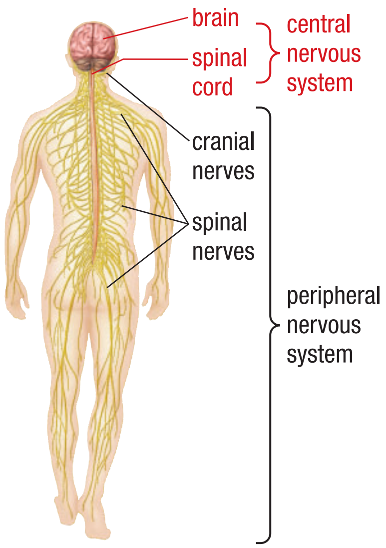

Figure 1 The central and peripheral nervous systems and their subsystems

The complexity of the human brain is what distinguishes humans from other animals and allows us to have complex behaviours, including language and the ability to develop culture and civilization. Humans have the most complex nervous system of all animals. Nevertheless, we have the same basic brain regions that are found in simpler vertebrates. The most significant changes in the evolution of the human brain have occurred in the region associated with reason, intellect, memory, language, and personality. Our reasoning ability, rather than the acuity of our senses, is what makes the human brain unique.

Nervous systems develop in different ways in different taxa. Vertebrates are thought to have evolved from the larval form of a primitive chordate. In chordates, the nervous system is formed dorsally as a hollow neural tube. The anterior end of the neural tube develops into the brain and the rest develops into the spinal cord. During development in vertebrates, the central cavity of the neural tube becomes the fluid-filled ventricles of the brain and the narrow central canal of the spinal cord.

The organization of the brain is exceedingly complex. One way to understand its complexity is to examine its development from the embryonic neural tube. A generalized vertebrate brain, approximately midway through its embryonic development, shows the principal regions found in all vertebrate brains. Early in embryonic development, the anterior part of the neural tube enlarges into three distinct regions. The forebrain was originally associated with olfaction or the sense of smell, the midbrain was primarily associated with vision, and the hindbrain was mainly associated with balance (**Figure 2**).

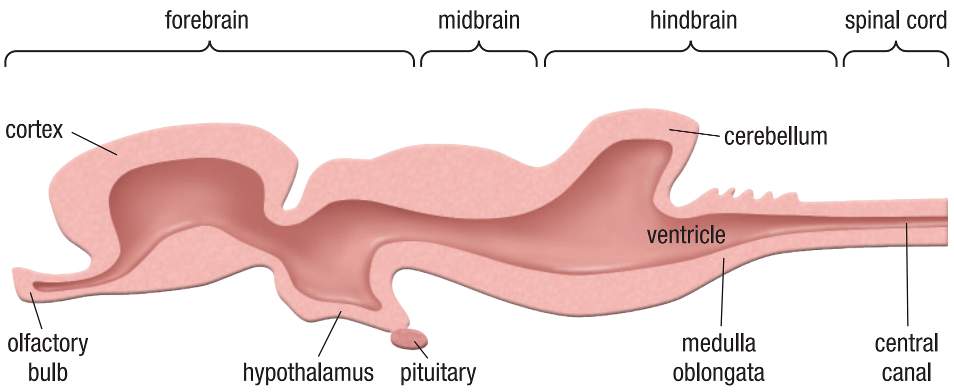

Figure 2 During the midway development of vertebrates, the brain is elongated. In later development in birds and mammals, the brain becomes folded so that the very prominent forebrain lies above the other regions and the size of the ventricle is reduced.

meninges three layers of connective tissue that surround and protect the brain and spinal cord

cerebrospinal fluid circulating fluid that surrounds the membranes of the brain and spinal cord; provides neural connection to the endocrine system

The brain and spinal cord are surrounded with, and protected by, three layers of connective tissue called the **meninges** (from *meninga* meaning "membrane"), and the **cerebrospinal fluid**. The cerebrospinal fluid circulates through the central canal of the spinal cord, through the ventricles of the brain, and between two of the meninges. It cushions the brain and spinal cord from jarring movements and impacts, nourishes them, and protects them from toxic substances.

The CNS manages body activities by integrating incoming sensory information from the PNS into compensating responses. It functions as the control centre of the body. In this section, you will examine the vertebrate CNS, beginning with the spinal cord and then moving on to the brain and its functions.

Spinal Cord

The spinal cord extends from the base of the brain down through a canal inside the vertebrae of the backbone. It carries impulses between the brain and the PNS and contains the interneuron circuits that control motor reflexes. In cross-section, the spinal cord has a butterfly-shaped core of **grey matter**, which consists of nerve cell bodies and dendrites. The grey matter is surrounded by **white matter**, which consists of axons, many of them surrounded by myelin sheaths (**Figure 3**). Pairs of spinal nerves connect with the spinal cord at spaces between the vertebrae.

grey matter the tissue of the brain and spinal cord where the cell bodies and dendrites of neurons are located

white matter the tissue of the brain and spinal cord, composed primarily of axons of neurons; in the spinal cord, it surrounds the grey matter

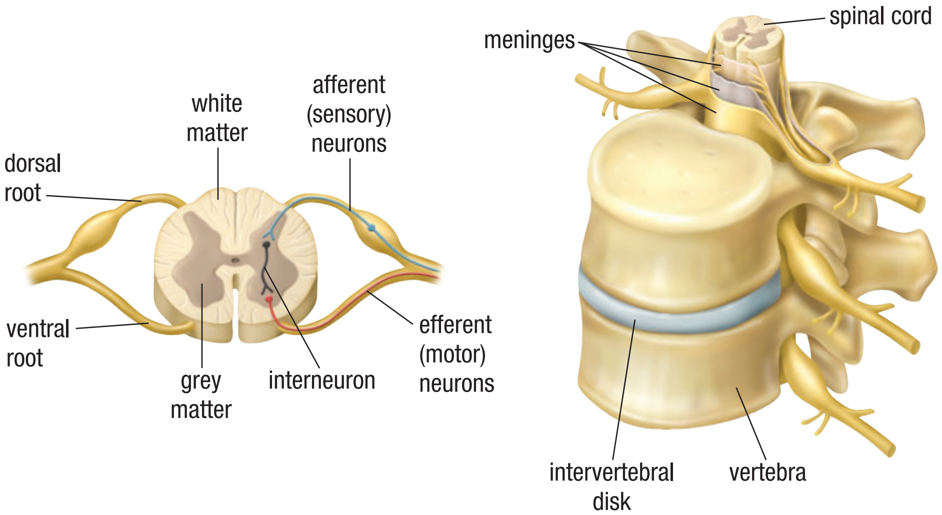

Figure 3 The spinal cord is protected by the vertebral column. Afferent (sensory) nerves enter the spinal cord through the dorsal root, and efferent nerves leave through the ventral root.

Afferent (incoming) axons enter the dorsal root of the spinal cord and make synapses with interneurons in the grey matter. The interneurons send axons upward through the white matter of the spinal cord to the brain. Efferent (outgoing) axons from the interneurons of the brain pass downward through the white matter of the cord and make synapses with the dendrites and cell bodies of efferent neurons in the grey matter of the cord. Axons from these efferent neurons exit the spinal cord through the ventral root of the spinal nerves. Efferent nerves in the ventral root carry information from the spinal cord to the peripheral muscles, organs, and glands.

Brain

The brain is the major centre that receives, integrates, stores, and retrieves information. Its interneuron networks generate responses that provide the basis for our voluntary movements, consciousness, behaviour, emotions, learning, reasoning, language, and memory, as well as many other complex activities. The three major divisions of the embryonic brain give rise to the structures of the adult brain. Like the spinal cord, each brain structure contains both grey matter and white matter and is surrounded by meninges and circulating cerebrospinal fluid.

The hindbrain of vertebrates develops into the **medulla oblongata** (commonly known as the medulla) and the **cerebellum**. The medulla contains the nerve centres that deal with involuntary behaviours, such as breathing, digestion, heart rate, and blood pressure. The cerebellum plays a major role in motor responses (voluntary movements of the skeletal muscles) and is responsible for balance and fine motor control. In higher mammals, a mass of fibres that connects the cerebellum to higher centres in the brain is so prominent that it is identified as the **pons** (bridge). The medulla and the pons, along with the midbrain, form a stalklike structure known as the

medulla oblongata the hindbrain region that connects the spinal cord to the cerebellum; important in autonomic nerve control

cerebellum the hindbrain region that is involved in muscle movement and balance

pons the brain region that transfers nerve signals between the cerebellum and the medulla brain stem, which connects the forebrain to the spinal cord. Ten pairs of nerves originate from the brain stem to serve the head, neck, and body trunk areas. The forebrain, which makes up most of the brain mass in humans, forms the **cerebrum**. The cerebrum is the most developed part of the brain. It controls most of the sensory and motor activities (**Figure 4**).

cerebrum the brain region that is involved in motor activities and sensory information; the largest and most developed region of the brain

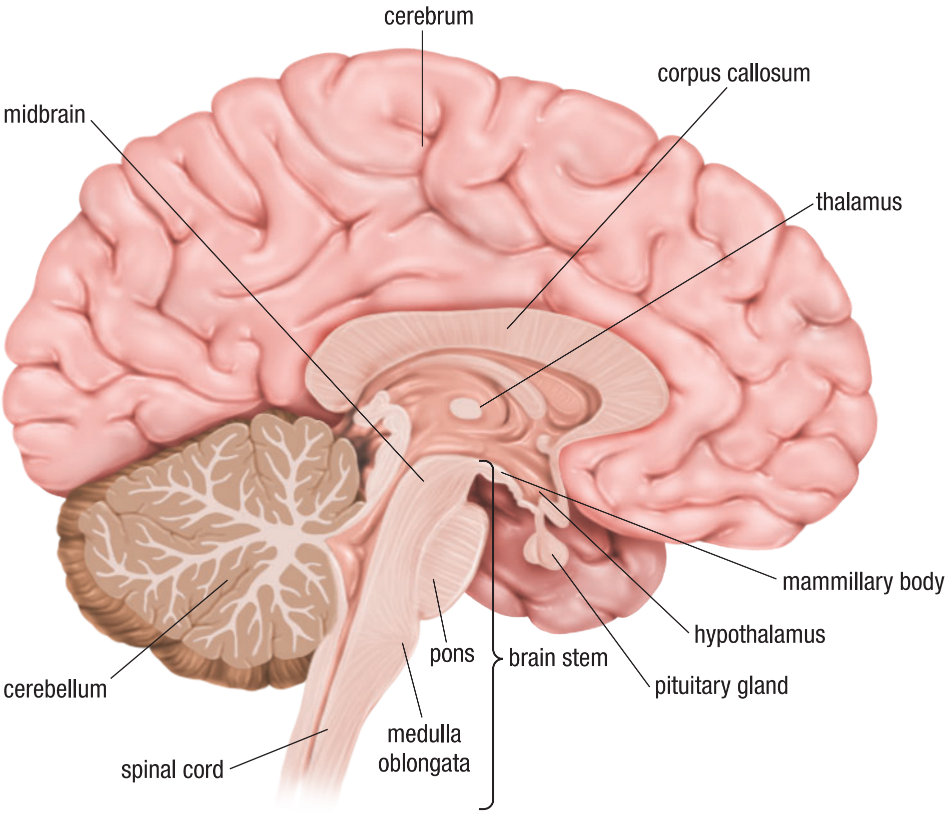

Figure 4 The adult brain loses the elongated structure of the embryonic brain. The cerebrum, which develops from the forebrain, folds to cover the regions of the brain that develop from the midbrain and hindbrain.

One of the trends in the evolution of the brain was the increasing prominence of the cerebrum. Beginning with reptiles, the cerebrum increased in size relative to the rest of the brain. In mammals, folds appeared, increasing the amount of brain surface area within a particular volume. The total mass of the brain relative to the size of the animal increased as well, permitting animals to undertake more complex tasks.

Cerebral Cortex

cerebral cortex the outermost layer of the cerebral hemispheres

The surface layer of the cerebrum, the **cerebral cortex**, is a thin layer of grey matter in which numerous unmyelinated neurons are found. It carries out all of the higher brain functions. The cerebrum is divided into right and left cerebral hemispheres. It is corrugated by fissures and folds that increase the surface area of the cerebral cortex and divide the brain into the frontal, parietal, temporal, and occipital lobes (**Figure 5**, next page). This structure reflects two of the evolutionary tendencies in the brains of mammals: the corrugation of the hemispheres and the development of a layer of grey matter on the periphery.

The two cerebral hemispheres can function separately. Each has its own communication lines internally and with the rest of the CNS and the body. The left hemisphere responds primarily to sensory signals from, and controls movements in, the right side of the body. The right hemisphere has the same relationship with the left side of the body. The opposite connection and control reflect the fact that the nerves carrying afferent and efferent signals cross from left to right within the spinal cord or brain stem. Thick axon bundles, which form a structure called the corpus callosum, connect the two cerebral hemispheres and coordinate their functions.

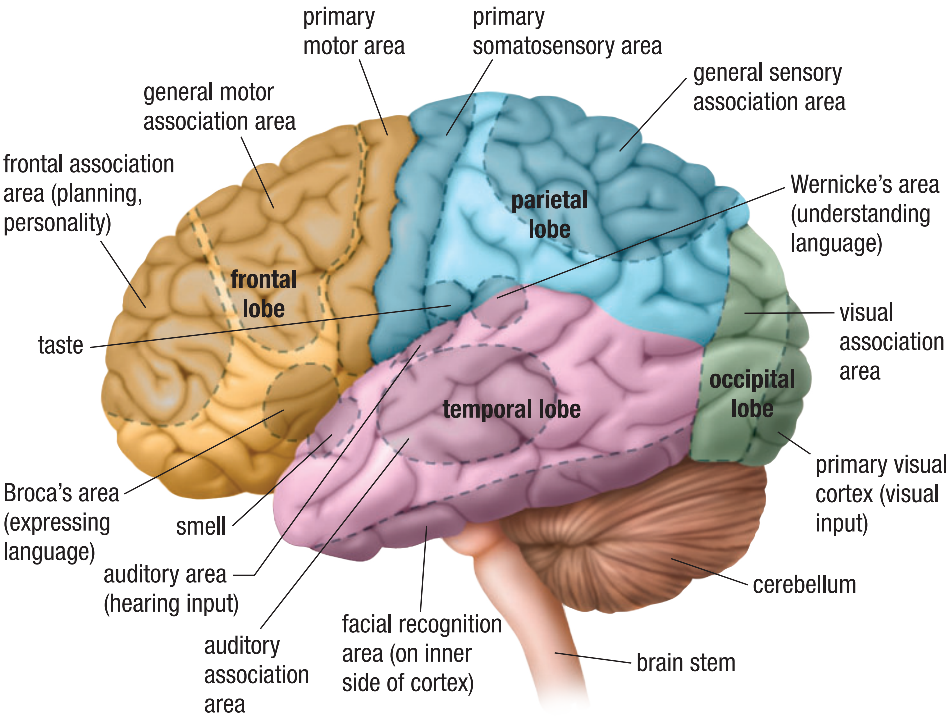

Figure 5 The cerebral cortex of the lobes of the cerebrum is divided into major regions and association areas.

SENSORY REGIONS OF THE CEREBRAL CORTEX

Areas that receive and integrate sensory information are distributed over the cerebral cortex. In each hemisphere, the primary somatosensory area, which registers information about touch, pain, temperature, and pressure, runs in a band across the parietal lobes of the brain. Other sensory regions of the cerebral cortex have been identified with hearing, vision, smell, and taste. The primary motor area of the cerebral cortex runs in a band across the frontal lobe, just in front of the primary somatosensory area.

In the primary somatosensory and motor areas, some body parts (such as the lips and fingers) are represented by large regions, and other body parts (such as the arms and legs) are represented by relatively small regions. The relative sizes produce a distorted image of the human body (**Figure 6**, next page) that is quite different from the actual body proportions. The differences are reflected in the precision of touch and movement in structures such as the lips, tongue, and fingers.

Cerebellum

The cerebellum has a folded structure that increases its relative size. It is connected to the pons, but it is separate in structure and function from the brain stem. Through its extensive connections with other parts of the brain, the cerebellum receives sensory input that originates from receptors in the muscles and joints; from balance receptors in the inner ear; and from the receptors of touch, vision, and hearing. The sensory input conveys information about how the body trunk and limbs are positioned, in which direction they are moving, and the degree to which different muscles are contracted or relaxed. The cerebellum integrates this input and compares it with signals from the cerebrum that control voluntary body movements. Output from the cerebellum to the cerebrum, brain stem, and spinal cord modify and fine-tune body movements to keep the body in balance and directed toward targeted positions in space.

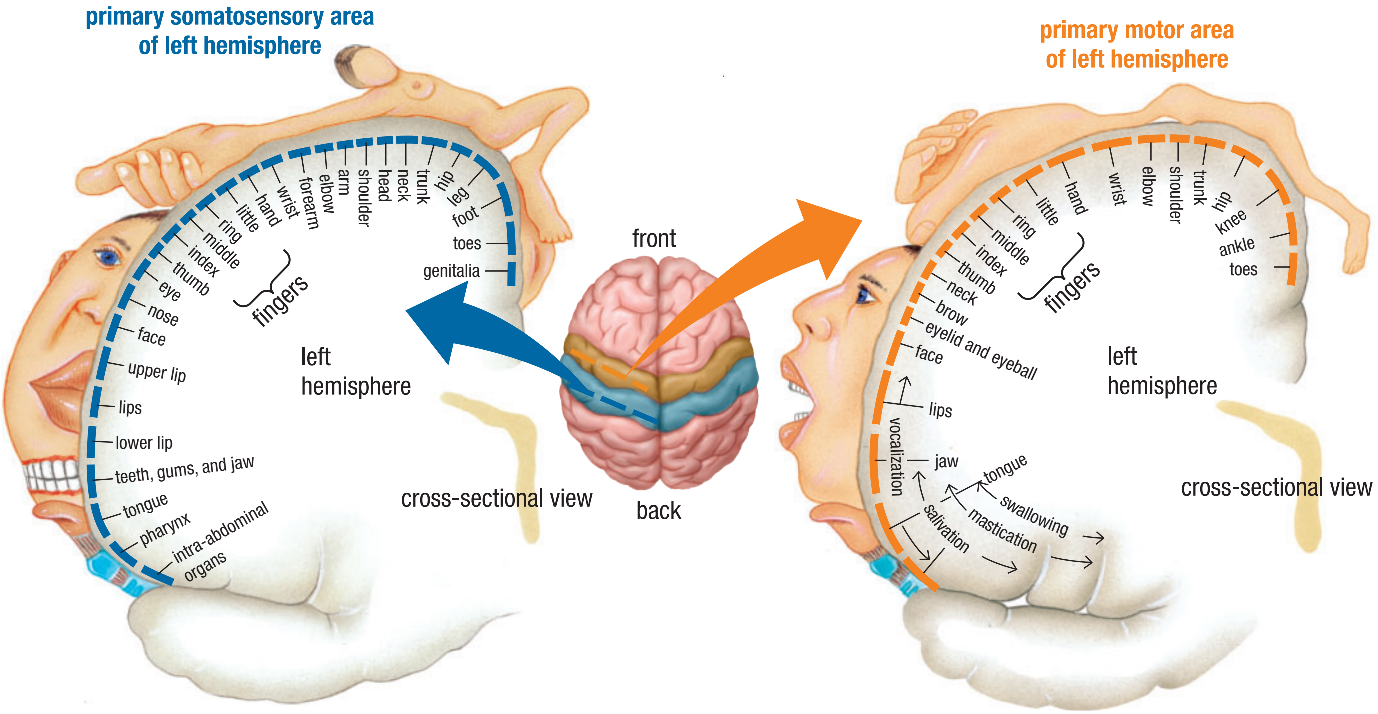

Figure 6 The primary somatosensory and motor areas of the cerebrum form a band across the top of the brain. The distorted images of the human body show the relative areas of the sensory and motor cortex devoted to different body regions.

Thalamus, Hypothalamus, and Basal Nuclei

thalamus the brain region that interprets sensory input and signals the cerebrum

The **thalamus** forms a major switchboard that receives sensory information and relays it to the appropriate regions of the cerebral cortex. As well, it plays a role in alerting the cerebral cortex to full wakefulness or in inducing drowsiness or sleep.

The hypothalamus is a relatively small conical area that occurs in all vertebrates. It contains centres that regulate basic homeostatic functions of the body. Some of these centres set and maintain body temperature by triggering reactions such as shivering or sweating. Others constantly monitor the osmotic balance of the blood by testing its composition of ions and other substances. The hypothalamus is an important part of the endocrine system. It produces some of the hormones that are released by the pituitary gland and governs the release of other pituitary hormones.

The basal nuclei are grey-matter centres that surround the thalamus on both sides of the brain. They moderate the voluntary movements that are directed by motor centres in the cerebrum. Damage to the basal nuclei can affect the planning and fine-tuning of movements. This can lead to stiff, rigid motions of the limbs and unwanted or misdirected motor activities, such as tremors of the hands. Parkinson's disease, in which affected individuals exhibit all of these symptoms, results from degeneration of centres in and near the basal nuclei.

Blood–Brain Barrier

blood–brain barrier a barrier formed by tight junctions between endothelial cells in the capillaries in the brain that blocks the movement of most substances into the brain via the bloodstream

The brain is somewhat isolated from other parts of the body, so many substances that enter the body are unable to enter the brain. Unlike the epithelial cells that line the capillary walls elsewhere in the body and allow small molecules and ions to pass freely from the blood to the surrounding fluids, the endothelial cells that form capillaries in the brain have tight junctions between them. The tight junctions set up a **blood–brain barrier** that prevents most substances dissolved in the blood from entering the cerebrospinal fluid. This offers protection for the brain and spinal cord from infection by viruses, bacteria, and toxic substances that may circulate in the blood. Infections of the brain are rare, but not impossible. While the blood–brain barrier normally prevents cells, such as white blood cells, from entering the brain, an immune response activates

T-cells that are able to cross the barrier. The blood–brain barrier also allows a more stable composition of the cerebrospinal fluid, protecting it from the wide fluctuations that occur in blood in response to meals and other factors. This maintains a stable environment for neurotransmission.

Some areas of the brain, the circumventricular organs, are not behind the blood–brain barrier. For example, in the part of the hypothalamus involved in communication with the pituitary gland, the blood vessels do not have tight junctions, allowing direct exposure to the bloodstream. The pineal gland, which secretes melatonin directly into the bloodstream, is also not protected by the blood–brain barrier.

A few molecules and ions, such as oxygen, carbon dioxide, alcohol, caffeine, nicotine, and anesthetics, can move directly across the lipid bilayer of the cell membranes by diffusion. A few other substances are moved across the plasma membrane by highly selective transport proteins. The most significant of these transported molecules is glucose, which is the source of metabolic energy for the cells of the brain.

Imaging the Living Brain

Because the brain is encased in the skull, observing what happens inside it has historically been challenging. New technologies, however, enable us to indirectly observe the living brain by creating images without physically entering the skull. These technologies have become valuable tools in understanding how the brain functions. More importantly, these tools enable neuroscientists to understand and diagnose neurological diseases and disorders. Much has been learned about the functions of various brain regions by studying patients with brain damage caused by strokes, infections, tumours, and other conditions. Technologies such as functional magnetic resonance imaging (fMRI), 3-D ultrasound, and positron emission tomography (PET) allow researchers to identify the normal functions of specific brain regions in non-invasive ways. The instruments record a subject's brain activity during various mental and physical tasks by detecting minute increases in blood flow or metabolic activity in specific regions (**Figure 7**). CAREER LINK

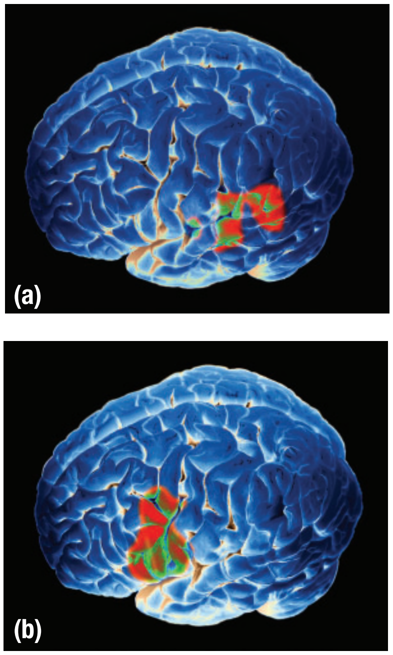

Figure 7 Areas of heightened neural activity are highlighted by different colours in this PET image of a living brain. Image (a) shows brain activity when hearing words. Image (b) shows brain activity when thinking about words.

Left Brain, Right Brain

Most of the other higher functions of the human brain, such as abstract thought and reasoning; the associations that form the basis of personality; spatial recognition; and mathematical, musical, and artistic ability, involve the coordinated participation of many regions of the cerebral cortex. Some of these regions are equally distributed in both hemispheres, and others are more concentrated in one hemisphere.

Among the functions that are more or less equally distributed between the two hemispheres is the ability to recognize faces. Consciousness, the sense of time, and recognizing emotions also seem to be distributed in both hemispheres. The left hemisphere specializes in spoken and written language, abstract reasoning, and precise mathematical calculations. The right hemisphere specializes in non-verbal conceptualizing, intuitive thinking, musical and artistic abilities, and spatial recognition functions such as fitting pieces into a puzzle. The right hemisphere also specializes in mathematical estimates and approximations that can be made by visual or spatial representations of numbers. Thus, in most people, the left hemisphere is verbal and mathematical, and the right hemisphere is intuitive, spatial, artistic, and musical.

The labels "left-brained" and "right-brained" are sometimes used when referring to someone's abilities. These labels can only be used loosely, however, to describe tendencies. While there is some measurable dominance of different functions on different sides of the brain, most productive functioning is integrated in both sides. There is no clear-cut division of functions, except that the right side of the body is controlled by the left side of the brain, and vice versa.

In the next section, you will explore the peripheral nervous system. As indicated by its name, this system links the periphery of the body with the central nervous system.

11.3 Review

Summary

- The central nervous system (CNS) consists of the brain and spinal cord. The spinal cord carries signals between the brain and the peripheral nervous system (PNS), and also controls reflexes.
- Cerebrospinal fluid provides nutrients to the CNS and cushions the CNS. A blood–brain barrier allows only selected substances to enter the cerebrospinal fluid.
- Grey-matter centres in the pons and medulla control involuntary functions, such as heart rate, blood pressure, respiration rate, and digestion. Centres in the midbrain coordinate responses to visual and auditory sensory input.
- The cerebellum integrates sensory input with visual and auditory signals to coordinate body movements.
- The primary somatosensory areas of the cerebral cortex register incoming sensory information. The primary motor areas of the cerebrum control voluntary movements of skeletal muscles in the body.
- The thalamus receives, filters, and relays sensory and motor information. The hypothalamus regulates basic homeostatic functions and contributes to endocrine control. The basal nuclei affect the planning and fine-tuning of body movements.
- Some functions, such as long-term memory and consciousness, are equally distributed between the two cerebral hemispheres. Other functions are concentrated in the left hemisphere or the right hemisphere.

Questions

1. What are the three main regions of the brain that are shared by all primates? What makes the human brain different? K/U
2. What are the main functions of the spinal cord? K/U
3. In a collision with an opposing player, a hockey player suffers damage to the cerebellum. How might this affect the player's body movements? K/U A
4. Which side of the brain controls which side of the body? What connects the two hemispheres? K/U
5. What does it mean to be "left-brained" or "right-brained"? K/U
6. One of the newest and most effective methods for scanning the brain is MEG, or magnetoencephalography. Use the Internet and other sources to research this technology. Prepare a brochure, based on your research, that includes the following information:
   - the underlying scientific principles of MEG
   - how and why it is used in neuroscience
   - the advantages and disadvantages of MEG, compared with other technologies T/I C
7. Bigger animals have bigger brains. Does this mean that bigger animals are smarter than smaller animals? Explain your answer. K/U T/I
8. A man suffers a stroke. He is unable to speak, but he can read and understand text. Explain how his brain has most likely been affected. K/U T/I
9. What is the function of the blood–brain barrier, and how does it accomplish this function? K/U
10. What are some techniques that are used today to study brain functions? K/U
11. Which part of the brain most likely evolved first: the brain stem or the cerebellum? Explain your reasoning. K/U T/I
12. Scientists have recently found a connection between sight and touch in the brain. Your brain not only processes what the object looks like, but remembers what it feels like to touch it as well. K/U T/I
    (a) Why do you think that the brain makes such a strong connection between the mind and touch?
    (b) How could this benefit you?

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