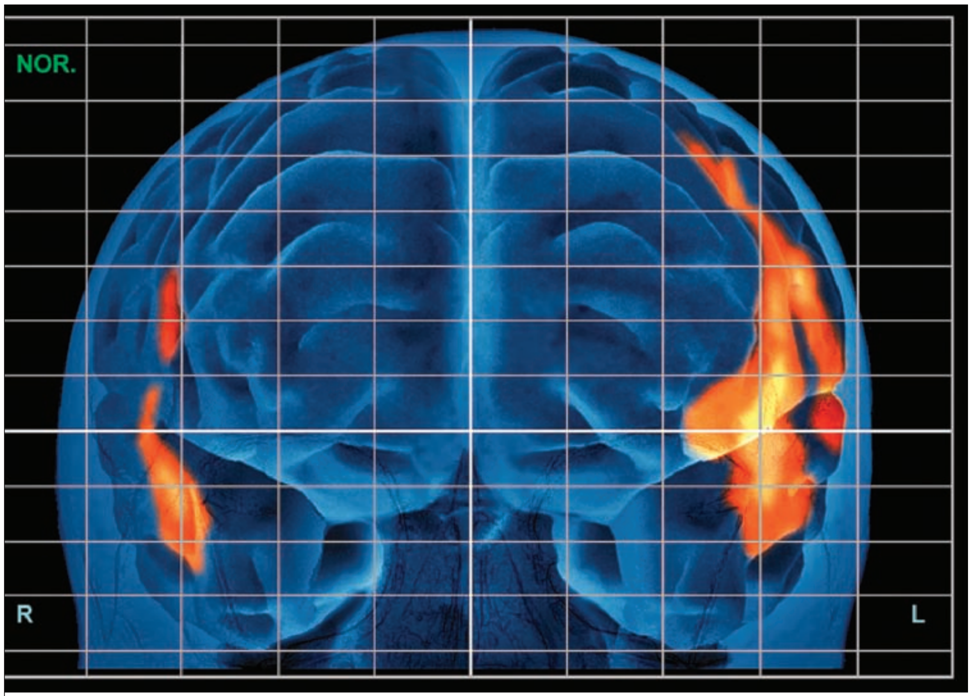

Activity in the human brain while reading aloud. The image combines an MRI of a male brain with a PET scan, which shows that blood circulation increases in the language, hearing, and vision areas of the brain, especially in the left hemisphere.

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38 Nervous Systems

STUDY PLAN

38.1 Invertebrate and Vertebrate Nervous Systems Compared

Cnidarians and echinoderms have nerve nets

More complex invertebrates have cephalized nervous systems

Vertebrates have the most specialized nervous systems

38.2 The Peripheral Nervous System

The somatic system controls the contraction of skeletal muscles, producing body movements

The autonomic system is divided into sympathetic and parasympathetic divisions

38.3 The Central Nervous System (CNS) and Its Functions

The spinal cord relays signals between the PNS and the brain and controls reflexes

The brain integrates sensory information and formulates compensating responses

The brain stem regulates many vital housekeeping functions of the body

The cerebellum integrates sensory inputs to coordinate body movements

Gray-matter centers control a variety of functions

The cerebral cortex carries out all higher brain functions in humans

Some higher functions are distributed in both cerebral hemispheres; others are concentrated in one hemisphere

38.4 Memory, Learning, and Consciousness

Memory takes two forms, short term and long term

Learning involves combining past and present experiences to modify responses

Consciousness involves different states of awareness

WHY IT MATTERS

The conductor's baton falls and the orchestra plays the first notes of a Mozart symphony. Unaware of the complex interactions of their nervous systems, the musicians translate printed musical notation into melodious sounds played on their instruments. Although their fingers and arms move to produce precise harmonies, the musicians are only vaguely conscious of these movements, learned through years of practice. Their only conscious endeavor is to interpret the music in line with the conductor's directions.

From the back of the hall, a common housefly, *Musca domestica,* moves in random twists and turns that bring it toward the stage. Although far less complex than that of a human, the fly's nervous system contains networks of neurons that work in the same way, in patterns adapted to its lifestyle.

The fly does not register the sounds reverberating through the hall as a significant sensory input. However, some of its receptors are exquisitely sensitive to the presence of potential food molecules, including those in the sweat on the conductor's face. The fly's swoops and turns bring it closer to the conductor; soon it alights on the tip of his nose. When sensory receptors in the fly's footpads detect organic matter on the surface of the nose, they trigger an automated feeding response: the fly's proboscis lowers and its gut begins contractions that suck up the nutrients.

The conductor's eyes notice the insect's approach, and sensory receptors in his skin pinpoint the spot where it lands. Without missing a beat, the conductor's hand flicks toward that exact spot. But his nervous system and effectors, although highly sophisticated, are no match for the escape reflexes of the fly. The fly's sensory receptors detect the motion of the fingers, sending impulses to the fly's leg and wing muscles that launch it into flight long before the fingers reach the nose.

The fly wanders into the orchestra, attracted to potential nutrients on various musicians, who respond with flicking movements that are no more successful than those of the conductor. At last, the fly lands on the left hand of the timpanist, who is listening with pleasure to the music while he awaits his entrance late in the first movement. His right hand holds a mallet. With a skill born of long practice in hitting drums, gongs, and bells with speed and precision, the timpanist deftly swings his mallet and dispatches the fly, ending the latest contest between mammalian and arthropod nervous systems.

The nervous systems underlying these behaviors are one of the features that set animals apart from other organisms. As animals evolved, the need to find food, living space, and mates, and to escape predators and other dangers, provided a powerful selection pressure for increasingly complex and capable nervous systems. Neurons, described in the previous chapter, provide the structural and functional basis for all these systems. We can trace some of the developments along this extended evolutionary pathway by examining the nervous systems of living animals, from invertebrates to mammals, and especially humans.

38.1 Invertebrate and Vertebrate Nervous Systems Compared

The nervous systems of most invertebrates are relatively simple, typically containing fewer neurons, arranged in less complex networks, than vertebrate systems. As animal groups evolved, their nervous systems became more elaborate, providing the ability to integrate more sensory information and to formulate more complex responses. Our comparative survey of nervous systems begins with the simplest invertebrates.

Cnidarians and Echinoderms Have Nerve Nets

Cnidarians and echinoderms are radially symmetrical animals with body parts arranged regularly around a central axis like the spokes of a wheel. Their nervous systems, called **nerve nets,** are loose meshes of neurons organized within that radial symmetry.

The nerve nets of cnidarians such as sea anemones extend into each "spoke" of the body **(Figure 38.1a).** Their neurons lack clearly differentiated dendrites and axons. When part of the animal is stimulated, impulses are conducted through the nerve net in all directions from the point of stimulation. Although there is no cluster of neurons that plays the coordinating role of a brain, nerve cells may be more concentrated in some regions. For example, in scyphozoan jellyfish, which swim by rhythmic contractions of their bells, neurons are denser in a ring around the margin of the bell, in the same area as the contractile cells that produce the swimming movements.

In echinoderms, including sea stars, the nervous system is a modified nerve net, with some neurons organized into **nerves,** bundles of axons enclosed in connective tissue and following the same pathway. A *nerve ring* surrounds the centrally located mouth, and a *radial nerve* that is connected to nerve nets branches throughout each arm **(Figure 38.1b).** If the radial nerve serving an arm is cut, the arm can still move, but not in coordination with the other arms.

More Complex Invertebrates Have Cephalized Nervous Systems

More complex invertebrates have neurons with clearly defined axons and dendrites, and more specialized functions. Some neurons are concentrated into functional clusters called **ganglia** (singular, *ganglion*). A key evolutionary development in invertebrates is a trend toward *cephalization,* the formation of a distinct head region containing both ganglia that constitute a **brain,** the control center of the nervous system, and major sensory structures. One or more solid **nerve cords**—bundles of nerves—extend from the central ganglia to the rest of the body; they are connected to smaller nerves. Another evolutionary trend is toward bilateral symmetry of the body and the nervous system, in which body parts are mirror images on left and right sides. These trends toward cephalization and bilateral symmetry are illustrated here in flatworms, arthropods, and mollusks.

In flatworms, a small brain consisting of a pair of ganglia at the anterior end is connected by two or more longitudinal nerve cords to nerve nets in the rest of the body **(Figure 38.1c).** The brain integrates inputs from sensory receptors, including a pair of anterior eyespots with receptors that respond to light. The brain and longitudinal nerve cords constitute the flatworm's **central nervous system (CNS),** the simplest one known, while the nerves from the CNS to the rest of the body constitute the **peripheral nervous system (PNS).**

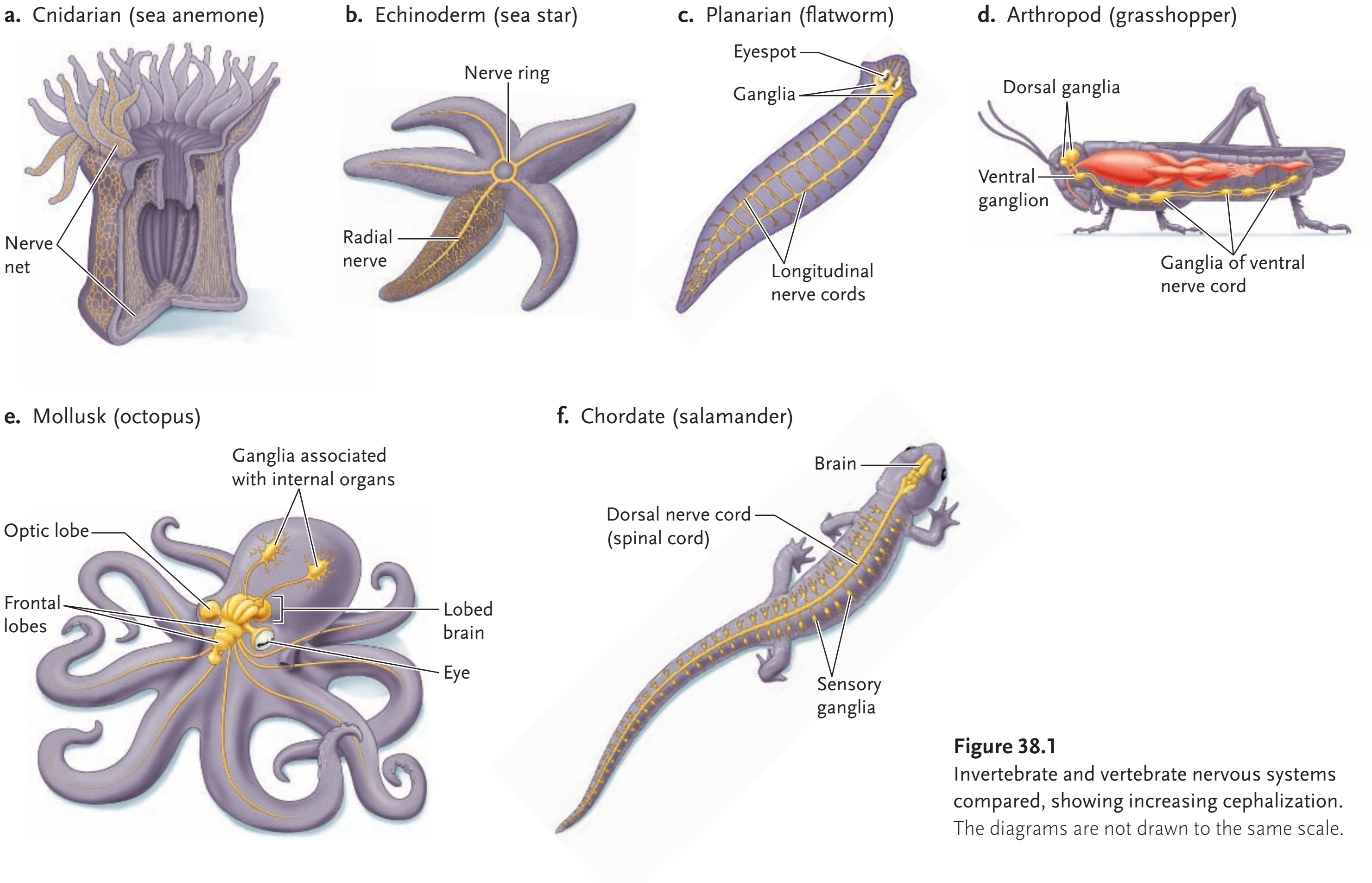


Figure 38.1
Invertebrate and vertebrate nervous systems compared, showing increasing cephalization.
The diagrams are not drawn to the same scale.

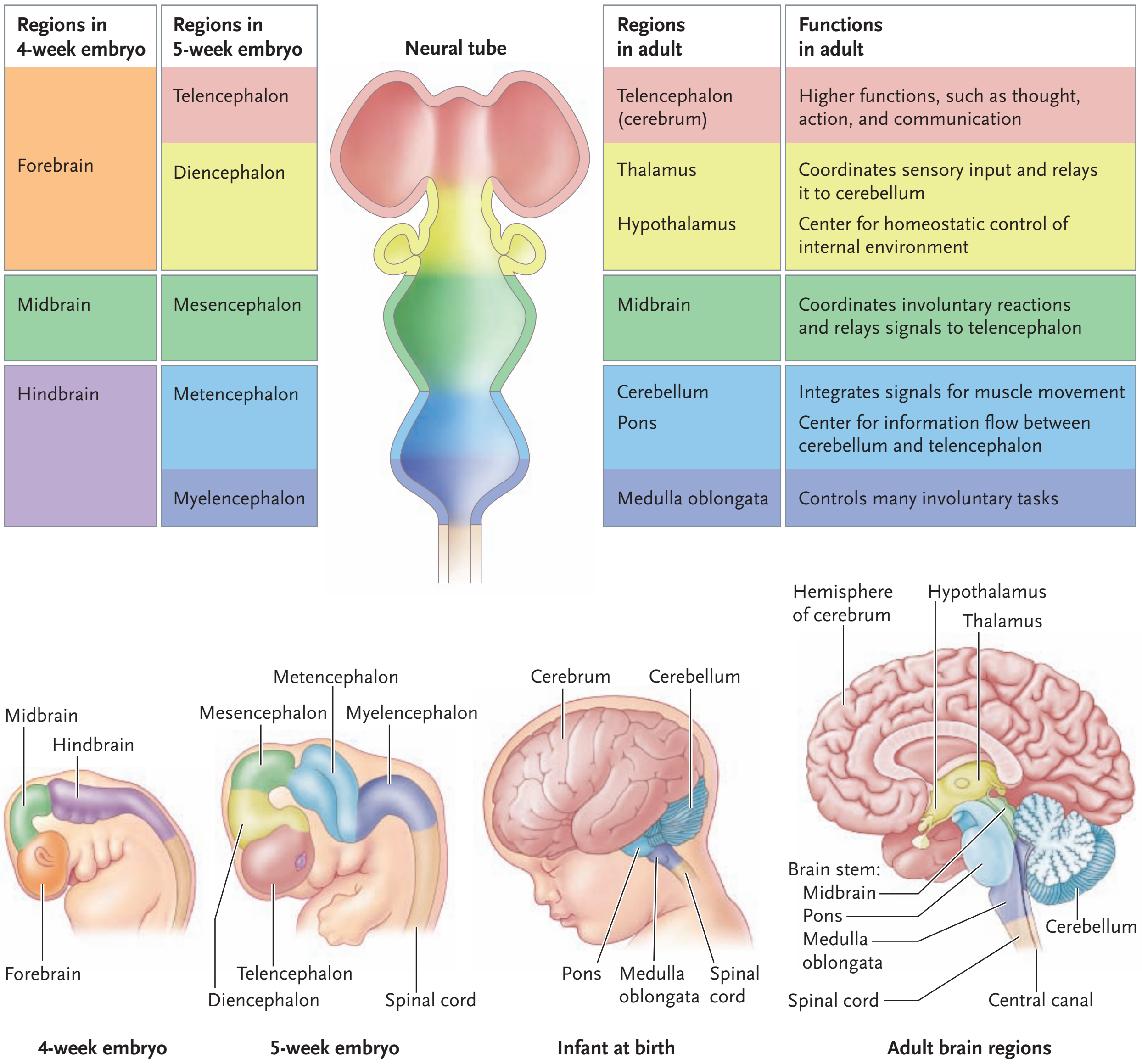
Arthropods such as insects have a head region that contains a brain consisting of dorsal and ventral pairs of ganglia, and major sensory structures, usually including eyes and antennae **(Figure 38.1d)**. The brain exerts centralized control over the remainder of the animal. A ventral nerve cord enlarges into a pair of ganglia in each body segment. In arthropods with fused body segments, as in the thorax of insects, the ganglia are also fused into larger masses forming secondary control centers.

Although different in basic plan from the arthropod system, the nervous systems of mollusks (such as clams, snails, and octopuses) also rely on neurons clustered into paired ganglia and connected by major nerves. Different mollusks have varying degrees of cephalization, with cephalopods having the most pronounced cephalization of any invertebrate group. In the head of an octopus, for example, a cluster of ganglia fuses into a complex, lobed brain with clearly defined sensory and motor regions. Paired nerves link different lobes with muscles and sensory receptors, including prominent optic lobes linked by nerves to large, complex eyes **(Figure 38.1e)**. Octopuses are capable of rapid movement to hunt prey and to escape from predators, behaviors that rely on rapid, sophisticated processing of sensory information.

Vertebrates Have the Most Specialized Nervous Systems

In vertebrates, the CNS consists of the brain and spinal cord, and the PNS consists of all the nerves and ganglia that connect the brain and spinal cord to the rest of the body **(Figure 38.1f)**. All vertebrate nervous systems are highly cephalized, with major concentrations of neurons in a brain located in the head. In contrast to invertebrate nervous systems, which have solid nerve cords located ventrally, the brain and nerve cord of vertebrates are hollow, fluid-filled structures located dorsally. The head contains specialized sensory organs, which are connected directly to the brain by nerves. Compared with invertebrates, the ganglia are greatly reduced in mass and functional activity except in the gut, which contains extensive interneuron networks.

The structure of the vertebrate nervous system reflects its pattern of development. The nervous system of a vertebrate embryo begins as the hollow **neural tube**, the anterior end of which develops into the brain and the rest into the **spinal cord.** The cavity of the neural tube becomes the fluid-filled **ventricles** of the brain and the **central canal** through the spinal cord. Adjacent tissues give rise to nerves that connect the brain and spinal cord with all body regions.



Regions in 4-week embryo	Regions in 5-week embryo	Regions in adult	Functions in adult
Forebrain	Telencephalon	Telencephalon (cerebrum)	Higher functions, such as thought, action, and communication
	Diencephalon	Thalamus Hypothalamus	Coordinates sensory input and relays it to cerebellum Center for homeostatic control of internal environment
Midbrain	Mesencephalon	Midbrain	Coordinates involuntary reactions and relays signals to telencephalon
Hindbrain	Metencephalon	Cerebellum Pons	Integrates signals for muscle movement Center for information flow between cerebellum and telencephalon
	Myelencephalon	Medulla oblongata	Controls many involuntary tasks

Figure 38.2 Development of the human brain from the anterior end of an embryo's neural tube.

Early in embryonic development, the anterior part of the neural tube enlarges into three distinct regions: the **forebrain**, **midbrain**, and **hindbrain** **(Figure 38.2).** A little later, the embryonic hindbrain subdivides into the *metencephalon* and *myelencephalon;* the midbrain develops into the *mesencephalon;* and the forebrain subdivides into the *telencephalon* and *diencephalon*.

The metencephalon gives rise to the *cerebellum,* which integrates sensory signals from the eyes, ears, and muscle spindles with motor signals from the telencephalon, and the *pons,* a major traffic center for information passing between the cerebellum and the higher integrating centers of the adult telencephalon. The myelencephalon gives rise to the *medulla oblongata* (commonly shortened to medulla), which controls many vital involuntary tasks such as respiration and blood circulation. The mesencephalon gives rise to the (adult) midbrain, which with the pons and the medulla constitutes the brain stem. The midbrain has centers for coordinating reflex responses (involuntary reactions) to visual and auditory (hearing) input and relays signals to the telencephalon.

The embryonic telencephalon develops into the *cerebrum* (or adult telencephalon), the largest part of the brain. The cerebrum controls higher functions such as thought, memory, language, and emotions, as well as voluntary movements. The diencephalon gives rise to the *thalamus,* a coordinating center for sensory input and a relay station for input to the cerebellum, and to the *hypothalamus,* the primary center for homeostatic control over the internal environment. In fishes, the cerebrum is little more than a relay station for olfactory (sense of smell) information. In amphibians, reptiles, and birds, it becomes progressively larger and contains greater concentrations of integrative functions. In mammals, the cerebrum is the major integrative structure of the brain.

In the following sections, we examine vertebrate nervous systems, and the human nervous system in particular, beginning with the peripheral nervous system.

Study Break

1. Distinguish between a nerve net, nerves, and nerve cords.
2. What is cephalization?
3. What nervous system structures arise from the embryonic hindbrain, and what are their functions?

38.2 The Peripheral Nervous System

Afferent neurons in the peripheral nervous system transmit signals to the CNS, and signals from the CNS are sent via efferent neurons in the peripheral nervous system to the effectors that carry out responses **(Figure 38.3).** The afferent part of the system includes all the neurons that transmit sensory information from their receptors. The efferent part of the system consists of the axons of neurons that carry signals to the muscles and glands acting as effectors. In mammals, 31 pairs of **spinal nerves** carry signals between the spinal cord and the body trunk and limbs, and 12 pairs of **cranial nerves** connect the brain directly to the head, neck, and body trunk. The efferent part of the PNS is further divided into somatic and autonomic systems (see Figure 38.3).

The Somatic System Controls the Contraction of Skeletal Muscles, Producing Body Movements

The **somatic system** controls body movements that are primarily conscious and voluntary. Its neurons, called motor neurons, carry efferent signals from the CNS to the skeletal muscles. The dendrites and cell bodies of motor neurons are located in the spinal cord; their axons extend from the spinal cord to the skeletal muscle cells they control. As a result, the somatic portions of the cranial and spinal nerves consist only of axons.

Although the somatic system is primarily under conscious, voluntary control, some contractions of skeletal muscles are unconscious and involuntary. These include the reflexes, shivering, and the constant muscle contractions that maintain body posture and balance.

The Autonomic System Is Divided into Sympathetic and Parasympathetic Divisions

The **autonomic nervous system** controls largely involuntary processes including digestion, secretion by sweat glands, circulation of the blood, many functions of the reproductive and excretory systems, and contraction of smooth muscles in all parts of the body. It is organized into *sympathetic* and *parasympathetic* divisions, which

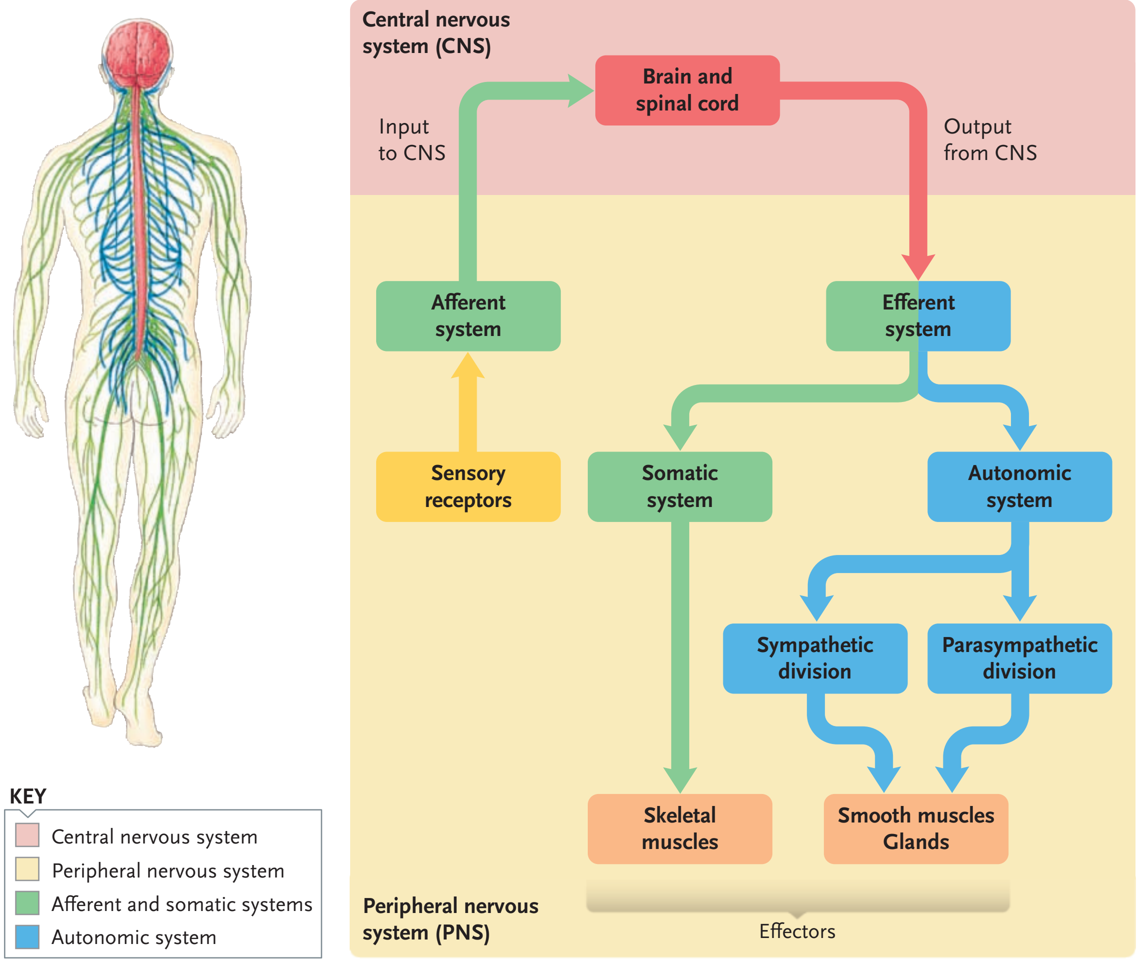


Figure 38.3
The central nervous system (CNS) and peripheral nervous system (PNS), and their subsystems.

are always active, and have opposing effects on the organs they affect, thereby enabling precise control **(Figure 38.4).** For example, in the circulatory system, sympathetic neurons stimulate the force and rate of the heartbeat, and parasympathetic neurons inhibit these activities. In the digestive system, sympathetic neurons inhibit the smooth muscle contractions that move materials through the small intestine, and parasympathetic neurons stimulate the same activities. These opposing effects control involuntary body functions precisely.

The pathways of the autonomic nervous system include two neurons. The first neuron has its dendrites and cell body in the CNS, and its axon extends to a ganglion outside the CNS in the PNS. There it synapses with the dendrites and cell body of the second neuron in the pathway. The axon of the second neuron extends from the ganglion to the effector carrying out the response.

The **sympathetic division** predominates in situations involving stress, danger, excitement, or strenuous physical activity. Signals from the sympathetic division increase the force and rate of the heartbeat, raise the blood pressure by constricting selected blood vessels, dilate air passages in the lungs, induce sweating, and open the pupils wide. Activities that are less important in an emergency, such as digestion, are suppressed by the sympathetic system. The **parasympathetic division,** in contrast, predominates during quiet, low-stress situations, such as while relaxing. Under its influence the effects of the sympathetic division, such as rapid heartbeat and elevated blood pressure, are reduced and "housekeeping" (maintenance) activities such as digestion predominate.

STUDY BREAK

Which of the two autonomic nervous system divisions predominates in the following scenarios? (a) You are hiking on a trail and suddenly a bear appears in your path. (b) It is a hot sunny day. You find a shady tree and sit down. Leaning against its trunk, you feel your eyes becoming heavy.

38.3 The Central Nervous System (CNS) and Its Functions

The central nervous system integrates incoming sensory information from the PNS into compensating responses, thus managing body activities. Our examina-

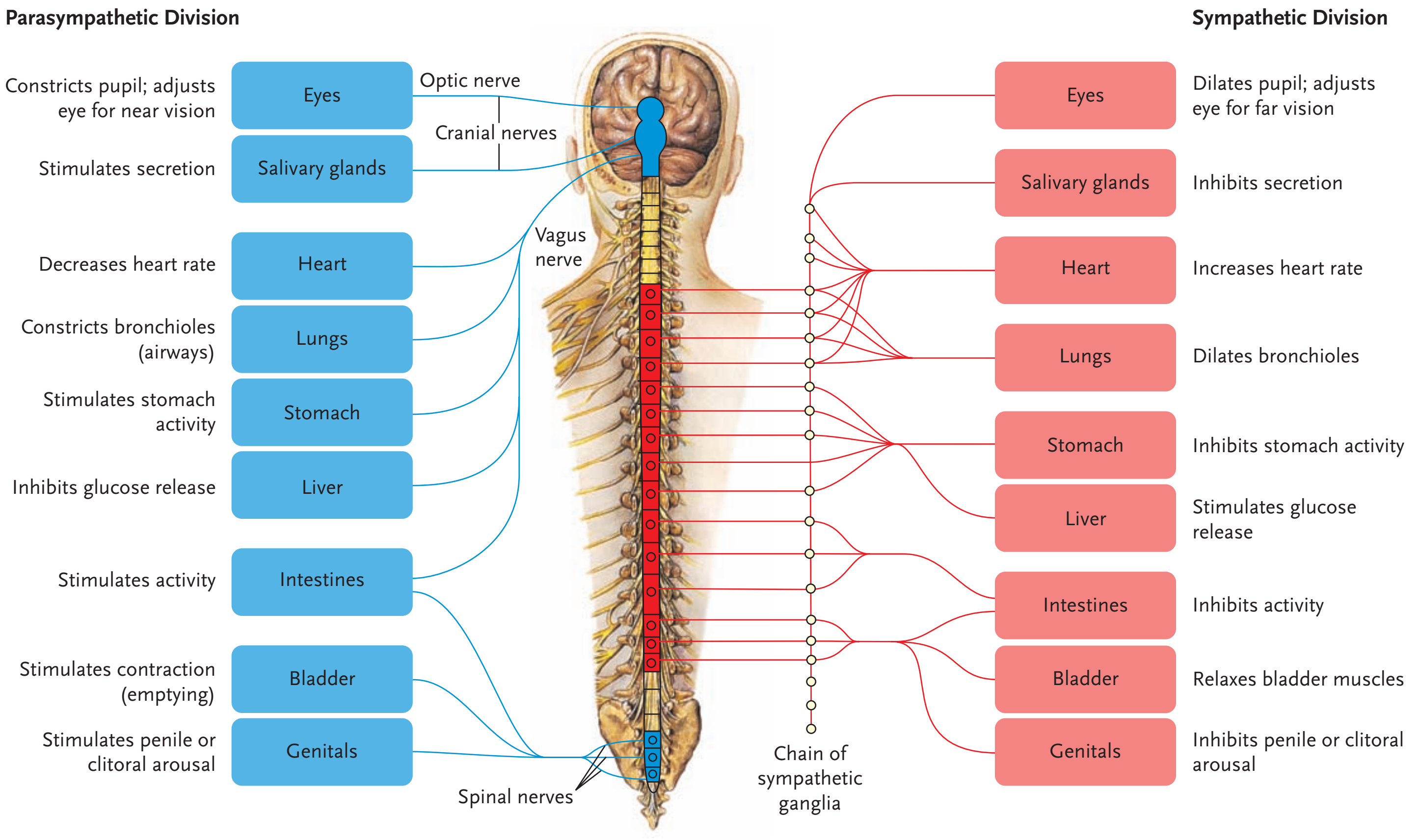


Figure 38.4

Effects of the sympathetic and parasympathetic divisions of the central nervous system on organ and gland function. Only one side of each division is shown; both are duplicated on the left and right sides of the body.

tion of the vertebrate CNS begins with the spinal cord, and then considers the brain and its functions.

The Spinal Cord Relays Signals between the PNS and the Brain and Controls Reflexes

The spinal cord, which extends dorsally from the base of the brain, carries impulses between the brain and the PNS and contains the interneuron circuits that control motor reflexes.

The spinal cord and brain are surrounded and protected by three layers of connective tissue, the **meninges** (*meninga* = membrane), and by **cerebrospinal fluid,** which circulates through the central canal of the spinal cord, through the ventricles of the brain, and between two of the meninges. The fluid cushions the brain and spinal cord from jarring movements and impacts, and it both nourishes the CNS and protects it from toxic substances.

In cross section, the spinal cord has a butterfly-shaped core of **gray matter,** consisting of nerve cell bodies and dendrites. This is surrounded by **white matter,** consisting of axons, many of them surrounded by myelin sheaths. Pairs of spinal nerves connect with the spinal cord at spaces between the vertebrae (**Figure 38.5**).

The afferent axons entering the spinal cord make synapses with interneurons in the gray matter, which send axons upward through the white matter of the spinal cord to the brain. Conversely, axons from 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 gray matter of the cord. The axons of these efferent neurons exit the spinal cord through the spinal nerves.

The gray matter of the spinal cord also contains interneurons of the pathways involved in **reflexes,** programmed movements that take place without conscious effort, such as the sudden withdrawal of a hand from a hot surface (see Figure 38.5). When your hand touches the hot surface, the heat stimulates an afferent neuron, which makes connections with at least two interneurons in the spinal cord. One of these interneurons stimulates an efferent neuron, causing the *flexor* muscle of the arm to contract, which bends the arm and withdraws the hand almost instantly from the hot surface. The other interneuron synapses with an efferent neuron connected to an *extensor* muscle, relaxing it so that the flexor can move more quickly. Interneurons connected to the reflex circuits also send signals to the brain, making you aware of the stimulus causing the reflex. You know from experience that when a reflex movement withdraws your hand from a hot surface or other damaging stimulus, you feel the pain shortly *after* the hand is withdrawn. This is the extra time required for impulses to travel from the neurons of the reflex to the brain (see discussion of the neurotransmitter substance P in Section 37.3).

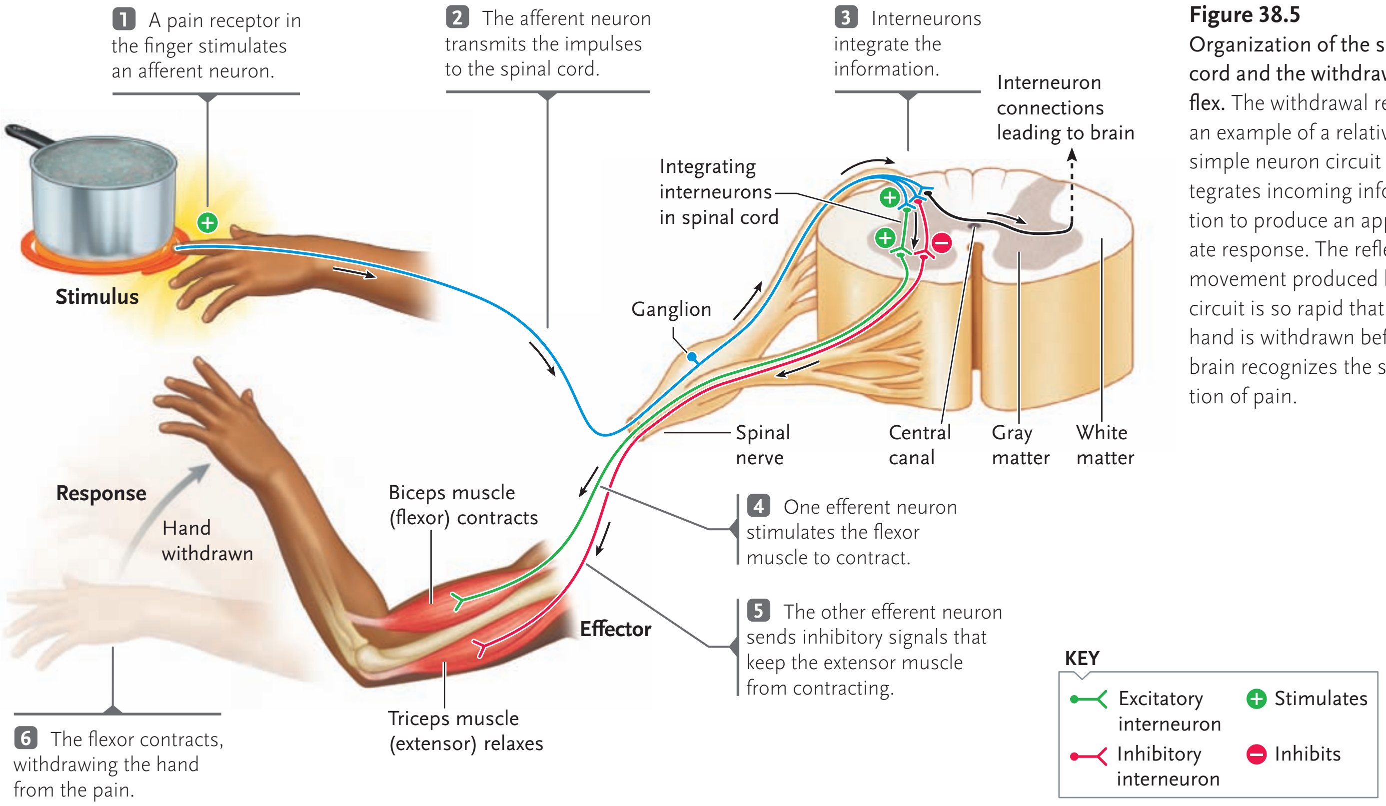


Figure 38.5
Organization of the spinal cord and the withdrawal reflex. The withdrawal reflex is an example of a relatively simple neuron circuit that integrates incoming information to produce an appropriate response. The reflex movement produced by this circuit is so rapid that the hand is withdrawn before the brain recognizes the sensation of pain.

The Brain Integrates Sensory Information and Formulates Compensating Responses

The brain is the major center that receives, integrates, stores, and retrieves information in vertebrates. Its interneuron networks generate responses that provide the basis for our voluntary movements, consciousness, behavior, emotions, learning, reasoning, language, and memory, among many other complex activities.

Major Brain Structures. We have noted that the three major divisions of the embryonic neural tube—forebrain, midbrain, and hindbrain—give rise to the structures of the adult brain. Like the spinal cord, each brain structure contains both gray matter and white matter and is surrounded by meninges and circulating cerebrospinal fluid **(Figure 38.6).**

The hindbrain develops into three major structures in the adult brain: the *cerebellum,* the *pons,* and the *medulla oblongata* (the *medulla*) (see Figure 38.2). The pons and medulla, along with the midbrain, form a stalklike structure known as the **brain stem,** which connects the forebrain with the spinal cord. All but two of the twelve pairs of cranial nerves also originate from the brain stem. The cerebellum, with its deeply folded surface, is an outgrowth of the pons.

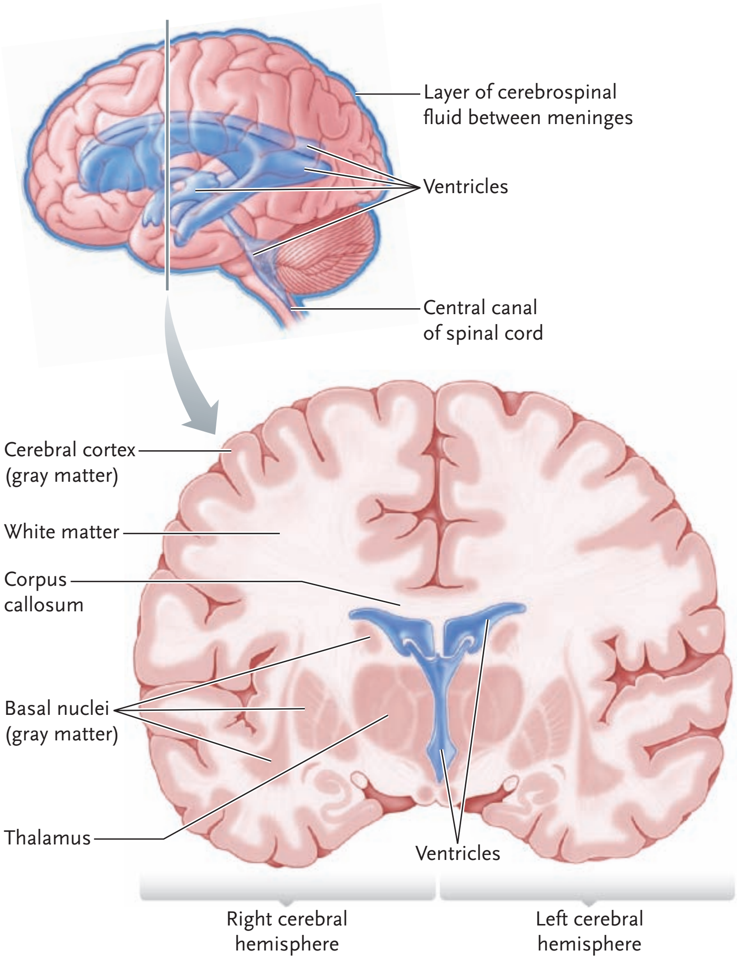


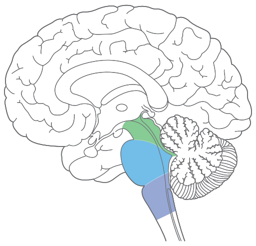
Figure 38.6
The human brain, illustrating the distribution of gray matter and white matter, and the locations of the four ventricles (in blue) with their connection to the central canal of the spinal cord.

The forebrain, which makes up most of the mass of the brain in humans, forms the *telencephalon (cerebrum)*. The cerebrum, the largest part of the brain in humans, is organized into the left and right *cerebral hemispheres,* which have many fissures and folds (see Figure 38.6). Each hemisphere consists of **cerebral cortex,** a thin outer shell of gray matter covering a thick core of white matter. The basal nuclei, consisting of several regions of gray matter, are located deep within the white matter.

The Blood-Brain Barrier. Unlike the epithelial cells forming capillary walls elsewhere in the body, which allow small molecules and ions to pass freely from the blood to surrounding fluids, those forming capillaries in the brain are sealed together by tight junctions (see Figure 5.27). The tight junctions set up a **blood-brain barrier** that prevents most substances dissolved in the blood from entering the cerebrospinal fluid and thus protects the brain and spinal cord from viruses, bacteria, and toxic substances that may circulate in the blood.

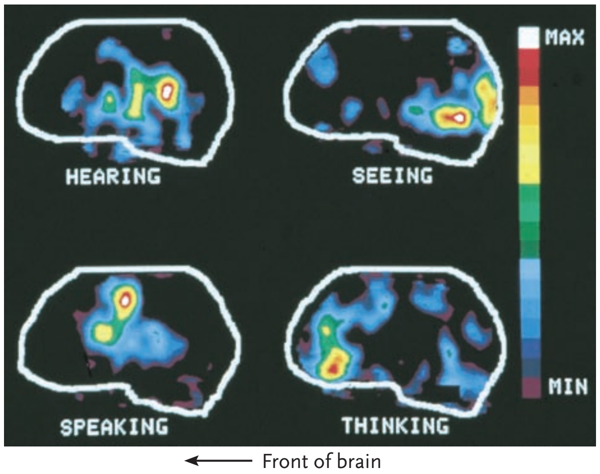
A few types of molecules and ions, such as oxygen, carbon dioxide, alcohol, and anesthetics, can move directly across the lipid bilayer of the epithelial cell membranes by diffusion. A few other substances—most significantly glucose, the only molecule that brain and spinal cord cells can oxidize for energy—are moved across the plasma membrane by highly selective transport proteins.

The Brain Stem Regulates Many Vital Housekeeping Functions of the Body



Physicians and scientists have learned much about the functions of various brain regions by studying patients with brain damage from stroke, infection, tumors, or mechanical disturbance. Techniques such as *functional magnetic resonance imaging (fMRI)* and *positron emission tomography (PET)* allow researchers to identify the normal functions of specific brain regions in noninvasive 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 38.7).**

From such medical and experimental analyses, we know that gray-matter centers in the brain stem control



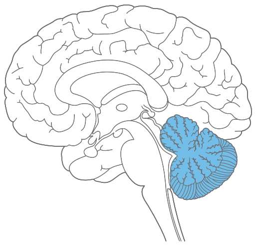
Courtesy of Dr. Marcus Raichle, courtesy of Washington University School of Medicine, St. Louis

Figure 38.7
PET scans showing regions of the brain active when a person performs specific mental tasks. The colors show the relative activity of the sections, with white the most active.

many vital body functions without conscious involvement or control by the cerebrum. Among these functions are the heart and respiration rates, blood pressure, constriction and dilation of blood vessels, coughing, and reflex activities of the digestive system such as vomiting. Damage to the brain stem has serious and sometimes lethal consequences.

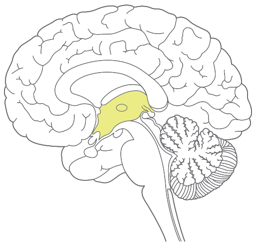
A complex network of interconnected neurons known as the **reticular formation** (*reticulum* = netlike structure) runs through the length of the brain stem, connecting to the thalamus at the anterior end and to the spinal cord at the posterior end **(Figure 38.8).** All incoming sensory input goes to the reticular formation, which integrates the information and then sends signals to other parts of the CNS. The reticular formation has two parts. The ascending reticular formation, also called the *reticular activating system,* contains neurons that convey stimulatory signals via the thalamus to arouse and activate the cerebral cortex. It is responsible for the sleep-wake cycle; depending on the level of stimulation of the cortex, various levels of alertness and consciousness are produced. Lesions in this part of the brain stem result in coma. The other part, the descending reticular formation, receives information from the hypothalamus and connects with interneurons in the spinal cord that control skeletal muscle contraction, thereby controlling muscle movement and posture. The reticular formation filters incoming signals, helping to discriminate between important and unimportant ones. Such filtering is necessary because the brain is unable to process every one of the signals from millions of sensory receptors. For example, the action of the reticular formation enables you to sleep through many sounds but waken to specific ones, such as a cat meowing to be let out or a baby crying.

The Cerebellum Integrates Sensory Inputs to Coordinate Body Movements



Although the cerebellum is an outgrowth of the pons (see Figure 38.8), 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 from receptors in muscles and joints, from balance receptors in the inner ear, and from the receptors of touch, vision, and hearing. These signals convey information about how the body trunk and limbs are positioned, the degree to which different muscles are contracted or relaxed, and the direction in which the body or limbs are moving. The cerebellum integrates these sensory signals and compares them with signals from the cerebrum that control voluntary body movements. Outputs from the cerebellum to the cerebrum, brain stem, and spinal cord modify and fine-tune the movements to keep the body in balance and directed toward targeted positions in space. The cerebellum of all mammals has essentially the same capabilities and works in the same way. The human cerebellum also contributes to the learning and memory of motor skills such as typing.

Gray-Matter Centers Control a Variety of Functions



Gray-matter centers derived from the embryonic forebrain include the thalamus, hypothalamus, and basal nuclei **(Figure 38.9).** These centers contribute to the control and integration of voluntary movements, body temperature and glandular secretions, osmotic balance of the blood and extracellular fluids, wakefulness, and the

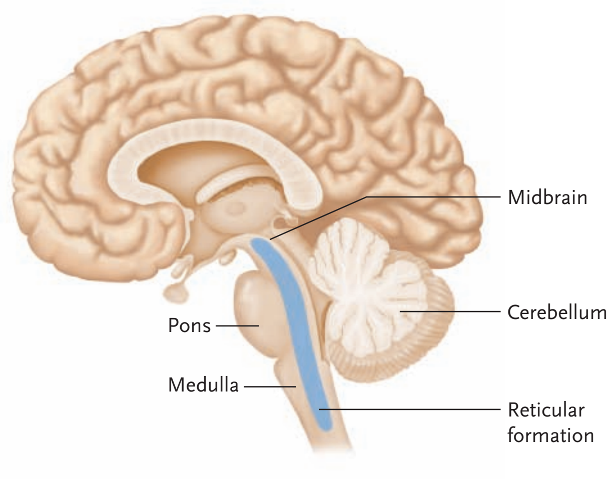


Figure 38.8
Location of the reticular formation (in blue) in the brain stem.

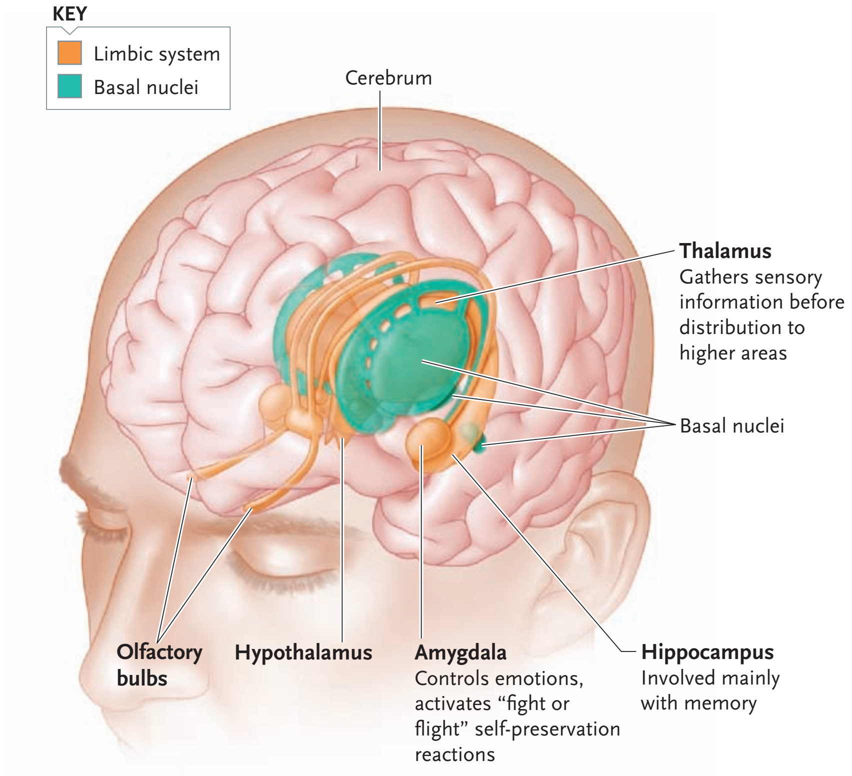


Figure 38.9
Basal nuclei, thalamus, and hypothalamus gray-matter centers. The centers shown in this view are those in the left hemisphere.

emotions, among other functions. Some of the gray-matter centers route information to and from the cerebral cortex, and between the forebrain, brain stem, and cerebellum.

The **thalamus** (see Figure 38.9) forms a major switchboard that receives sensory information and relays it to the regions of the cerebral cortex concerned with motor responses to sensory information of that type. Part of the thalamus near the brain stem cooperates with the reticular formation in alerting the cerebral cortex to full wakefulness, or in inducing drowsiness or sleep.

The **hypothalamus** (see Figure 38.9) contains centers that regulate basic homeostatic functions of the body and contribute to the release of hormones. Some centers 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. If departures from normal levels are detected, the hypothalamus triggers responses such as thirst or changes in urine output that restore the osmotic and fluid balance.

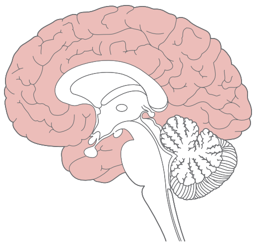
The centers of the hypothalamus that detect blood composition and temperature are directly exposed to the bloodstream—they are the only parts of the brain *not* protected by the blood-brain barrier. Parts of the hypothalamus also coordinate responses triggered by the autonomic system, making it an important link in such activities as control of the heartbeat, contraction of smooth muscle cells in the digestive system, and glandular secretion. Some regions of the hypothalamus establish a biological clock that sets up daily metabolic rhythms, such as the regular changes in body temperature that occur on a daily cycle.

The **basal nuclei** are gray-matter centers that surround the thalamus on both sides of the brain (see Figure 38.9). They moderate voluntary movements directed by motor centers in the cerebrum. Damage to the basal nuclei can affect the planning and fine-tuning of movements, leading to stiff, rigid motions of the limbs and unwanted or misdirected motor activity, such as tremors of the hands and inability to start or stop intended movements at the intended place and time. Parkinson disease, in which affected individuals exhibit all of these symptoms, results from degeneration of centers in and near the basal nuclei.

Parts of the thalamus, hypothalamus, and basal nuclei, along with other nearby gray-matter centers—the amygdala, hippocampus, and olfactory bulbs—form a functional network called the **limbic system** (*limbus* = arc), sometimes called our "emotional brain" (see Figure 38.9). The **amygdala** works as a switchboard, routing information about experiences that have an emotional component through the limbic system. The **hippocampus** is involved in sending information to the frontal lobes, and the **olfactory bulbs** relay inputs from odor receptors to both the cerebral cortex and the limbic system. The olfactory connection to the limbic system may explain why certain odors can evoke particular, sometimes startlingly powerful emotional responses.

The limbic system controls emotional behavior and influences the basic body functions regulated by the hypothalamus and brain stem. Stimulation of different parts of the limbic system produces anger, anxiety, fear, satisfaction, pleasure, or sexual arousal. Connections between the limbic system and other brain regions bring about emotional responses such as smiling, blushing, or laughing.

The Cerebral Cortex Carries Out All Higher Brain Functions in Humans



The gray matter of each hemisphere, the cerebral cortex, contains the processing centers for the integration of neural input and the initiation of neural output. The white matter of the cerebral hemispheres, by contrast, contains the neural routes for signal transmission between parts of the cerebral cortex, or from the cerebral cortex to other parts of the CNS. No information processing occurs in the white matter.

Over the course of evolution, the surface area of the cerebral cortex increased by continually folding in

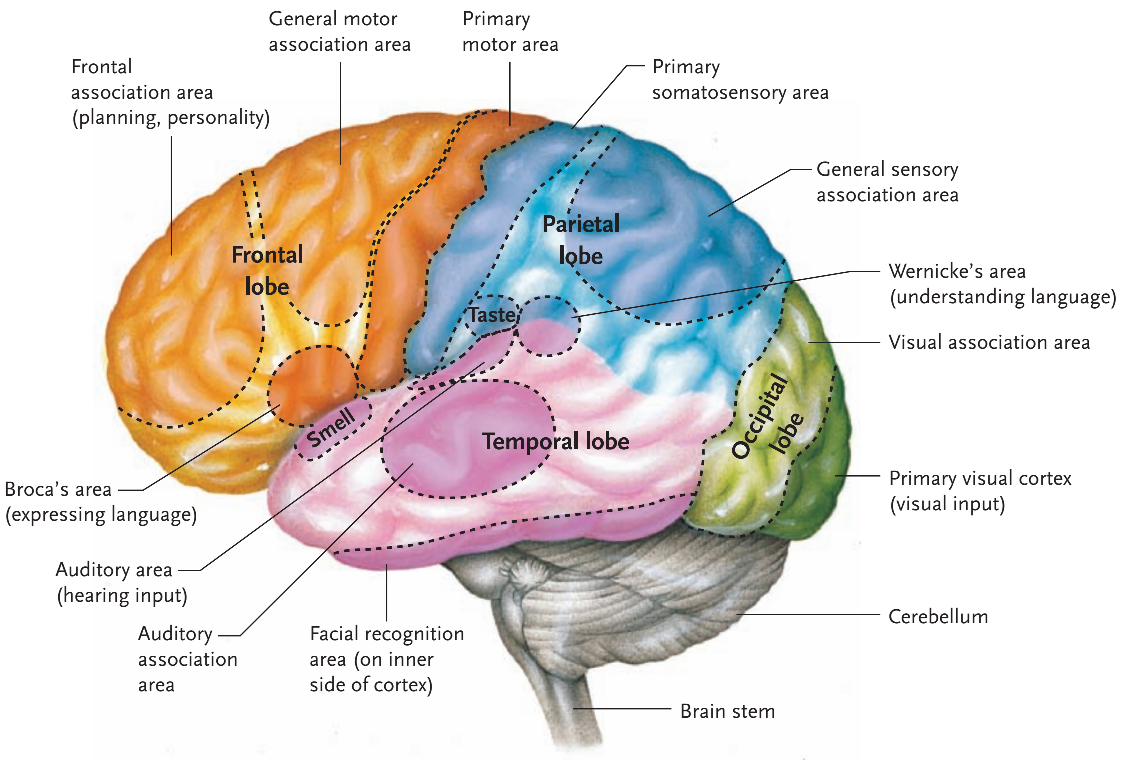


Figure 38.10
The lobes of the cerebrum, showing major regions and association areas of the cerebral cortex.

on itself, thereby expanding the structure into sophisticated information encoding and processing centers. Primates have cerebral cortexes with the largest number of convolutions. In humans, each cerebral hemisphere is divided by surface folds into *frontal, parietal, temporal,* and *occipital* lobes **(Figure 38.10).** Uniquely in mammals, the cerebral cortex of the cerebral hemispheres is organized into six layers of neurons; these layers are the newest part of the cerebral cortex in an evolutionary sense.

The two cerebral hemispheres can function separately, and each has its own communication lines internally and with the rest of the CNS and the body. The left cerebral hemisphere responds primarily to sensory signals from, and controls movements in, the right side of the body. The right hemisphere has the same relationships to the left side of the body. This opposite connection and control reflects 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, forming a structure called the **corpus callosum,** connect the two cerebral hemispheres and coordinate their functions.

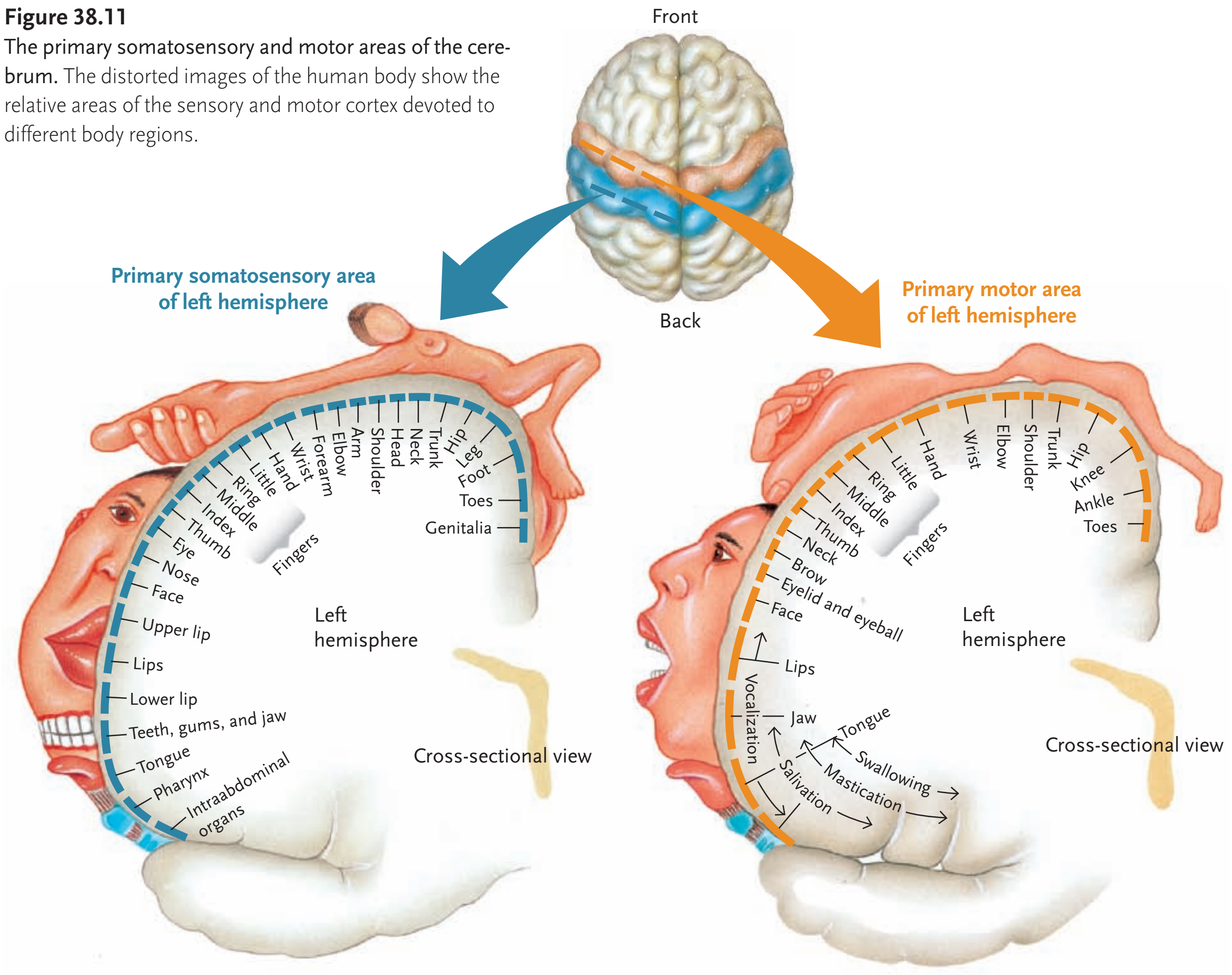
Sensory Regions of the Cerebral Cortex. Areas that receive and integrate sensory information are distributed over the cerebral cortex. In each hemisphere, the **primary somatosensory area,** which registers information on touch, pain, temperature, and pressure, runs in a band across the parietal lobes of the brain (see Figure 38.10). Experimental stimulation of this band in one hemisphere causes prickling or tingling sensations in specific parts on the opposite side of the body, beginning with the toes at the top of each hemisphere and running through the legs, trunk, arms, and hands, to the head **(Figure 38.11).**

Other sensory regions of the cerebral cortex have been identified with hearing, vision, smell, and taste (see Figure 38.10). Regions of the temporal lobes on both sides of the brain receive auditory inputs from the ears, while inputs from the eyes are processed in the primary visual cortex in both occipital lobes. Olfactory input from the nose is processed in the olfactory bulbs, located on the ventral side of the temporal lobes. Regions in the parietal lobes receive inputs from taste receptors on the tongue and other locations in the mouth.

Motor Regions of the Cerebral Cortex. The **primary motor area** of the cerebral cortex runs in a band just in front of the primary somatosensory area (see Figure 38.10). Experimental stimulation of points along this band in one hemisphere causes movement of specific body parts on the opposite side of the body, corresponding generally to the parts registering in the primary somatosensory area at the same level (see Figure 38.11). Other areas that integrate and refine motor control are located nearby.

In both the primary somatosensory and primary motor areas, some body parts, such as the lips and fingers, are represented by large regions, and others, such as the arms and legs, are represented by relatively small regions. As shown in Figure 38.11, the relative sizes produce a distorted image of the human body that is quite different from the actual body proportions. The differences are reflected in the precision of

Figure 38.11
The primary somatosensory and motor areas of the cerebrum. The distorted images of the human body show the relative areas of the sensory and motor cortex devoted to different body regions.



touch and movement in structures such as the lips, tongue, and fingers.

Association Areas. The sensory and motor areas of the cerebral cortex are surrounded by **association areas** (see Figure 38.10), which integrate information from the sensory areas, formulate responses, and pass them on to the primary motor area. Two of the most important association areas are *Wernicke's area* and *Broca's area* (see Figure 38.10), which function in spoken and written language. They are usually present on only one side of the brain—in the left hemisphere in 97% of the human population. Comprehension of spoken and written language depends on Wernicke's area, which coordinates inputs from the visual, auditory, and general sensory association areas. Interneuron connections lead from Wernicke's area to Broca's area, which puts together the motor program for coordination of the lips, tongue, jaws, and other structures producing the sounds of speech, and passes the program to the primary motor area. The brain-scan images in Figure 38.7 dramatically illustrate how these brain regions participate as a person performs different linguistic tasks.

People with damage to Wernicke's area have difficulty comprehending spoken and written words, even though their hearing and vision are unimpaired. Although they can speak, their words usually make no sense. People with damage to Broca's area have normal comprehension of written and spoken language, and know what they want to say, but are unable to speak except for a few slow and poorly pronounced words. Often, such people are also unable to write. Other areas of the brain are also involved in language functions.

Some Higher Functions Are Distributed in Both Cerebral Hemispheres; Others Are Concentrated in One Hemisphere

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

Among the functions more or less equally distributed between the two hemispheres is the ability to recognize faces. This function is concentrated along the bottom margins of the occipital and temporal lobes (see Figure 38.10). People with damage to these lobes are often unable to recognize even close relatives by sight but can recognize voices immediately. Functions such as consciousness, the sense of time, and recognizing emotions also seem to be distributed in both hemispheres.

Typically some brain functions are more localized in one of the two hemispheres, a phenomenon called **lateralization.** The unequal distribution of these functions was originally worked out in the 1960s by Roger Sperry and Michael S. Gazzaniga of the California Institute of Technology (Sperry received a Nobel Prize for his research in 1981) in subjects who had had their corpus callosum cut surgically **(Figure 38.12).**

Studies of people with split hemispheres as well as surveys of brain activity by PET and fMRI have confirmed that, for the vast majority of people, the left hemisphere specializes in spoken and written language, abstract reasoning, and precise mathematical calculations. The right hemisphere specializes in nonverbal conceptualizing, intuitive thinking, musical and artistic abilities, and spatial recognition functions such as fitting pieces into a puzzle. The right hemisphere also handles mathematical estimates and approximations that can be made by visual or spatial representations of numbers. Thus the left hemisphere in most people is verbal and mathematical, and the right hemisphere is intuitive, spatial, artistic, and musical.

STUDY BREAK

1. Human newborn babies, as well as premature babies, have an incompletely developed blood-brain barrier. Should this condition influence what food and medications are given to them?
2. Distinguish the structure and functions of the cerebellum from those of the cerebral cortex.

38.4 Memory, Learning, and Consciousness

We set memory, learning, and consciousness apart from the other functions because they appear to involve coordination of structures from the brain stem to the cerebral cortex. **Memory** is the storage and retrieval of a sensory or motor experience, or a thought. **Learning** involves a change in the response to a stimulus based on information or experiences stored in memory. **Consciousness** may be defined as awareness of ourselves, our identity, and our surroundings, and an understanding of the significance and likely consequences of events that we experience.

Memory Takes Two Forms, Short Term and Long Term

Psychology research and our everyday experience indicate that humans have at least two types of memory. **Short-term memory** stores information for seconds, minutes, or at most an hour or so. **Long-term memory** stores information from days to years or even for life. Short-term memory, but not long-term memory, is usually erased if a person experiences a disruption such as a sudden fright, a blow, a surprise, or an electrical shock. For example, a person knocked unconscious by an accident typically cannot recall the accident itself or the events just before it, but long-standing memories are not usually disturbed.

To explain these differences, investigators propose that short-term memories depend on transient changes in neurons that can be erased relatively easily, such as changes in the membrane potential of interneurons caused by EPSPs and IPSPs (excitatory and inhibitory postsynaptic potentials) and the action of indirect neurotransmitters that lead to reversible changes in ion transport (see Section 37.3). By contrast, storage of long-term memory is considered to involve more or less permanent molecular, biochemical, or structural changes in interneurons, which establish signal pathways that cannot be switched off easily.

All memories probably register initially in short-term form. They are then either erased and lost, or committed to long-term form. The intensity or vividness of an experience, the attention focused on an event, emotional involvement, or the degree of repetition may all contribute to the conversion from short-term to long-term memory.

The storage pathway typically starts with an input at the somatosensory cortex that then flows to the amygdala, which relays information to the limbic system, and to the hippocampus, which sends information to the frontal lobes, a major site of long-term memory storage. People with injuries to the hippocampus cannot remember information for more than a few minutes; long-term memory is limited to information stored before the injury occurred.

How are neurons and neuron pathways permanently altered to create long-term memory? One change that has been much studied is **long-term potentiation:** a long-lasting increase in the strength of synaptic connections in activated neural pathways following brief periods of repeated stimulation. The synapses become increasingly sensitive over time, so that a constant level of presynaptic stimulation is converted into a larger postsynaptic output that can last hours, weeks, months, or years. (*Insights from the Molecular Revolution* describes experiments investigating the basis of long-term potentiation in neurons of the hippocampus.) Other changes consistently noted as part of long-term memory include more or less permanent alterations in the number and

Figure 38.12 Experimental Research

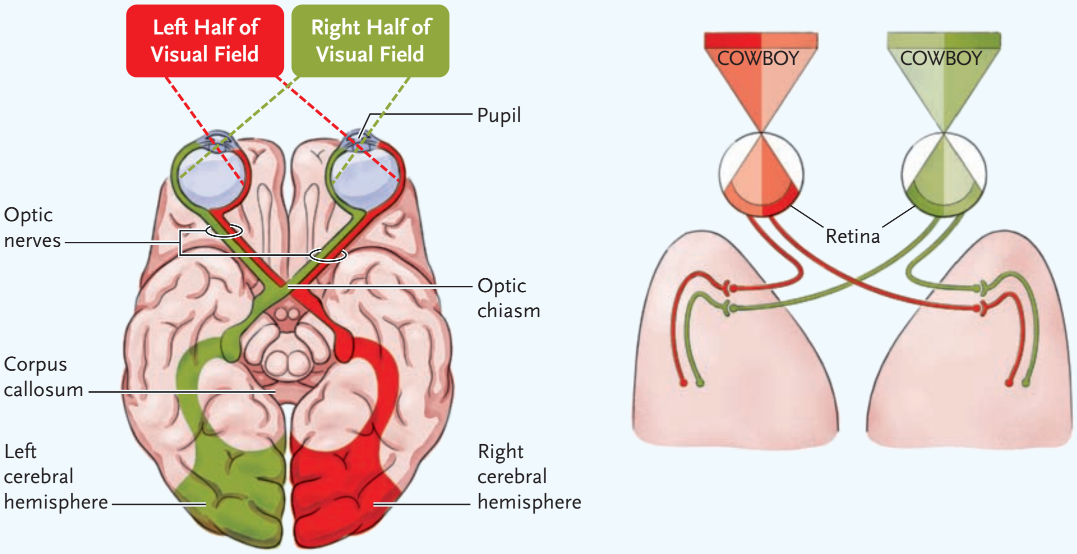
Investigating the Functions of the Cerebral Hemispheres

QUESTION: Do the two cerebral hemispheres have different functions?

EXPERIMENT: Roger Sperry and Michael Gazzaniga studied split-brain individuals, in whom the corpus callosum connecting the two cerebral hemispheres had been surgically severed to relieve otherwise uncontrollable epileptic convulsions. In one experiment, they tested how subjects perceived words that were projected onto a screen in front of them.

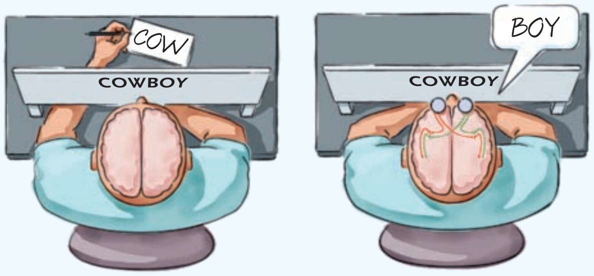
The retinas of the eyes gather visual information and send signals via the optic nerves to the cerebral hemispheres (Figure 38.12a). Light from the *left* half of the visual field reaches light receptors on the *right* sides of the retinas, and parts of the two optic nerves carry signals to the *right* cerebral hemisphere. Light from the *right* half of the visual field reaches light receptors on the *left* sides of the retinas, and signals are sent to the *left* cerebral hemisphere.

The researchers projected words such as COWBOY in such a way that the subjects could see only the left half of the word (COW) with the left eye and the right half of the word (BOY) with the right eye (Figure 38.12b). Sperry asked the subjects to say what word they saw, and he asked them to write the perceived word with the left hand—a hand that was deliberately blocked from the subject's view.


a. Pathway of visual information from eyes to cerebral hemisphere

b. Experimental set up—COW seen by right sides of retinas and BOY by left sides

RESULTS: The split-brain subjects said the word in the right half of the visual field (BOY), but wrote the word in the left half of the visual field (COW).



CONCLUSIONS: The studies showed that the left and right hemispheres are specialized in different tasks. The left hemisphere processes language and was able to recognize BOY but received no information about COW. The right hemisphere directs motor activity on the left side of the body and was able to direct the left hand to write COW. However, the subjects could not say what word they wrote. That is, cutting the corpus callosum interrupted communication between the two halves of the cerebrum. In effect, one cerebral hemisphere did not know what the other was doing, and information stored in the memory on one side was not available to the other. In normal individuals, information is shared across the corpus callosum; they would see COWBOY and be able to speak and write the entire word.

Insights from the Molecular Revolution

Knocked-Out Mice with a Bad Memory

Long-term potentiation (LTP) in neurons of the hippocampus is thought to be central to the conversion of short-term to long-term memory. An indirect neurotransmitter, glutamate, is most often involved in the process. One of the receptors that binds glutamate in postsynaptic membranes of the hippocampus is the *NMDA receptor;* a prolonged series of stimuli causes glutamate to bind to the receptor, which opens an ion channel that forms part of the receptor's structure. Among other effects, Ca^{2+} ions flowing inward through the channel activate a protein kinase in the cytoplasm called *CaMKII*. (Protein kinases are enzymes that, when activated, add phosphate groups to certain proteins; addition of the phosphate groups increases or reduces activity of the proteins.)

One of the target proteins for the activated CaMKII is itself. After it adds phosphate groups to its own structure, CaMKII no longer needs to be activated by calcium—it remains turned on at elevated levels. Its more or less permanent activation makes the neuron more sensitive to incoming signals and increases the number of the signals it sends to other neurons. Researchers hypothesize that this change is a major contributor to LTP in the neuron. Among the supporting evidence is the observation that chemical blockage of the NMDA receptor impairs spatial learning and long-term memory in mice.

A research group at the Massachusetts Institute of Technology led by a Nobel Prize–winning scientist, Susumu Tonegawa, applied molecular techniques to test this hypothesis. Tonegawa's group created a strain of "knockout" mice (see Section 18.2), from which the gene encoding the NMDA receptor has been eliminated.

To test the effects of the knockout on LTP in the neurons, the investigators dissected out brain slices and used microelectrodes to stimulate neurons in the hippocampus. Unlike the response of neurons with an intact NMDA receptor, repeated stimulation was not followed by any potentiation in the knockout neurons.

Would the lack of potentiation in the hippocampal neurons result in the failure of long-term memory storage in the knockout mice? The researchers tested this outcome by placing the knockout mice in a pool in which they had to swim until they could find a submerged platform on which to rest. The knockout mice were much slower than normal mice in finding the platform in initial trials, and, unlike normal mice, were unable to remember its location in later trials.

The results thus support the hypothesis that the NMDA receptor is involved in the conversion from short-term to long-term memory, and that the hippocampus has a central role in this activity. The novel approach used by the Tonegawa group also provides a new, molecular research method by which to analyze higher brain function.

the area of synaptic connections between neurons, in the number and branches of dendrites, and in gene transcription and protein synthesis in interneurons.

Experiments have shown that protein synthesis is critical to long-term memory storage in animals as varied as *Drosophila* and rats. For example, goldfish were trained to avoid an electrical shock by swimming to one end of an aquarium when a light was turned on. The fish could remember the training for about a month under normal conditions; if exposed to a protein synthesis inhibitor while being trained, they forgot the training within a day.

Learning Involves Combining Past and Present Experiences to Modify Responses

As with memory, all animals appear to be capable of learning to some degree. Learning involves three sequential mechanisms, (1) storing memories, (2) scanning memories when a stimulus is encountered, and (3) modifying the response to the stimulus in accordance with the information stored as memory.

One of the simplest forms of memory is **sensitization**—increased responsiveness to mild stimuli after experiencing a strong stimulus. The process was nicely illustrated by Eric Kandel of Columbia University and his associates in experiments with a shell-less marine snail known as the Pacific sea hare, *Aplysia californica,* which is frequently used in research involving reflex behavior, memory, and learning. Many of its neuron circuits have been completely worked out, allowing investigators to follow the reactions of each neuron active in pathways such as learning. The first time the researchers administered a single sharp tap to the siphon (which admits water to the gills), the slug retracted its gills by a reflex movement. However, at the next touch, whether hard or gentle, the siphon retracted much more quickly and vigorously. Sensitization in *Aplysia* has been shown to involve changes in synapses, which become more reactive when more serotonin is released by action potentials. Kandel received the Nobel Prize in 2000 for his research.

Learning skills or procedures, such as tying one's shoes, typing, or playing a musical instrument, involve additional regions of the brain, particularly the cerebellum, where motor activity is coordinated. As we learn such skills, the process gradually becomes automated so that we do not think consciously about each step. (Learning and its relationship to animal behavior are considered further in Chapter 54.)

Consciousness Involves Different States of Awareness

The spectrum of human consciousness ranges from alert wakefulness to daydreaming, dozing, and sleep. Even during sleep there is some degree of awareness, because sleepers can respond to stimuli and waken, unlike someone who is unconscious. Moving between the states of consciousness has been found to involve changes in neural activity over the entire surface of the telencephalon. These changes can be seen using an *electroencephalogram* (EEG), which records voltage changes detected by electrodes placed on the scalp.

When an individual is fully awake, the EEG records a pattern of rapid, irregular *beta waves* **(Figure 38.13).** With mind at rest and eyes closed, the person's EEG pattern changes to slower and more regular *alpha waves*. As drowsiness and light sleep come on, the wave trains gradually become larger, slower, but again less regular; these slower pulsations are called *theta waves*. During the transition from drowsiness to deep sleep, the EEG pattern shifts to even slower *delta waves*. The heart and breathing rates become slower and the skeletal muscles increasingly relaxed, although the sleeper may still change position and move the arms and legs.

Periodically during deep sleep, the delta wave pattern is replaced by the rapid, irregular beta waves characteristic of the waking state. The person's heartbeat and breathing rate increase, the limbs twitch, and the eyes move rapidly behind the closed eyelids, giving this phase its name of **rapid-eye-movement (REM) sleep.** The REM sleep phase occurs about every 1.5 hours while a healthy adult is sleeping, and lasts for 10 to 15 minutes. Sleepers do most of their dreaming during REM sleep, and most research subjects awakened from REM sleep report they were experiencing vivid dreams.

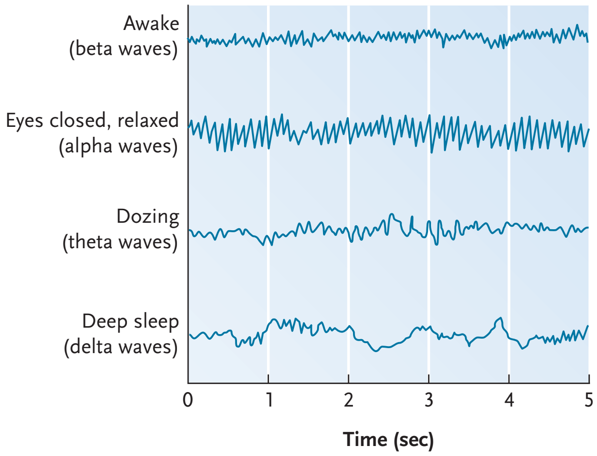


Figure 38.13
Brain waves characteristic of various states of consciousness.

As mentioned earlier, the reticular activating system controls the sleep-wake cycle. It sends signals to the spinal cord, cerebellum, and cerebral cortex, and receives signals from the same locations. The flow of

Unanswered Questions

What gives humans their unique brain capacity?

The human brain is larger relative to our body size than the brains of other mammals and has more functions. How did that come to be the case? At the simplest conceptual level, the answer must lie in the human genome. Researchers led by David Haussler of the University of California, Santa Cruz, have found evidence for unique human DNA that appears to play a central role in giving humans their unique brain capacity. Haussler's group compared the sequences of the human genome with the sequences of the genomes of other primates and other vertebrates. They looked for regions in the human genome that show significantly accelerated rates of base-pair changes since divergence from our common ancestor with the chimpanzee. The investigators found 49 such regions and dubbed them "human accelerated regions," or HARs.

One of the regions—*HAR1*—had dramatic changes that made it stand out from the rest. Haussler's group therefore focused on learning more about the region, looking specifically to see if it contained a gene and, if it did, what that gene encoded. Computer analysis of *HAR1* indicated the presence of what seemed to be a gene, and biochemical analysis confirmed that conclusion by detecting the presence of an RNA encoded by the gene. Interestingly the RNA is not an mRNA, meaning that the gene does not encode a protein. Rather, it is a structural RNA; that is, when it is expressed, it functions in the cell as an RNA. The researchers next investigated where and when the *HAR1* gene was expressed by looking for the RNA product in human embryonic brain tissue samples taken from different stages of development. The results showed that *HAR1* is expressed in a particular type of neuron in the developing human cerebral cortex at 7 to 19 weeks of development. That period of development is crucial for neuron specification in the cerebral cortex.

The researchers conclude that *HAR1* is a highly promising candidate for a gene involved in uniquely human biology. Work is now continuing to determine how the RNA encoded by *HAR1* functions in the cell. Does it interact with a protein, or with another RNA? How does it play a role in neuron specification in the developing cerebral cortex? As the project continues, the investigators hope to be able to use the mouse model to examine key aspects of *HAR1* function, because human experiments are not possible for ethical reasons. Haussler's group is also investigating other HARs to see what genes they might contain and what functions those genes might have in human brain development and function.

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signals along these circuits determines whether we are awake or asleep.

Many other animals also alternate periods of wakefulness and sleep or inactivity. Although sleep obviously has restorative effects on mental and physical functions, the physiological basis of these effects remains unknown.

In the previous chapter we learned about neurons, and in this chapter we have discussed the organization of neurons into nervous systems, as well as the structures of the brain and their functions. In the next chapter we consider the sensory systems that provide input for the brain to process.

STUDY BREAK

An aging person often experiences a progressive decline in cognitive function. This typically begins with short-term memory loss and the inability to learn new information. What brain changes might be occurring?

Review

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38.1 Invertebrate and Vertebrate Nervous Systems Compared

- The simplest nervous systems are the nerve nets of cnidarians. Echinoderms have modified nerve nets, with some neurons grouped into nerves (Figure 38.1a–b).
- Flatworms, arthropods, and mollusks have a simple central nervous system (CNS), consisting of ganglia in the head region (a brain), and a peripheral nervous system (PNS), consisting of nerves from the CNS to the rest of the body (Figure 38.1c–e).
- In vertebrates, the CNS consists of a large brain located in the head and a hollow spinal cord, and the PNS consists of all the nerves and ganglia connecting the CNS to the rest of the body (Figure 38.1f).
- In the vertebrate embryo, the anterior end of the hollow neural tube develops into the brain, and the rest develops into the spinal cord. The embryonic brain enlarges into the forebrain, midbrain, and hindbrain, which develop into the adult structures (Figure 38.2).

Animation: Comparisons of animal nervous systems

Animation: Bilateral nervous systems

Animation: Vertebrate nervous system divisions

38.2 The Peripheral Nervous System

- Afferent neurons in the PNS conduct signals to the CNS, and signals from the CNS travel via efferent neurons to the effectors—muscles and glands—that carry out responses (Figure 38.3).
- The somatic system of the PNS controls the skeletal muscles, producing voluntary body movements as well as involuntary muscle contractions that maintain balance, posture, and muscle tone.
- The autonomic system of the PNS, which controls involuntary functions, is organized into the sympathetic division and the parasympathetic division (Figure 38.4).

Animation: Autonomic nerves

38.3 The Central Nervous System (CNS) and Its Functions

- The spinal cord carries signals between the brain and the PNS. Its neuron circuits control reflex muscular movements and some autonomic reflexes (Figure 38.5).
- The medulla, pons, and midbrain form the brain stem, which connects the cerebrum, thalamus, and hypothalamus with the spinal cord.
- The cerebrum is divided into right and left cerebral hemispheres, which are connected by a thick band of nerve fibers, the corpus callosum. Each hemisphere consists of the cerebral cortex, a thin layer of gray matter, covering a thick core of white matter. Other collections of gray matter, the basal nuclei, are deep in the telencephalon (Figure 38.6).
- Cerebrospinal fluid provides nutrients and cushions the CNS (Figure 38.6). A blood-brain barrier allows only selected substances to enter the cerebrospinal fluid.
- Gray-matter centers in the pons and medulla control involuntary functions. Centers in the midbrain coordinate responses to visual and auditory sensory inputs.
- The reticular formation receives sensory inputs from all parts of the body and sends outputs to the cerebral cortex that help maintain balance, posture, and muscle tone. It also regulates states of wakefulness and sleep (Figure 38.8).
- The cerebellum integrates sensory inputs on the positions of muscles and joints, along with visual and auditory information, to coordinate body movements.
- The telencephalon's subcortical gray-matter centers control many functions. The thalamus receives, filters, and relays sensory and motor information to and from regions of the cerebral cortex. The hypothalamus regulates basic homeostatic functions of the body and contributes to the endocrine control of body functions. The basal nuclei affect the planning and fine-tuning of body movements (Figure 38.9).
- The limbic system includes parts of the thalamus, hypothalamus, and basal nuclei, as well as the amygdala and hippocampus. It controls emotions and influences the basic body functions controlled by the hypothalamus and brain stem (Figure 38.9).
- The primary somatosensory areas of the cerebral cortex register incoming information on touch, pain, temperature, and pressure from all parts of the body. In general, the right cerebral hemisphere receives sensory information from the left side of the body and vice versa (Figures 38.10 and 38.11).
- The primary motor areas control voluntary movements of skeletal muscles (Figures 38.10 and 38.11).
- The association areas integrate sensory information and formulate responses that are passed on to the primary motor areas. Wernicke's area integrates visual, auditory, and other sensory information into the comprehension of language; Broca's area coordinates movements of the lips, tongue, jaws, and other structures to produce the sounds of speech (Figure 38.10).
- Long-term memory and consciousness are equally distributed between the two cerebral hemispheres. Spoken and written language, abstract reasoning, and precise mathematical calculations are left hemisphere functions; nonverbal conceptualizing, mathematical estimation, intuitive thinking, spatial recognition,

and artistic and musical abilities are right hemisphere functions (Figure 38.12).

Animation: Organization of the spinal cord

Animation: Regions of the vertebrate brain

Animation: Human brain development

Animation: Sagittal view of a human brain

Animation: Primary motor cortex

Animation: Receiving and integrating areas

Animation: Path to visual cortex

38.4 Memory, Learning, and Consciousness

- Memory is the storage and retrieval of a sensory or motor experience or a thought. Short-term memory involves temporary storage of information, whereas long-term memory is essentially permanent.
- Learning involves modification of a response through comparisons made with information or experiences that are stored in memory.
- Consciousness is the awareness of ourselves, our identity, and our surroundings. It varies through states from full alertness to sleep and is controlled by the reticular activating system (Figure 38.13).

  Animation: Structures involved in memory

Questions

Self-Test Questions

1. Ganglia first became enlarged and fused into a lobed brain in the evolution of:
   a. vertebrates.
   b. annelids.
   c. flatworms.
   d. cephalopods.
   e. mammals.
2. The metencephalon develops into the:
   a. spinal cord.
   b. cerebellum.
   c. mesencephalon.
   d. medulla oblongata.
   e. cerebrum.
3. The autonomic nervous system is subdivided into:
   a. afferent and efferent systems.
   b. sympathetic and parasympathetic divisions.
   c. skeletal and smooth muscle innervations.
   d. voluntary and involuntary controls.
   e. peripheral and central systems.
4. People with severe insect-sting allergies carry an *epipen* containing medication that they can inject in an emergency. The medication causes smooth muscles in the lung passages to relax so they can breathe but causes their hearts to pound rapidly. This is an example of stimulation of the:
   a. parasympathetic system.
   b. sympathetic system.
   c. somatic nervous system.
   d. limbic system.
   e. voluntary system.
5. Which one of the following structures participates in a reflex?
   a. the gray matter of the brain
   b. the white matter of the brain
   c. the gray matter of the spinal cord
   d. an interneuron that stimulates an afferent neuron
   e. an interneuron that inhibits an afferent neuron
6. Which of the following statements about the blood-brain barrier is incorrect?
   a. It is formed of capillary walls composed of tight junctions.
   b. It transports glucose to brain cells by means of transport proteins.
   c. It allows alcohol to pass through its lipid bilayer.
   d. It moves oxygen through the lipid bilayer.
   e. It reduces blood supply to brain cells compared with other body cells.
7. A segment of the brain stem that coordinates spinal reflexes with higher brain centers and regulates breathing and wakefulness is the:
   a. reticular formation.
   b. white matter of the pons.
   c. white matter of the medulla.
   d. hypothalamus.
   e. cerebellum.
8. Cushioning and nourishing the brain and spinal cord and filling the ventricles of the brain is (are):
   a. meninges.
   b. myelin.
   c. cerebrospinal fluid.
   d. ganglia.
   e. astrocytes.
9. Which structure and function are correctly paired below?
   a. thalamus: relays emotion signals through the limbic system
   b. basal nuclei: relay inputs from odor receptors to the cerebrum
   c. hypothalamus: releases hormones; sets up daily rhythms
   d. amygdala: relays sensory information to the cerebrum
   e. olfactory bulbs: moderate motor centers in the cerebrum
10. A patient had a tumor in Wernicke's area. It was initially diagnosed when he could not:
    a. understand his morning newspaper.
    b. hear his child crying.
    c. see the traffic light turn red.
    d. speak.
    e. feel if the car heater was on.

Questions for Discussion

1. Meningitis is an inflammation of the meninges, the membranes that cover the brain and spinal cord. Diagnosis involves using a needle to obtain a sample of cerebrospinal fluid to analyze for signs of infection. Why analyze this fluid and not blood?
2. An accident victim arrives at the emergency room with severe damage to the reticular formation. Based on information in this chapter, describe some of the symptoms that the examining physician might discover.
3. In the 1930s and 1940s prefrontal lobotomy, in which neural connections in the frontal lobes of both cerebral hemispheres were severed, was used to treat behavioral conditions such as extreme anxiety and rebelliousness. Although the procedure calmed patients, it had side effects such as apathy and a seriously disrupted personality. In view of the information presented in this chapter, why do you think the operation had these effects?

Experimental Analysis

How would you demonstrate that gene activity in the brain altered with aging in mice?

Evolution Link

How do paleontologists contribute to our understanding of the evolution of the brain?