Organization of the Nervous System 4.1

Learning Objectives

- Describe the general role of the nervous and endocrine systems in human physiology
- List the three steps in forming a response to an environmental challenge
- Describe what is meant by "afferent" and "efferent" fibers
- List the major components of the central nervous system
- List the major components of the peripheral nervous system
- List the three meninges and describe their relative position in the CNS
- Identify the cerebrum and cerebellum of the brain
- Define gyrus and sulcus
- Identify the longitudinal fissure, central sulcus, and lateral fissure
- Identify the five lobes of the cerebrum
- Describe the composition of the cerebrospinal fluid
- List the ventricles and describe what they are
- Describe what is meant by the blood-brain barrier
- Describe white matter and gray matter
- Define the term "nucleus" when applied to the CNS
- Describe the term "tract"
- Identify the spinal cord, medulla, pons, and midbrain

THE NEUROENDOCRINE SYSTEM CONTROLS PHYSIOLOGICAL SYSTEMS

The organ systems of the body cooperate—work together—to make life possible. Cooperation requires coordination, the proper alignment of the physiological systems so that their cooperation produces homeostasis. The control systems are manifold. **The nervous system provides short-term and rapid control. The endocrine system provides long-term and steady control.** These two systems interact, and physiologists often speak of the neuroendocrine system to reflect the fact that both the nervous system and the endocrine system cooperate to control all other organ systems in the body.

This control system is extraordinarily complex and complicated. The brain itself occupies a volume of $\sim 1350\ cm^3$. Approximately 100 billion (10^{11}) neurons make connections to other neurons. Some neurons make only a few connections, whereas others may make many thousands. Approximately $10-100 \times 10^{12}$ contacts allow these neurons to communicate with each other. Somehow, this extraordinarily large number of contacts produces self-aware human behavior. In addition to all these neurons, about 10 times as many other cells play a supportive role and may also be involved in processing information. Many more neurons reside outside the central nervous system (CNS), in the periphery.

A CENTRAL TENET OF PHYSIOLOGICAL PSYCHOLOGY IS THAT NEURAL PROCESSES *COMPLETELY* EXPLAIN ALL BEHAVIOR

"Behavior" is the way a person or thing acts, especially in response to some outside influence. Because this behavior involves action, it is readily observable. It includes gross and fine body movements intended to accomplish a task, spoken language, and nonverbal modes of communication. In addition, humans exhibit a wide range of **affective behaviors**, relating to emotions, and **cognitive behaviors**, relating to thinking. What causes all of these internal and external behaviors?

Aristotle (384–322 BC) hypothesized that the mind is responsible for behavior. To Aristotle, the mind was not a material entity. The mind perceived, imagined, thought, emoted, desired, felt pain, reasoned, and remembered. The philosophy in which the mind controls behavior is called **mentalism**. Although science denies the controlling presence of a nonmaterial entity, we still use mentalist terms such as perception, imagination, emotion, motivation, memory, attention, and reason. Aristotle's ideas went largely unchallenged until the Renaissance. René Descartes (1596–1650) wrote a book, *Treatise on Man*, in which he tried to explain how the mind might be united to the body. In his view, the interface between mind and body was the brain. Descartes postulated that sensory information traveled from the skin, for example, to the brain. The mind then learned of our sensations through the brain. The mind could command action, but it did so through actions on the brain that were then conveyed to the muscles. Descartes sought to explain everything in terms of a machine analogy. He thought that the operation of all things, however complex, could be explained by some

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mechanism. He postulated hydraulics analogies to explain sensation: touching an object produces a pressure which squirts fluid along nerves into the brain. The fluid then enters fluid-filled cavities called **ventricles** and is sensed there by the mind. Descartes posited that the mind resided in the **pineal body**, a small bit of tissue located in the center of the brain besides one of the ventricles. On the output side, the pineal gland directed fluid from the ventricles down other nerves to activate muscles. The philosophical doctrine that the body is controlled by two entities, a mind and a brain, is called **dualism**. This left Descartes with a formidable problem: how could a nonmaterial entity interact with a material brain? This has been called the **mind—body problem**.

Besides writing *On The Origin of Species* in 1858, Charles Darwin (1809—1892) wrote another book entitled *On the Expression of the Emotions in Man and Animals*. Darwin's *Origin of Species* sought to explain the origin of the tremendous variety of animals and plants that are now present in the world by **natural selection** working on variations among members of a species already present in the population. Although Darwin had no mechanism to explain natural selection, because genes had not yet been identified, he forcibly argued from an amazing detail of information that evolution produced different species, and that the hallmark of the different species was a different character of body. The brain is part of the body, and so it is reasonable to suppose that evolution also changes the brain. In his second book, *On the Expression of the Emotions in Man and Animals*, Darwin argued that expressions of emotions are like physical attributes of the body: they are subject to evolution. This idea is still controversial today. How much of our behavior is **"hard-wired"** as opposed to **plastic**? Here "plastic" refers to the ability to change behavior based on past experiences or new inputs. Darwin's ideas implied that **the brain causes behavior**. This idea is now so well established that it is a central tenet of neuroscience: behavior arises from neural function *alone*. This idea is called **materialism**.

THE NEW MIND—BODY PROBLEM IS HOW CONSCIOUSNESS ARISES FROM A MATERIAL BRAIN

We all have subjective experiences of consciousness and of self. You are an individual distinct from other human beings, with distinguishable internal feelings and perceptions. What exactly is it in you that sees, hears, or is conscious? Because of overwhelming evidence that specific deficits in brain function produce specific deficits in mental function, we have come to believe that the brain somehow produces this mystical thing that is conscious and self-aware. This thing is not material in the ordinary sense of the word, just like an idea is not a material thing. The new mind—body problem is the inverse of Descartes' mind—body problem: how can a material thing (the brain) produce the nonmaterial thing that we identify as "self"? We can call this the mind and be in reasonable agreement with other notions of the mind. We cannot answer these questions here. These ideas are presented here so that the student can understand the ultimate goal of neuroscience: explain all behavior, including the subjective experience of consciousness and self-awareness. Although these are extremely important questions, most physiologists take a narrower aim of explaining how the nervous system integrates bodily functions, and not mental ones.

EXTERNAL BEHAVIORAL RESPONSES REQUIRE SENSORS, INTERNAL PROCESSES, AND MOTOR RESPONSE

Responding to changes in the external environment has three components:

1. appraisal of environmental conditions;
2. deciding the behavioral response;
3. activating the behavior.

These three components of a behavioral response correspond roughly to three identifiable branches of the nervous system.

THE APPRAISAL OF ENVIRONMENTAL CONDITIONS IS ACHIEVED THROUGH THE USE OF THE SENSES

The senses consist of the five classical senses: vision, hearing, taste, smell, and touch, but they include other senses such as balance, pain, temperature, pressure, and joint position. The "environment" that we sense includes the internal environment as well as the external environment. Thus, we have a sensation of hunger that results directly from our internal environment and indirectly from the external environment. Our internal environment includes the orientation of our body parts in the external environment, which is sensed by a combination of vision, balance, and proprioceptive sensors that apprise us of the location of our joints.

"DECIDING" THE BEHAVIORAL RESPONSE IS ACHIEVED THROUGH INTEGRATIVE CENTERS OF THE CNS

Once the environmental conditions have been sensed, the appropriate behavioral response must be engaged. Higher centers of the CNS determine the appropriate response. **Afferent** fibers bring sensory information from the periphery toward an appropriate processing station. This information is in the form of action potentials and, in general, its **intensity** is encoded by the **number of sensory cells** that are activated and by the **frequency of action potentials** generated by these cells. The **quality** of the sensory information is encoded by the type of sensory cell that fires and from the connections that this sensory cell makes in the brain. The information of the types of sensory cells firing and their intensity is integrated by the higher centers, which then initiate a response.

BEHAVIOR IS BROUGHT ABOUT BY EFFERENT FIBERS ACTIVATING EFFECTOR CELLS

The higher centers initiate a response by activating **efferent** fibers that bring information away from the CNS toward effector cells. In many cases, these effector cells are motoneurons that subsequently activate muscles, causing us to move. Responses to changes in our environment could include increased secretion of hormones as would occur upon perception of danger, or it might include modulation of digestion or any of a host of other responses.

THE NERVOUS SYSTEM IS DIVIDED INTO THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM

The nervous system is broken down into anatomically and functionally discrete elements. The two main divisions are the **central nervous system** and the **peripheral nervous system.**

The **CNS** consists of the **brain** and the **spinal cord**. This part of the nervous system is encased in bone for protection. The brain is surrounded by the bones of the cranium and the spinal cord is surrounded and protected by the vertebrae.

The afferent fibers leading to the CNS and efferent fibers leading away from the CNS comprise the **peripheral nervous system**. The sensory afferent nerve fibers that bring sensory information from the periphery to the CNS constitute the incoming arm of the peripheral nervous system. The outgoing, or efferent arm, is the other half. The peripheral nervous system is further subdivided into:

A. the somatic sensory system, consisting of sensory afferent fibers;
B. the somatic motor system, consisting of motor efferent fibers;
C. the autonomic nervous system, consisting of both afferent and efferent fibers.

The autonomic nervous system is further subdivided into a **sympathetic** and **parasympathetic** system. These divisions are distinguished on the basis of the anatomical location, the types of neurotransmitters, and their effects on the function of their innervated tissues. The autonomic nervous system controls cardiac muscle, smooth muscle, exocrine glands and some endocrine glands, and adipose tissue. The sympathetic nervous system typically prepares the body for emergency action, whereas the parasympathetic system promotes ordinary activity such as digestion. A third division of the autonomic nervous system is the **enteric nervous system**. The enteric nervous system is a network of neurons in the walls of the digestive tract. This system includes sensors in the lining of the tract; **ganglia**, or collections of neurons that integrate the responses; and cells that engage effector cells. Information flows between the enteric nervous system and the CNS, but the enteric nervous system can also function on its own. The basic organization of the nervous system is shown schematically in Figure 4.1.1.

THE BRAIN HAS READILY IDENTIFIABLE SURFACE FEATURES

The brain is covered by tough connective tissue called **meninges**, a three-layered structure that protects the brain from physical damage. The outermost layer is the **dura mater**, which derives from the latin for "hard mother." The dura mater covers the entire CNS in a loose sack. The middle layer is the **arachnoid**, from the Greek meaning "spider-like." This is a delicate sheet that follows the brain's contours and processes a fluid, the **cerebrospinal fluid (CSF)**, that bathes the entire CNS. Immediately apposed to the brain's surface is the **pia mater**, which means "soft mother." The CSF fills the space between the arachnoid and the pia mater. The CSF provides a cushion for the brain and allows the brain to move a little within the cranium.

The most obvious anatomical feature of the brain is its gross bilateral symmetry. A plane drawn perpendicular to the face and passing through the midline reveals a bilateral symmetry to the entire body. Such a plane is called the **midsaggital plane** and any section taken parallel to it is called a **saggital section**.

Looking at the brain from the top or the side, the two largest structures are the **cerebrum** and the **cerebellum**. From the top, the cerebrum is divided into left and right **hemispheres**. These two halves of the brain are separated by a **longitudinal fissure**. This fissure does not penetrate all the way through the brain. The two halves are connected anatomically and functionally through **commissures** that transfer information between the two hemispheres. Much of the information flows between the two hemispheres through a structure called the **corpus callosum**. The commissures are internal to the brain and cannot be seen from its surface.

The cerebellum is a bilaterally symmetrical structure at the back of and underneath the cerebrum. It lies adjacent and posterior to the **brain stem**. The cerebellum helps coordinate complicated motor movements. Both the cerebrum and the cerebellum consist of a fairly thin sheet of tissue, the **cortex**, which is folded so that it can fit into the skull. This allows for an increased area of cortex for each of these important structures. The folds produce bumps and cracks on the surface. A bump is called a **gyrus** and the crack or valley between adjacent bumps is called a **sulcus**. The **central sulcus** divides the front of the brain from its rear. The plural of these structures are **gyri** and **sulci**. Some of the sulci are deep and long and are called fissures. The **longitudinal fissure** divides the cerebrum into right and left hemispheres. The **lateral fissure,** also called the **Sylvian sulcus**, separates some of the lobes of the cerebrum, as shown in Figure 4.1.2 (lateral view).

The cerebrum is the main portion of the brain that is visible from its exterior. It is a convoluted structure that consists of four lobes named for the cranial bones under which they lie and another lobe buried beneath these. The four surface lobes are the **frontal lobe**, at the anterior of the brain; the **temporal lobe**, on the lateral surfaces beneath the temporal bone; the **parietal lobe**,

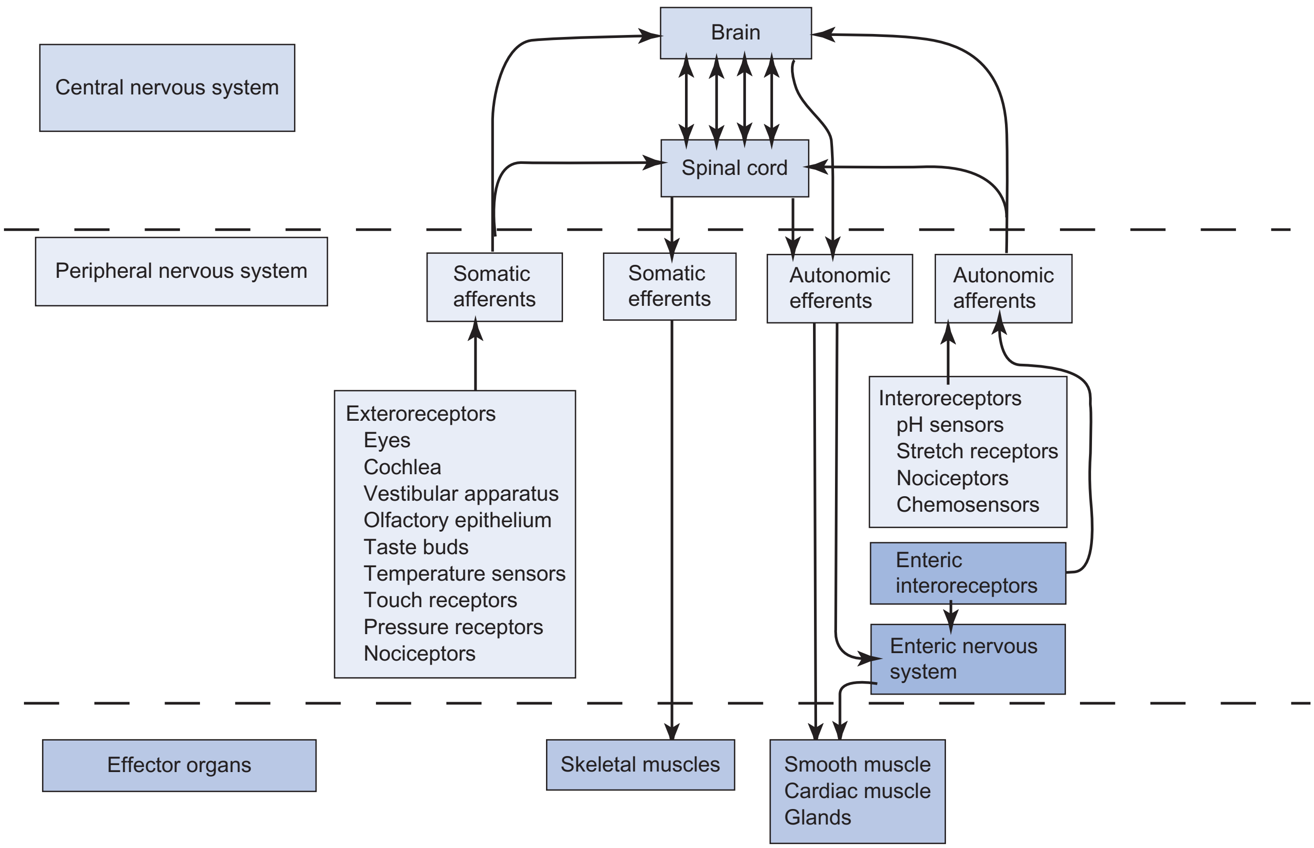

FIGURE 4.1.1 General organizational scheme of the nervous system. A variety of sensors, both internal and external, transmit information to the CNS by somatic or autonomic afferents. The CNS consists of the brain and spinal cord. These process the sensory information and initiate responses that travel to effector organs over somatic or autonomic efferent pathways. The enteric nervous system communicates with the CNS, but it can also function on its own by receiving sensory information, processing it, and initiating responses locally. The peripheral nervous system consists of afferent and efferent fibers and the ganglia that exist outside of the CNS.

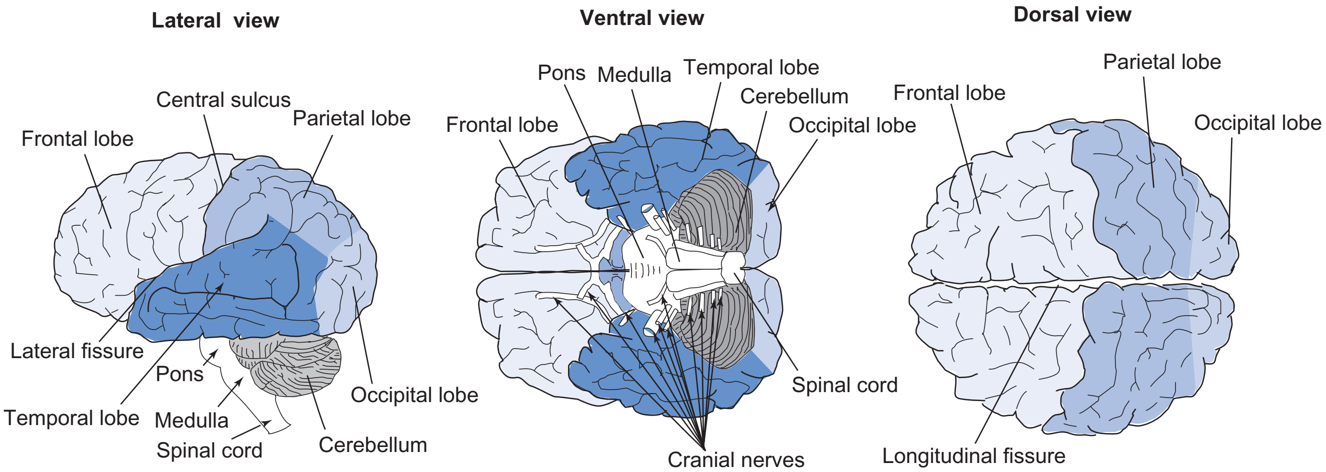

FIGURE 4.1.2 Gross anatomical surface features of the brain. The top and side views show the arrangement of the four lobes of the cerebrum: the frontal, temporal, parietal, and occipital. The cerebellum is a crinkled structure at the back of and underneath the cerebrum, just dorsal to the brain stem. The ventral view shows the cranial nerves I–XII.

at the top of the brain; and the **occipital lobe**, at the posterior surface of the cerebrum. The **insular lobe** can be seen by opening the Sylvian sulcus.

Parts of each of these lobes are dedicated to specific functions. The **frontal lobe** is important in foresight and planning and is important in motor tasks. As discussed in Chapter 4.4, the primary motor cortex is located in the frontal lobe immediately forward of the central sulcus. The premotor and supplementary motor cortexes are located adjacent to the primary cortex in the frontal lobe. These areas are essential for the proper planning of motor tasks. The frontal lobe contains **Broca's area**, in the inferior frontal gyrus, usually in the left hemisphere.

TABLE 4.1.1 Names and Main Function of the Cranial Nerves

Cranial Nerve	Common Name	Function	Cranial Nerve	Common Name	Function
I	Olfactory nerve	Smell	VII	Facial	Motor to face; taste at front of tongue
II	Optic nerve	Vision	VIII	Vestibulocochlear	Sound, rotation, and gravity
III	Oculomotor nerve	Muscles of the eye	IX	Glossopharyngeal nerve	Taste at back of tongue; salivary secretion; blood pressure and gas sense
IV	Trochlear nerve	Superior oblique eye muscle	X	Vagus	Autonomic afferent and efferents
V	Trigeminal nerve	Chewing muscles; sensory from the face	XI	Spinal accessory	Motor to sternocleidomastoid, trapezius
VI	Abducens	Lateral rectus eye muscle	XII	Hypoglossal nerve	Motor for the tongue

Damage to it causes **expressive aphasia**, the inability to form coherent speech.

The **parietal lobe** contains the somatosensory cortex and the sensory association cortex in which a variety of sensory information is processed and integrated to form a coherent model of the body's position in the world in order to plan motor activities. Visual information, balance, and proprioceptive (body sense) information all mingle here. The parietal lobe contains **Wernicke's area**, which is involved in the understanding of speech. Damage to this area causes **receptive aphasia**, in which the person cannot understand speech.

The main function of the **occipital lobe** is to process visual information. Some processing occurs in the retina itself and in the lateral geniculate nucleus, but the visual cortex in the occipital lobe is responsible for generating conscious awareness and identification of objects in the visual field.

If we turn the brain over and look at it from the bottom, we see the bottom parts of the cerebrum—the temporal lobe, frontal lobe, and occipital lobe—and the cerebellum, and we also see a whitish structure in the center, leading toward the posterior or back of the brain. Attached to this structure are a number of what look a little like white wires. These are the **cranial nerves**. The whitish structure itself is the **brain stem**. It has a number of parts. In this view (Figure 4.1.2, ventral view) the most obvious parts of the brain stem are the pons and the medulla. A synopsis of the functions of the cranial nerves is shown in Table 4.1.1.

CSF FILLS THE VENTRICLES AND CUSHIONS THE BRAIN

Transverse slices of the brain reveal hollow spaces called **ventricles**. The ventricles include two **lateral ventricles**, a **third ventricle**, and a **fourth ventricle**. All of these are filled with **CSF**. Channels connect all of the ventricles. The lateral ventricles are connected to the third ventricle by an **interventricular foramen**, and the third ventricle connects to the fourth through the **cerebral aqueduct** (also called the aqueduct of Sylvius). CSF can leave the fourth ventricle through apertures on its lateral and medial surfaces (the **lateral and median apertures**, respectively). CSF leaving through these apertures can circulate through the subarachnoid spaces surrounding the brain and spinal cord. The location of these four ventricles and the circulation of CSF is shown schematically in Figure 4.1.3.

The CSF cushions the brain and spinal cord against mechanical shock. In addition, the extracellular fluid (ECF) of the brain is in direct contact with the CSF, so CSF composition dictates brain ECF composition. Table 4.1.2 shows the composition of the CSF in comparison to that of plasma. The CSF lacks the high protein content of the plasma, and so its osmolarity is balanced by increased concentrations of Na^+ and Cl^- ions. Its density is almost the same as brain tissue, so that the brain nearly floats in this fluid. This gives rise to the phenomenon of **countrecoup.** Blows to the head accelerate the skull which transmits the force to the CSF directly beneath it, which simultaneously transmits force to the brain tissue because of the incompressibility of the fluid. On the opposite side, however, the skull pulls away from the fluid, creating a momentary partial vacuum. When the skull is no longer accelerated by the blow, the vacuum collapses and the brain smashes into the skull on the side opposite to the original blow.

Specialized structures called **choroid plexuses** produce the CSF. These structures consist of specialized blood supplies covered with specialized **ependymal cells** that form a continuous layer separating CSF from the blood. The choroid plexus projects into the temporal horn of each lateral ventricle, the posterior portion of the third ventricle, and the roof of the fourth ventricle. These cells make about 0.35 mL of CSF each minute, or about 500 mL per day. A corresponding amount is reabsorbed daily by **arachnoid villi**, which are specialized finger-like projections of the arachnoid membrane into the venous sinuses. The ventricles contain about 35 mL of CSF, while the brain and spinal cord contain about 100 mL. Thus the CSF turns over 3–4 times per day ($500\ mL\ day^{-1}/135\ mL$). The circulation of the CSF is shown in Figure 4.1.3.

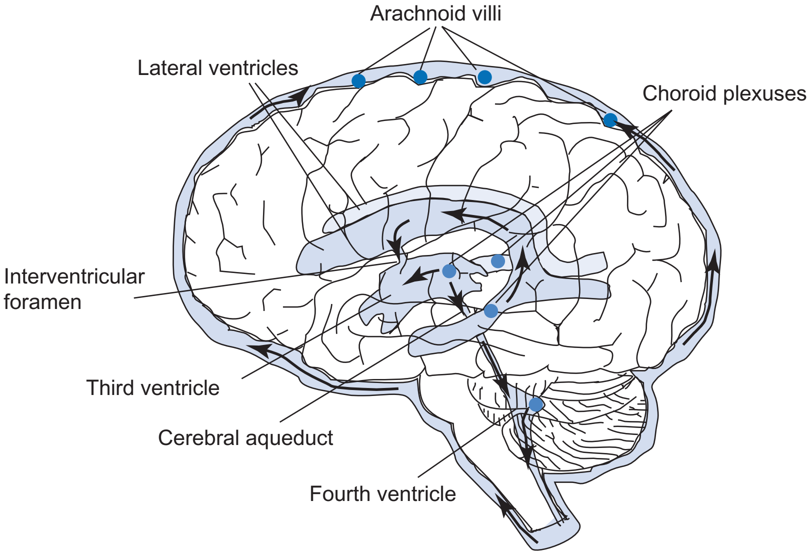

FIGURE 4.1.3 The four ventricles of the brain and circulation of the CSF. Two lateral ventricles have a complicated shape, being continuous with a portion above and another portion below and lateral to the third ventricle, which is centered on the midline. The fourth ventricle is below the third, immediately ventral to the cerebellum. The choroid plexuses, within the ventricles, produce CSF from blood. The CSF circulates between the ventricles through canals. The lateral ventricles communicate with the third ventricle through the interventricular foramen (foramen of Monro); the third and fourth ventricles communicate through the cerebral aqueduct and the fourth ventricle communicates with the spinal fluid in the arachnoid space through two lateral apertures (foramen of Luschka) and a median aperture (foramen of Magendie), not shown.

TABLE 4.1.2 Constituents of CSF Compared to Plasma

Constituent	Lumbar CSF	Plasma
Na^+	148 mM	142 mM
K^+	3 mM	4 mM
Cl^-	125 mM	105 mM
Glucose	50–75 mg/dL	70–100 mg/dL
Protein	15–45 mg/dL	$6–8 \times 10^3$ mg/dL
pH	7.3	7.4

The rate of CSF production is nearly independent of its pressure, whereas the absorption of CSF increases directly with CSF pressure. This results in CSF pressure of about 10–15 mmHg. This is extremely important because the skull presents an incompressible limit to the contents of the cranium. Increases in CSF fluid volume must be paid by decreases in the volume of nervous tissue. Cerebral hemorrhage, for example, causes a rapid rise in intracranial pressure, with subsequent reduction of blood flow, impairment of oxygen delivery, and subsequent rapid deterioration of brain function. For this reason, head trauma patients are monitored carefully for increases in CSF pressure.

THE BLOOD-BRAIN BARRIER PROTECTS THE BRAIN

The endothelial cells of the brain capillaries are joined tightly together, rather than having slit pores or being fenestrated as in the microcirculation of other vascular beds (see Chapter 5.10). This arrangement forms a continuous cellular layer between the blood and the brain ECF, forming a blood-brain barrier. This barrier also exists between the blood and the CSF. The blood-brain barrier is highly permeable to oxygen, CO_2, water, and most lipid-soluble materials such as anesthetics and alcohol. It is slightly permeable to plasma electrolytes but it is impermeable to plasma proteins and a variety of other materials. The cells that line the surfaces of the ventricles, however, are permeable to most materials. Thus, drugs that cannot cross the blood-brain barrier, and thus are ineffective when administered through the blood, can be effective when administered directly into the CSF (Figure 4.1.4).

CROSS SECTIONS OF THE BRAIN AND STAINING REVEAL INTERNAL STRUCTURES

A frontal section of the brain (a section along a plane parallel to the face or front of the body) at about the middle of the brain reveals a number of structures as shown in Figure 4.1.5.

The frontal section shown in Figure 4.1.5 shows readily identifiable differences in the gross appearance of different regions. Some areas appear grayer (shown in dark blue in Figure 4.1.5) because of their greater concentration of cell bodies with their attendant nuclei and synthetic machinery. The white areas (shown in light blue in Figure 4.1.5) owe their appearance to the many neuronal processes, the axons, that are encased with myelin. The myelin consists of many wrappings of the cell membranes of supportive cells and thus contains a large proportion of phospholipids. These produce the white appearance of these areas. These areas are accordingly called **gray matter** and **white matter.** Some areas of the brain have a mottled gray and white appearance, and these areas are called **reticular matter** (from the latin "rete" meaning "network"). As shown in Figure 4.1.5, gray areas have more or less the same locations and extents in different individuals and these conglomerations of cells also serve the same functions. These areas are called **nuclei** and are given specific names. In some cases, functional areas were discovered by their response to ablation (surgical or electrical destruction of the area) or excitation. In these cases the functional areas are also given specific names. There are a large number of named nuclei which serve well-defined functions. These will be introduced during discussions of their functions.

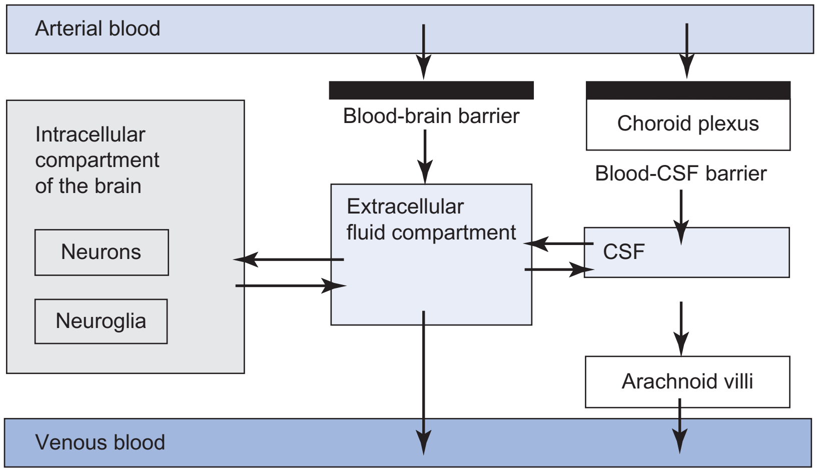

FIGURE 4.1.4 Fluid transfer between blood and brain ECF and CSF. The ECF of the brain is tightly sealed from the blood so that only permeable materials are transferred to the brain's ECF. This excludes most large molecular materials such as plasma proteins. The CSF is similarly insulated from the blood. The blood-brain barrier and the blood-CSF barrier can sometimes determine the efficacy of drugs targeted to the brain. There is ready and easy transfer between brain ECF and CSF so that drugs administered into the CSF have ready access to the target neurons.

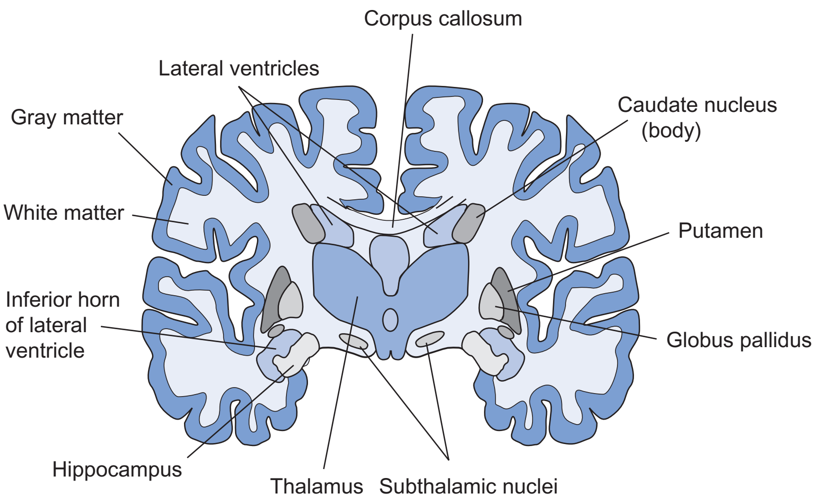

FIGURE 4.1.5 Frontal section of the brain reveals areas distinguishable to the unaided eye. The cortex, or area of the brain next to the surface, appears darker because it contains mostly cell bodies with their darker nuclei. These darker areas are called the "gray matter." Other areas that contain a concentration of cell bodies are called nuclei, and some are shown here. The basal ganglia consist of the caudate nucleus, the putamen, and the globus pallidus. Together with the thalamus, the subthalamic nuclei, and the substantia nigra, the basal ganglia help control movement. The substantia nigra is located in the midbrain. Many other areas can be identified by other sections.

Cell bodies are collected into specialized areas called nuclei and their processes are often collected into **tracts**. These tracts become evident only when many nerve processes (axons) are traveling together toward similar locations. They are evident in the spinal cord, where sensory inputs travel up the cord and efferent fibers travel down the cord, and in the brain itself. The corpus callosum is a large tract that contains some 200 million nerve fibers that transmit information from one hemisphere to the other.

GRAY MATTER IS ORGANIZED INTO LAYERS

The cerebral cortex lies beneath the pia mater and covers the surface of most of the brain, as viewed from the top. It contains many folds, or gyri, as shown in Figure 4.1.5. The cerebral cortex consists of two parts: the **neocortex** and the **limbic cortex**. The neocortex covers most of the surface of the cerebrum as viewed from outside the brain. The limbic cortex covers the **cingulate gyrus**, the fold of the cerebrum immediately adjacent to the longitudinal fissure above the corpus callosum (see Figure 4.1.7). Both of these are organized further into layers. The neocortex is organized into six layers of cells, whereas the limbic cortex is organized into four layers. Each of these is involved in specialized functions such as (a) the input of sensory information, (b) integration of inputs, and (c) outputs to other parts of the brain or efferent pathways. In the same way, neurons within the gray matter of the spinal cord are organized in **laminae**, or layers.

OVERALL FUNCTION OF THE NERVOUS SYSTEM DERIVES FROM ITS COMPONENT CELLS

The function of the nervous system is to command and coordinate responses of the body to change in environmental conditions, either internal or external. It is axiomatic that this response arises somehow from the myriad events occurring in the individual cells within the nervous system. We become apprised of changes in the environmental conditions: first by sensory cells that directly sense these changes; second by the cells that receive inputs from these sensory cells. This information must be integrated along with other signals to select the appropriate response. In the end, effector organs are activated, again by collections of single neurons, but the choice of which neurons and their timing is the result

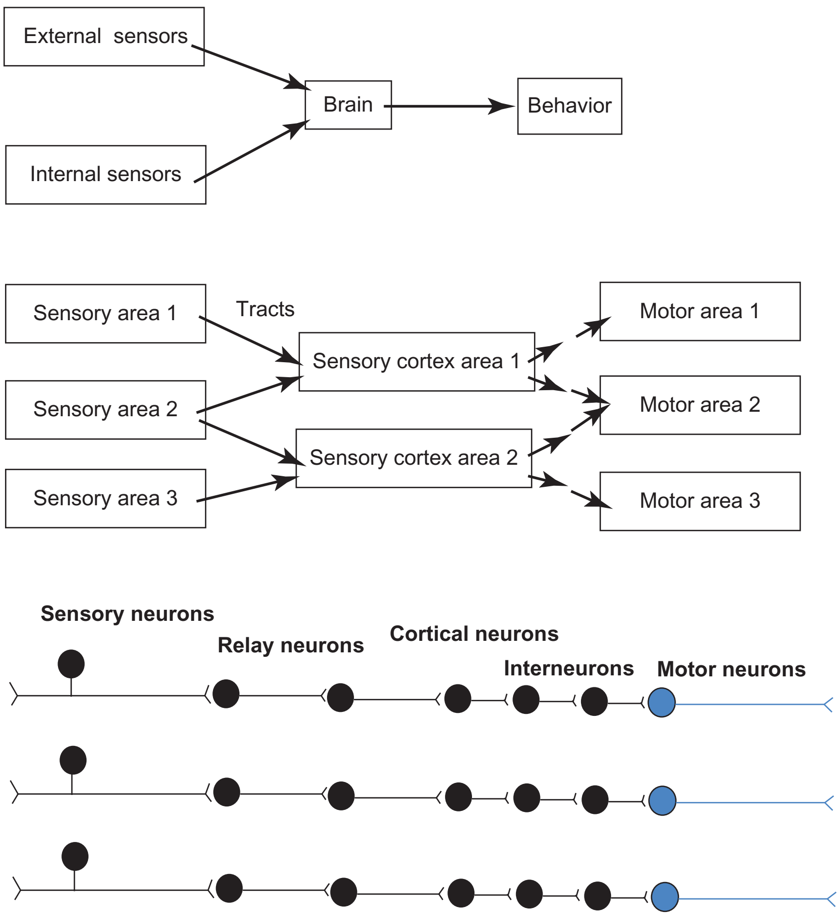

FIGURE 4.1.6 Different levels of organization in the nervous system. The brain mediates our behavior after being apprised of changes in either our internal or external world. This mediation can be viewed from the nuclei level of organization, in which the activity of many neurons is simultaneously modified. All of the activity, of course, also occurs at the cellular level. It is an axiom of neurophysiology that all behavior derives from the activity of neurons. How this activity "summates" to produce conscious behavior is a difficult and still largely unsolved problem.

of central processing. This entire process can be looked at on at least three levels of organization, as shown in Figure 4.1.6. The brain level simply indicates that the brain somehow produces our behavior when information of our external or internal world reaches it. The second level, the nuclei level, indicates that information flows between populations of neurons that comprise relatively large parts of the brain. The third level, the neuron level, indicates that all of these processes occurring on these grand scales arise from the individual events that occur between nerve cells.

OVERVIEW OF THE FUNCTIONS OF SOME MAJOR AREAS OF THE CNS

THE FOREBRAIN *CONSISTS OF THE* CEREBRAL CORTEX, BASAL GANGLIA, *AND THE* LIMBIC SYSTEM

The cerebral cortex is the convoluted surface that is visible from the outside of the brain (Figure 4.1.2) and consists of four external lobes: the frontal, temporal, parietal, and occipital lobes. The insular lobe lies beneath these. Each hemisphere has each of these five lobes. The cerebral cortex forms a neural map of the world that integrates external sensors with internal ones so that the body can be placed in this map to plan motor tasks. The external surface of the body maps onto the cortex so that adjacent areas on the surface of the body are processed in adjacent areas of the cortex. This is true of both sensory inputs and motor outputs. In addition, there are topographic projections of "visual space" and "auditory space" onto the cortex. Areas of the cortex are designated as **primary**, **secondary**, or **tertiary** depending on their role in sensory perception or motor control.

The basal ganglia include the **putamen**, **globus pallidus**, and **caudate** nuclei (Figure 4.1.5). These are located deep within the forebrain just below the white matter of the cortex. These structures receive inputs from all lobes of the cerebral cortex and send connections to the prefrontal and premotor cortices by way of the thalamus. The basal ganglia assist in movement and suppress useless and unwanted movements. They also inhibit muscle tone throughout the body.

The limbic system includes the **amygdala**, the **hippocampus**, **cingulate gyrus**, **corpus callosum**, and **fornix.** The cingulate gyrus lies just above the corpus callosum and immediately adjacent to the longitudinal fissure. The amygdala and hippocampus are regions of the cortex buried in the temporal lobe adjacent to the floor of the third ventricle and lateral to it. This complex of forebrain structures plays important roles in the emotions and sociosexual behavior. However, the limbic system has multiple functions and is important in motivation and memory formation as well.

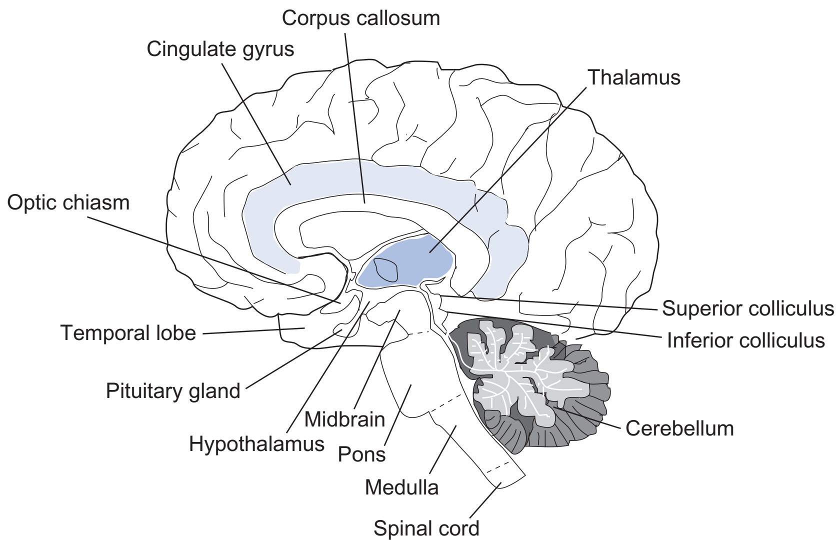

FIGURE 4.1.7 Midsaggital section of the brain and brain stem. The plane of section is parallel to the longitudinal fissure, perpendicular to the face.

THE DIENCEPHALON OR "BETWEEN BRAIN" INCLUDES THE THALAMUS *AND* HYPOTHALAMUS

The thalamus physically occupies a central position between the brain stem and the forebrain. It is an important relay point for information going both ways. The thalamus contains about 20 nuclei. Many of these relay sensory information to the cerebral cortex. Other regions are engaged in motor functions whereas still others are involved with attention and memory.

The hypothalamus derives its name from its location immediately below the thalamus. It regulates a wide variety of homeostatic functions including (a) thirst; (b) urine output; (c) food intake; (d) body temperature; and (e) hormone secretion. The hypothalamus coordinates the autonomic functions of the body, partly through nerve activity and partly through hormonal activity.

THE BRAIN STEM CONSISTS OF THE MIDBRAIN, PONS, *AND* MEDULLA OBLONGATA

The midbrain lies above the pons and is divided into two parts: the **tectum** and the **tegmentum**. The tectum receives input from the eyes and the ears to the **superior colliculus** and **inferior colliculus**, which together make up the tectum. These structures allow us to simultaneously process visual and auditory stimuli to search for the source of a sound, for example. The tegmentum lies below the tectum and consists of a number of nuclei that are involved in controlling eye and limb movements.

The pons lies ventral to the cerebellum and superior to the medulla, as shown in Figure 4.1.7. Areas of the pons, together with centers in the medulla, help regulate breathing. The pons also relays information from the cerebral cortex to the cerebellum.

The medulla is the rostral (toward the nose) extension of the spinal cord. It contains centers that regulate blood pressure and breathing and also helps coordinate swallowing, coughing, and vomiting.

THE HINDBRAIN CONSISTS OF THE BRAIN STEM AND THE CEREBELLUM

The cerebellum is the large structure lying beneath the occipital lobe and behind (dorsal to) the pons and medulla. It coordinates complex movements, and helps maintain posture and coordination of head and eye movements. The cerebellum integrates proprioceptive inputs from the spinal cord, motor control input from the cerebral cortex, and inputs about balance from the vestibular apparatus of the inner ear.

THE SPINAL NERVES AND CRANIAL NERVES CONNECT THE CNS TO THE PERIPHERY

The spinal cord extends from the base of the skull down to the sacrum. It is encased in a protective bony case, the spine, to which afferent sensory nerves arrive and efferent effector nerves leave. Tracts of axons travel in both directions up and down the cord to coordinate activities from the CNS to the periphery.

SUMMARY

The neuroendocrine system controls the entire spectrum of human behavior including our fine and gross motor movements, language, affective behavior (relating to the emotions) and cognitive behavior (relating to thinking), and sociosexual function and behavior. The nervous system provides short-term and rapid control whereas the endocrine system provides long-term and steady control. The two systems of control interact extensively, yet they differ in anatomic location and mechanisms of action.

The nervous system is broken down into two major divisions: the central nervous system (CNS) and the peripheral nervous system. The CNS consists of the brain and spinal cord. The peripheral nervous system in turn consists of three parts: the somatic sensory system, the somatic motor system, and the autonomic system. The somatic sensory system is made up of sensors that feed information to the CNS along afferent fibers. These

include all of the exteroreceptors, which include sight, touch, taste, hearing, balance, smell, temperature, and pain. The somatic motor system activates skeletal muscles through motor efferent fibers. The autonomic system itself consists of three parts: the sympathetic nervous system, the parasympathetic nervous system, and the enteric nervous system. The autonomic nervous system responds to sensory information about the internal state of the body, for which there are a number of interoreceptors that respond to pH and other chemicals, pain, and stretch. The autonomic nervous system also responds to higher CNS functions such as emotion and mood. The enteric nervous system interfaces with the autonomic nervous system but it can also function independently. Autonomic efferent fibers bring commands to effector organs such as the heart, smooth muscles, and glands.

The fragile parts of the CNS are encased in bone and three membranes, the meninges: the dura mater, arachnoid mater, and pia mater. It is also bathed in the CSF. The CSF fills the four ventricles: two lateral ventricles and the third and fourth ventricle. The CSF is made by the choroid plexuses located in each of the ventricles, and it is absorbed by arachnoid villi. The ventricles are connected by canals called the intraventricular foramina, the cerebral aqueduct, and lateral and medial foramina connecting the fourth ventricle with the spinal fluid. Many blood-borne materials cannot cross the blood-brain barrier because the capillaries are tightly lined with cells.

The brain consists of many parts. From its surface, it appears to be bilaterally symmetrical. A longitudinal fissure separates the left and right hemispheres, but the fissure penetrates only as far as the corpus callosum, a large collection of nerve fibers that communicates information between the two hemispheres. Four lobes of the cerebrum are visible from the surface: the frontal, temporal, parietal, and occipital lobes. The insular lobe is buried and can be seen by opening the lateral fissure, or Sylvian sulcus. The cerebrum folds into bumps (gyri) and valleys (sulci), each of which are devoted to specific functions and which have names. Also visible on the surface of the brain is the cerebellum at the back of and underneath the occipital lobe, part of the brain stem, and the cranial nerves.

Brain tissues consist of gray matter, white matter, and reticular matter. The gray matter appears gray on gross inspection because of a concentration of cell bodies with their nuclei. The white matter contains a preponderance of nerve fibers with high fat content. Reticular matter appears mottled. Collections of cell bodies in the deeper parts of the brain are named and generally serve specific functions. Axons often follow specific tracts in which many axons originate from one nucleus and travel to another. The gray matter itself is organized into layers.

The forebrain consists of the cerebrum, basal ganglia, and limbic system. The "between brain" consists of the thalamus and hypothalamus, and the hindbrain consists of the midbrain, pons medulla, and cerebellum. The spinal cord begins at the end of the medulla.

REVIEW QUESTIONS

1. The central sulcus separates which lobes of the cerebrum? The longitudinal fissure separates which lobes of the cerebrum? Name the five lobes of the cerebrum and identify them in a drawing of the brain.
2. What are the meninges?
3. What is gray matter? White matter? What is a nucleus (in neurophysiological terms)? What is a tract?
4. What are the ventricles? Name them. What is the composition of the CSF? Where is it made? Where is it resorbed? What is normal CSF pressure? Why is this important?
5. What is the blood-brain barrier?
6. What makes up the CNS? Name the major parts of the forebrain, diencephalon, and hindbrain.
7. How is information conveyed between right and left hemispheres?