



(d)

FIGURE 7.11 (continued) (d) Photo of a physician testing the patellar (knee jerk) reflex.

The simple *patellar* (pah-tel'ar), or *knee-jerk, reflex*, shown in Figure 7.11b and d, is an example of a two-neuron reflex arc, the most simple type in humans. The patellar reflex (in which the quadriceps muscle attached to the hit tendon is stretched) is familiar to most of us. It is usually tested during a physical exam to determine the general health of the motor portion of the nervous system. Most reflexes are much more complex than the two-neuron reflex, involving synapses between one or more association neurons in the CNS (integration center). A three-neuron reflex arc, the *flexor*, or *withdrawal, reflex*, in which the limb is withdrawn from a painful stimulus, is diagrammed in Figure 7.11c. The three-neuron reflex arc consists of five elements—receptor, sensory neuron, association neuron, motor neuron, and effector. Since there is always a delay at synapses (it takes time for the neurotransmitter to diffuse through the synaptic cleft), the more synapses there are in a reflex pathway, the longer the reflex takes to happen.

Many spinal reflexes involve only spinal cord neurons and occur without brain involvement. As

long as the spinal cord is functional, spinal reflexes such as the flexor reflex will work. On the other hand, some reflexes require that the brain become involved because many different types of information have to be evaluated to arrive at the “right” response. The response of the pupils of the eyes to light is a reflex of this type.

As noted earlier, reflex testing is an important tool in evaluating the condition of the nervous system. Whenever reflexes are exaggerated, distorted, or absent, nervous system disorders are indicated. Reflex changes often occur before the pathological condition has become obvious in other ways.

Central Nervous System

During embryonic development, the CNS first appears as a simple tube, the **neural tube**, which extends down the dorsal median plane of the developing embryo's body. By the fourth week, the anterior end of the neural tube begins to expand, and brain formation begins. The rest of the neural tube posterior to the forming brain becomes the spinal cord. The central canal of the neural tube, which is continuous between the brain and spinal cord, becomes enlarged in four regions of the brain to form chambers called **ventricles** (see Figure 7.17a and b, p. 243).

Functional Anatomy of the Brain

The adult brain's unimpressive appearance gives few hints of its remarkable abilities. It is about two good fistfuls of pinkish gray tissue, wrinkled like a walnut, and with the texture of cold oatmeal. It weighs a little over three pounds. Because the brain is the largest and most complex mass of nervous tissue in the body, it is commonly discussed in terms of its four major regions—*cerebral hemispheres*, *diencephalon* (di'en-sef'ah-lon), *brain stem*, and *cerebellum* (Figure 7.12).

Cerebral Hemispheres

The paired **cerebral** (ser'e-bral) **hemispheres**, collectively called the **cerebrum**, are the most superior part of the brain and together are a good deal larger than the other three brain regions combined. In fact, as the cerebral hemispheres develop and grow, they enclose and obscure most of the brain stem, so many brain stem structures cannot normally be seen unless a sagittal section is

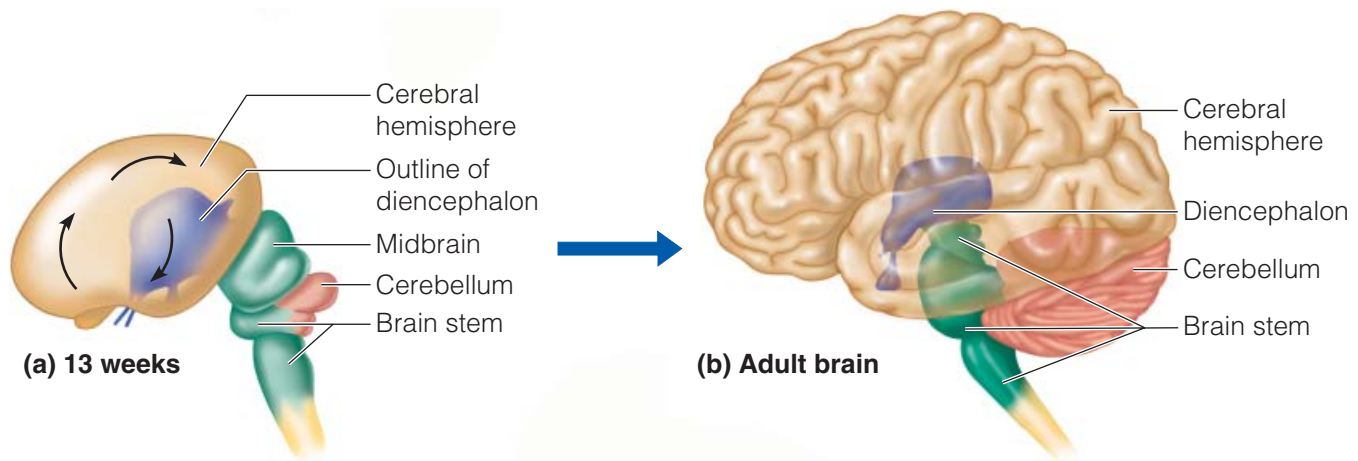


FIGURE 7.12 Development and regions of the human brain. The brain can be considered in terms of four main parts: cerebral hemispheres, diencephalon, brain stem, and cerebellum. In the developing brain **(a)**, the cerebral hemispheres are forced to grow posteriorly and laterally over the other brain regions by the bones of the skull. In the adult brain **(b)**, the cerebral hemispheres hide the diencephalon and the upper part of the brain stem. The left cerebral hemisphere is drawn so that it looks transparent, to reveal the location of the deeply situated diencephalon and superior part of the brain stem.

made. Picture how a mushroom cap covers the top of its stalk, and you have a fairly good idea of how the cerebral hemispheres cover the diencephalon and the superior part of the brain stem (see Figure 7.12).

The entire surface of the cerebral hemispheres exhibits elevated ridges of tissue called **gyri** (ji're; **gyrus**, singular; "twisters"), separated by shallow grooves called **sulci** (sul'ki; **sulcus**, singular; "furrows"). Less numerous are the deeper grooves called **fissures** (Figure 7.13a), which separate large regions of the brain. Many of the fissures and gyri are important anatomical landmarks. The cerebral hemispheres are separated by a single deep fissure, the *longitudinal fissure*. Other fissures or sulci divide each cerebral hemisphere into a number of **lobes**, named for the cranial bones that lie over them (see Figure 7.13a and b).

Speech, memory, logical and emotional response, as well as consciousness, interpretation of sensation, and voluntary movement, are all functions of neurons of the cerebral cortex, and many of the functional areas of the cerebral hemispheres have been identified (Figure 7.13c). The **somatic sensory area** is located in the **parietal lobe** posterior to the **central sulcus**. Impulses traveling from the body's sensory receptors (except for the special senses) are localized and interpreted in this

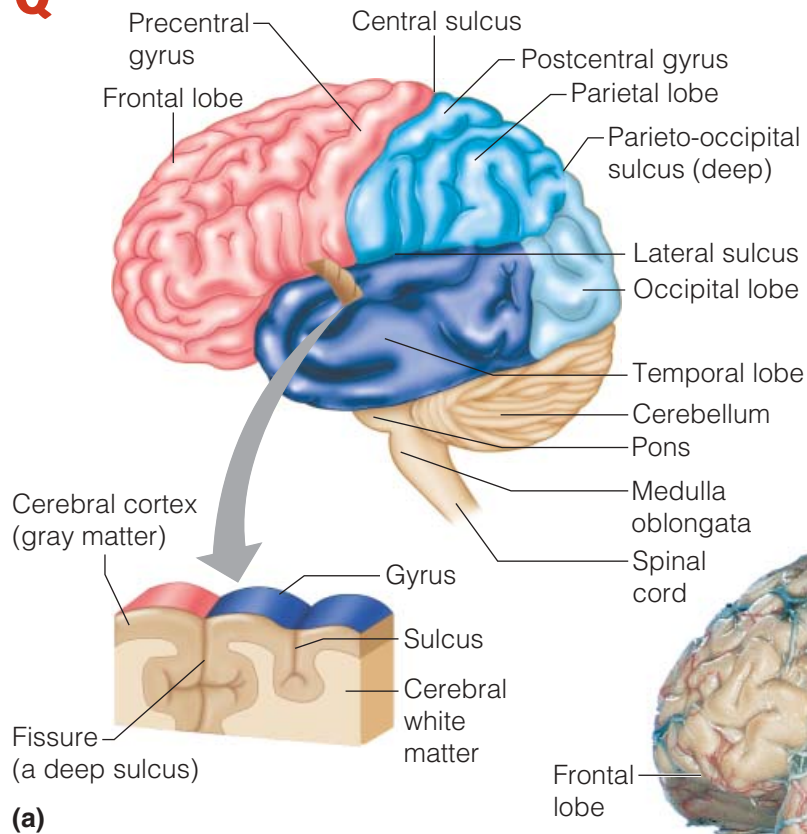
area of the brain. The somatic sensory area allows you to recognize pain, coldness, or a light touch. As illustrated in Figure 7.14, the body is represented in an upside-down manner in the sensory area. This spatial map is called the **sensory homunculus** (ho-mung'ku-lus; "little man"). Body regions with the most sensory receptors—the lips and fingertips—send impulses to neurons that make up a large part of the sensory cortex. Furthermore, the sensory pathways are crossed pathways—meaning that the left side of the sensory cortex receives impulses from the right side of the body, and vice versa.

Impulses from the special sense organs are interpreted in other cortical areas (see Figure 7.13b and c). For example, the visual area is located in the posterior part of the **occipital lobe**, the auditory area is in the **temporal lobe** bordering the *lateral sulcus*, and the olfactory area is found deep inside the temporal lobe.

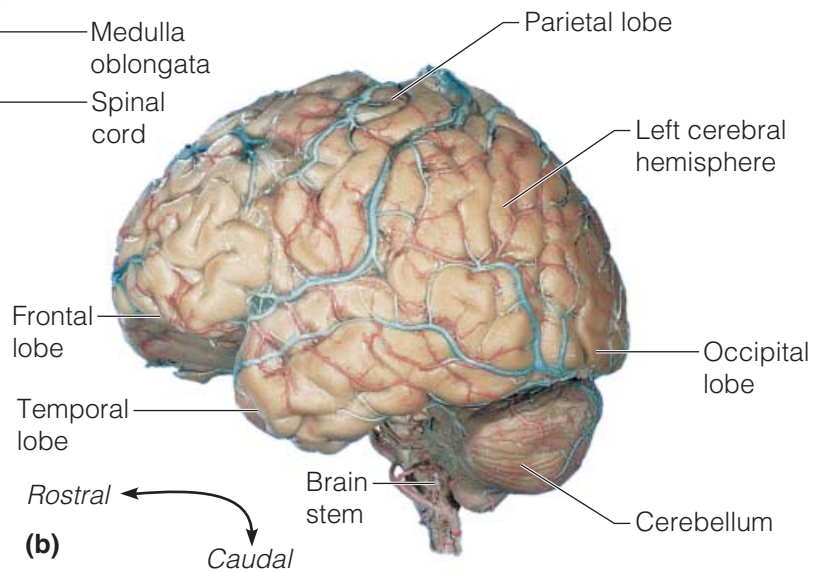
The **primary motor area** that allows us to consciously move our skeletal muscles is anterior to the central sulcus in the **frontal lobe**. The axons of these motor neurons form the major voluntary motor tract—the **corticospinal** (kor'tī-ko-spi'nal), or **pyramidal tract**, which descends to the cord. As in the somatic sensory cortex, the body is represented upside-down and the pathways are

Q

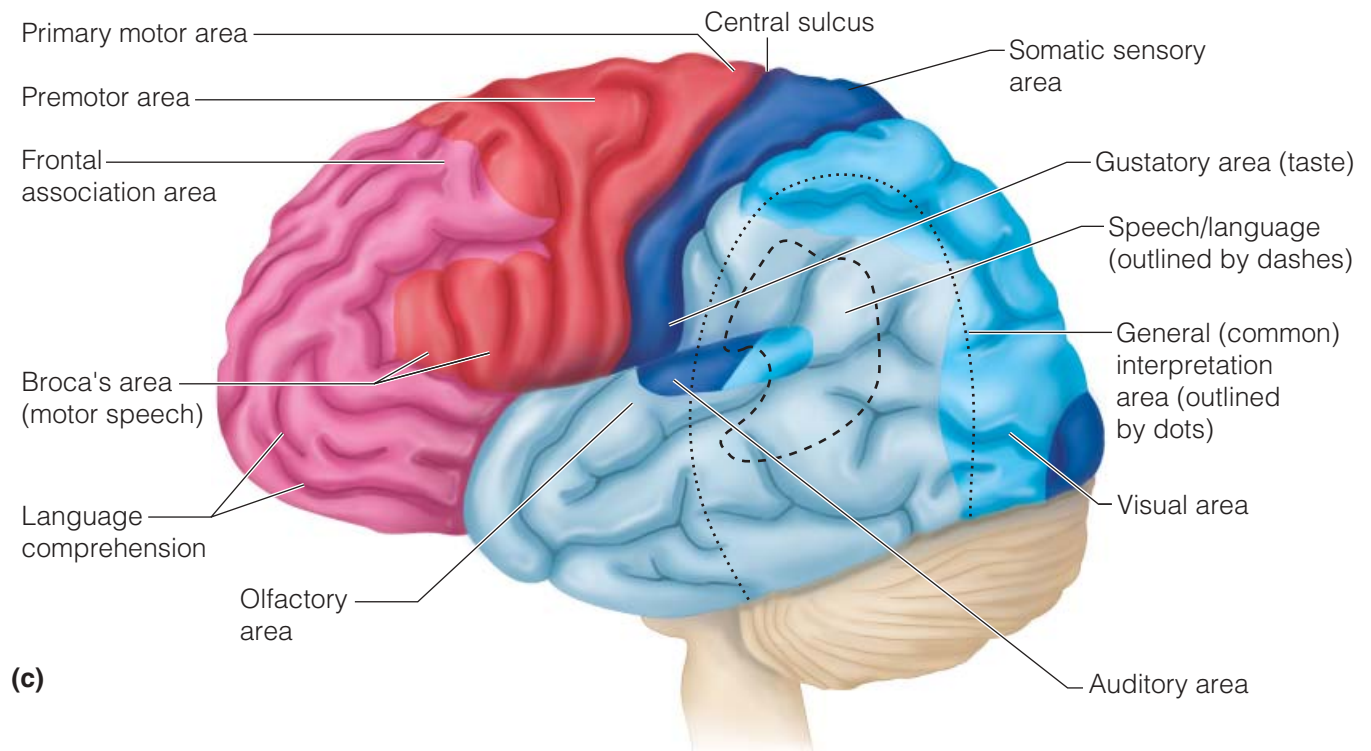
What sense(s) would be affected by temporal lobe damage? By occipital lobe damage?



(a)



(b)



(c)

A

Damage to the temporal lobe (depending on its site) might affect hearing and/or the sense of smell. Occipital lobe damage would cause visual problems.

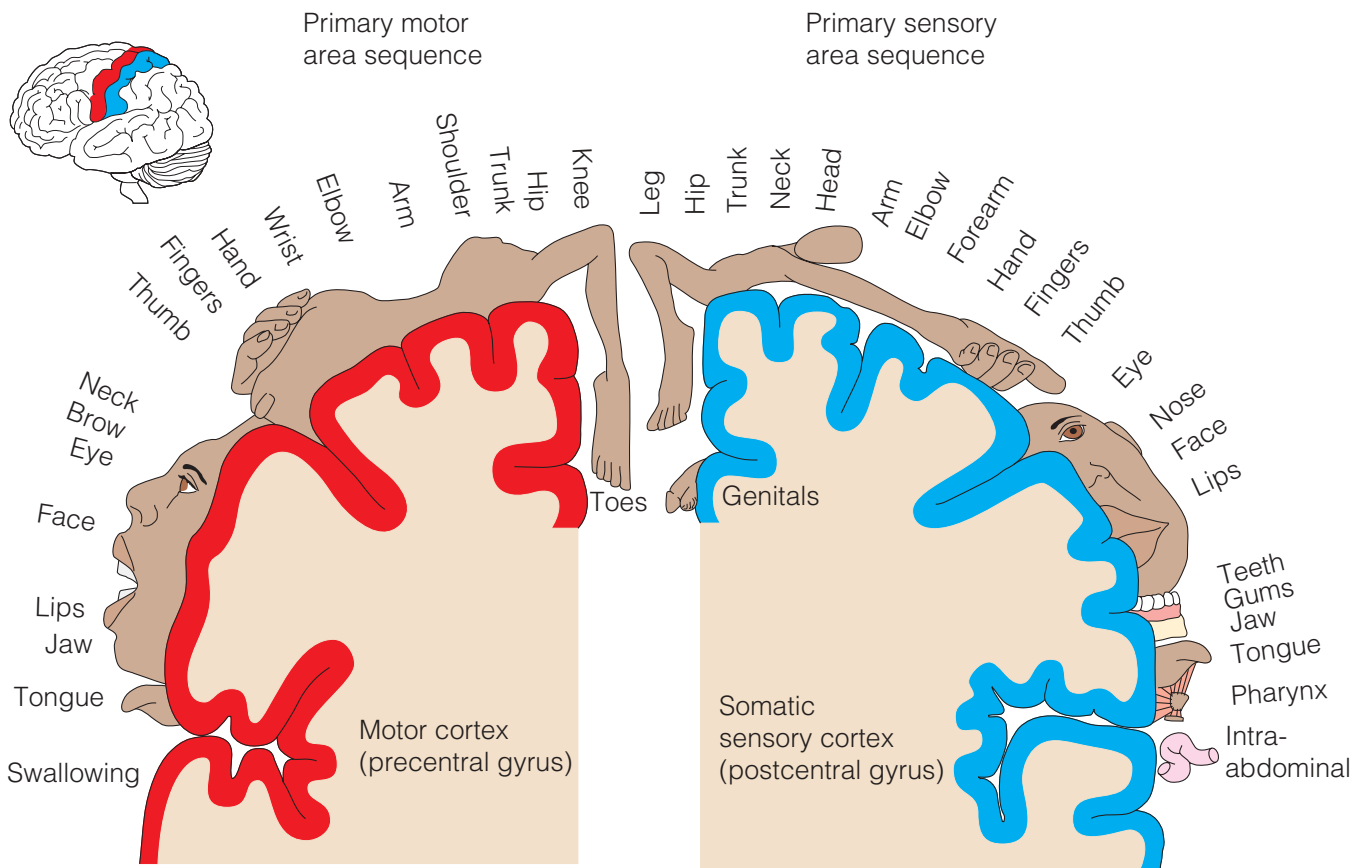


FIGURE 7.14 Sensory and motor areas of the cerebral cortex. The relative amount of cortical tissue devoted to each function is indicated by the amount of the gyrus occupied by the body area diagrams (homunculi). The primary motor cortex is shown on the right, the somatic sensory cortex is on the left.

crossed. Most of the neurons in this primary motor area control body areas having the finest motor control; that is, the face, mouth, and hands (see Figure 7.14). The body map on the motor cortex, as you might guess, is called the **motor** homunculus.

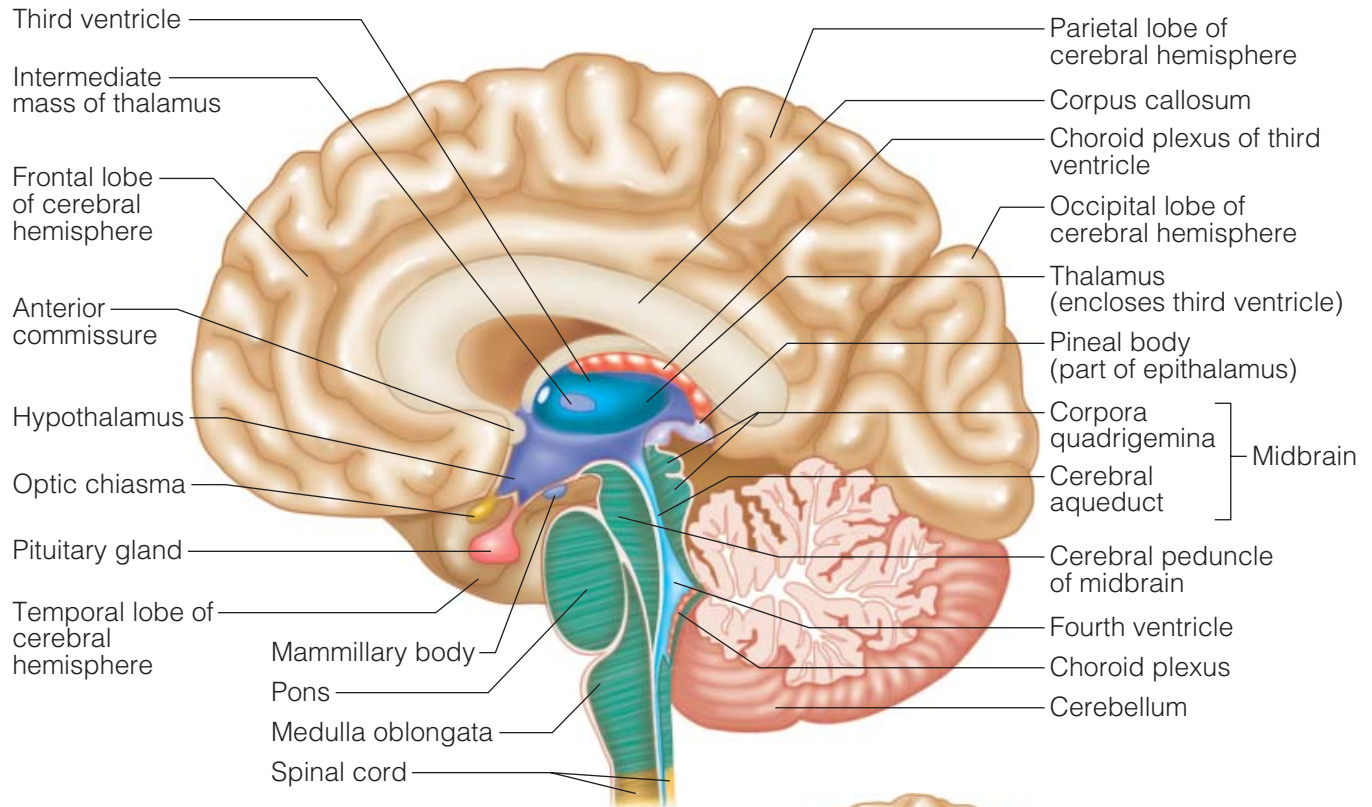
A specialized area that is very involved in our ability to speak, **Broca's** (bro'kahz) **area** (see Figure 7.13c), is found at the base of the precentral gyrus (the gyrus anterior to the central sulcus). Damage to this area, which is located in only one cerebral hemisphere (usually the left), causes inability to say words properly. You know what you want to say, but you can't vocalize the words.

Areas involved in higher intellectual reasoning and socially acceptable behavior are believed to be in the anterior part of the frontal lobes. Complex memories appear to be stored in the temporal and frontal lobes. The **speech area** is located at the

junction of the temporal, parietal, and occipital lobes. The speech area allows one to sound out words. This area (like Broca's area) is usually in only one cerebral hemisphere. The frontal lobes house areas involved with language comprehension (word meanings).

The cell bodies of neurons involved in the cerebral hemisphere functions named above are found only in the outermost **gray matter** of the cerebrum, the **cerebral cortex** (see Figure 7.13a). As noted earlier, the cortical region is highly ridged and convoluted, providing more room for the thousands of neurons found there.

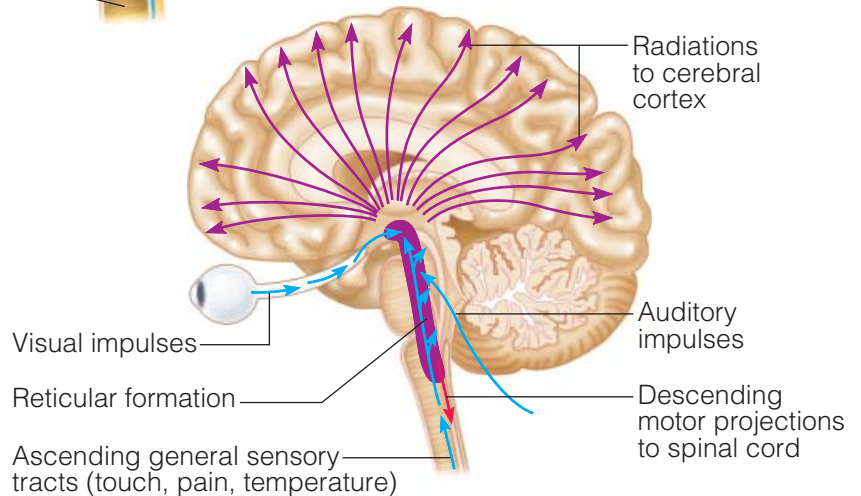
Most of the remaining cerebral hemisphere tissue—the deeper **cerebral white matter** (see Figure 7.13a)—is composed of fiber *tracts* (bundles of nerve fibers) carrying impulses to or from the cortex. One very large fiber tract, the **corpus**



(a)

FIGURE 7.15 Diencephalon and brain stem structures. (a) A midsagittal section of the brain.

(b) The reticular formation, which extends the length of the brain stem. Ascending arrows indicate sensory input to the cerebrum. Descending arrows indicate efferent output of reticular neurons.



(b)

callosum (kah-lo'sum), connects the cerebral hemispheres (Figure 7.15). The corpus callosum arches above the structures of the brain stem and allows the cerebral hemispheres to communicate with one another. This is important because, as already noted, some of the cortical functional areas are in only one hemisphere.

Although most of the gray matter is in the cerebral cortex, there are several “islands” of gray matter,

called the **basal nuclei**, or **basal ganglia**,* buried deep within the white matter of the cerebral hemispheres. The basal nuclei help regulate voluntary

*The term *basal ganglia* is a historical misnomer. Ganglia are peripheral nervous system structures but the basal ganglia are collections of nerve cell bodies *in the CNS*. Hence, *basal nuclei* is a more accurate term.

motor activities by modifying instructions sent to the skeletal muscles by the primary motor cortex.

Homeostatic Imbalance

Individuals who have problems with their basal nuclei are often unable to walk normally or carry out other voluntary movements in the usual normal way. *Huntington's disease* (or *Huntington's chorea*) and *Parkinson's disease*, two examples of such syndromes, are discussed in the "A Closer Look" box on pages 245–246. ▲

Diencephalon

The **diencephalon**, or **interbrain**, sits atop the brain stem and is enclosed by the cerebral hemispheres (see Figure 7.12). The major structures of the diencephalon are the *thalamus*, *hypothalamus*, and *epithalamus* (see Figure 7.15). The **thalamus**, which encloses the shallow *third ventricle* of the brain, is a relay station for sensory impulses passing upward to the sensory cortex. As impulses surge through the thalamus, we have a crude recognition of whether the sensation we are about to have is pleasant or unpleasant. The actual localization and interpretation of the sensation is done by the neurons of the sensory cortex.

The **hypothalamus** (literally, "under the thalamus") makes up the floor of the diencephalon. It is an important autonomic nervous system center because it plays a role in the regulation of body temperature, water balance, and metabolism. The hypothalamus is also the center for many drives and emotions, and as such it is an important part of the so-called **limbic system**, or "emotional-visceral brain." For example, thirst, appetite, sex, pain, and pleasure centers are in the hypothalamus. Additionally, the hypothalamus regulates the pituitary gland (an endocrine organ) and produces two hormones of its own. The **pituitary gland** hangs from the anterior floor of the hypothalamus by a slender stalk. (Its function is discussed in Chapter 9.) The **mammillary bodies**, reflex centers involved in olfaction (the sense of smell), bulge from the floor of the hypothalamus posterior to the pituitary gland.

The **epithalamus** (ep"i-thal'ah-mus) forms the roof of the third ventricle. Important parts of the epithalamus are the **pineal body** (part of the endocrine system) and the **choroid** (ko'roid) **plexus** of the third ventricle. The choroid plexuses, knots of capillaries within each ventricle, form the cerebrospinal fluid.

Brain Stem

The **brain stem** is about the size of a thumb in diameter and approximately 3 inches (approximately 7.5 cm) long. Its structures are the *midbrain*, *pons*, and *medulla oblongata*. In addition to providing a pathway for ascending and descending tracts, the brain stem has many small gray matter areas. These nuclei are part of the cranial nerves and control vital activities such as breathing and blood pressure. Identify the brain stem areas in Figure 7.15 as you read their descriptions that follow.

Midbrain The **midbrain** is a relatively small part of the brain stem. It extends from the mammillary bodies to the pons inferiorly. The **cerebral aqueduct** is a tiny canal that travels through the midbrain and connects the third ventricle of the diencephalon to the fourth ventricle below. Anteriorly, the midbrain is composed primarily of two bulging fiber tracts, the **cerebral peduncles** (literally, "little feet of the cerebrum"), which convey ascending and descending impulses. Dorsally located are four rounded protrusions called the **corpora quadrigemina** (kor'por-ah kwah'drĭ-jem'ĭ-nah) because they reminded some anatomist of two pairs of twins (*gemini*). These bulging nuclei are reflex centers involved with vision and hearing.

Pons The **pons** (ponz) is the rounded structure that protrudes just below the midbrain. *Pons* means "bridge," and this area of the brain stem is mostly fiber tracts. However, it does have important nuclei involved in the control of breathing.

Medulla Oblongata The **medulla oblongata** (mĕ-dul'ah ob"long-gă'tah) is the most inferior part of the brain stem. It merges into the spinal cord below without any obvious change in structure. Like the pons, the medulla is an important fiber tract area. The medulla also contains many nuclei that regulate vital visceral activities. It contains centers that control heart rate, blood pressure, breathing, swallowing, and vomiting, among others. The **fourth ventricle** lies posterior to the pons and medulla and anterior to the cerebellum.

Reticular Formation Extending the entire length of the brain stem is a diffuse mass of gray matter, the **reticular formation**. The neurons of the reticular formation are involved in motor control of the visceral organs. A special group of reticular formation neurons, the **reticular activating system (RAS)**, plays a role in consciousness and the awake/sleep