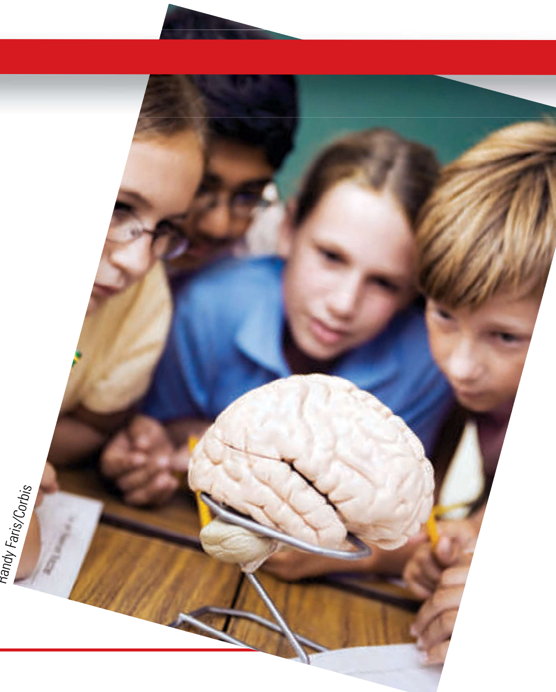
# Module 11

## Studying the Brain, and Older Brain Structures


Randy Faris/Corbis

### Module Learning Objectives

**11-1** Describe several techniques for studying the brain's connections to behavior and mind.

**11-2** Describe the components of the brainstem, and summarize the functions of the brainstem, thalamus, and cerebellum.

**11-3** Describe the limbic system's structures and functions.

The brain enables the mind—seeing, hearing, smelling, feeling, remembering, thinking, speaking, dreaming, loving. Moreover, it is the brain that self-reflectively analyzes the brain. When we're thinking *about* our brain, we're thinking *with* our brain—by firing across millions of synapses and releasing billions of neurotransmitter molecules. Neuroscientists tell us that the *mind is what the brain does.* Brain, behavior, and cognition are an integrated whole. But precisely where and how are the mind's functions tied to the brain? Let's first see how scientists explore such questions.

"I am a brain, Watson. The rest of me is a mere appendix."
-Sherlock Holmes, in Arthur Conan Doyle's "The Adventure of the Mazarin Stone"

## The Tools of Discovery: Having Our Head Examined

**11-1** How do neuroscientists study the brain's connections to behavior and mind?

A century ago, scientists had no tools high-powered yet gentle enough to explore the living human brain. Early case studies of patients by physicians and others helped localize some of the brain's functions. Damage to one side of the brain often caused numbness or paralysis on the body's opposite side, suggesting that the body's right side is wired to the brain's left side, and vice versa. Damage to the back of the brain disrupted vision, and to the left-front part of the brain produced speech difficulties. Gradually, these early explorers were mapping the brain.

Now, within a lifetime, a new generation of neural cartographers is probing and mapping the known universe's most amazing organ. Scientists can selectively **lesion** (destroy) tiny clusters of brain cells, leaving the surrounding tissue unharmed. In the laboratory, such studies have revealed, for example, that damage to one area of the hypothalamus in a rat's brain reduces eating, to the point of starvation, whereas damage in another area produces overeating.

**lesion** [LEE-zhuhn] tissue destruction. A brain lesion is a naturally or experimentally caused destruction of brain tissue.

Today's neuroscientists can also electrically, chemically, or magnetically *stimulate* various parts of the brain and note the effect. Depending on the stimulated brain part, people may—to name a few examples—giggle, hear voices, turn their head, feel themselves falling, or have an out-of-body experience (Selimbeyoglu & Parvizi, 2010). Scientists can even snoop on the messages of individual neurons. With tips so small they can detect the electrical pulse in a single neuron, modern microelectrodes can, for example, now detect exactly where the information goes in a cat's brain when someone strokes its whisker. Researchers can also eavesdrop on the chatter of billions of neurons and can see color representations of the brain's energy-consuming activity.

Right now, your mental activity is emitting telltale electrical, metabolic, and magnetic signals that would enable neuroscientists to observe your brain at work. Electrical activity in your brain's billions of neurons sweeps in regular waves across its surface. An **electroencephalogram (EEG)** is an amplified readout of such waves. Researchers record the brain waves through a shower-cap-like hat that is filled with electrodes covered with a conductive gel. Studying an EEG of the brain's activity is like studying a car engine by listening to its hum. With no direct access to the brain, researchers present a stimulus repeatedly and have a computer filter out brain activity unrelated to the stimulus. What remains is the electrical wave evoked by the stimulus (**FIGURE 11.1**).

AJPhoto/Science Source

**Figure 11.1**
**An electroencephalogram providing amplified tracings of waves of electrical activity in the brain** Here it is displaying the brain activity of this 4-year-old who has epilepsy.

"You must look into people, as well as at them," advised Lord Chesterfield in a 1746 letter to his son. Unlike EEGs, newer neuroimaging techniques give us that Superman-like ability to see inside the living brain. For example, the **CT (computed tomography) scan** examines the brain by taking X-ray photographs that can reveal brain damage. Even more dramatic is the **PET (positron emission tomography) scan** (**FIGURE 11.2** on the next page), which depicts brain activity by showing each brain area's consumption of its chemical fuel, the sugar glucose. Active neurons are glucose hogs, and after a person receives temporarily radioactive glucose, the PET scan can track the gamma rays released by this "food for thought" as the person performs a given task. Rather like weather radar showing rain activity, PET-scan "hot spots" show which brain areas are most active as the person does mathematical calculations, looks at images of faces, or daydreams.

In **MRI (magnetic resonance imaging)** brain scans, the person's head is put in a strong magnetic field, which aligns the spinning atoms of brain molecules. Then, a radio-wave pulse momentarily disorients the atoms. When the atoms return to their normal spin, they emit signals that provide a detailed picture of soft tissues, including the brain. MRI scans have revealed a larger-than-average neural area in the left hemisphere of musicians who display perfect pitch (Schlaug et al., 1995). They have also revealed enlarged *ventricles*—fluid-filled brain areas

**electroencephalogram (EEG)** an amplified recording of the waves of electrical activity sweeping across the brain's surface. These waves are measured by electrodes placed on the scalp.

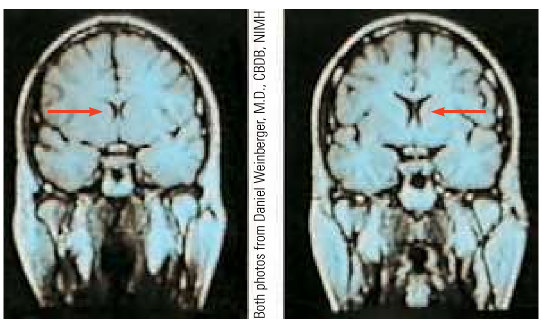
**CT (computed tomography) scan** a series of X-ray photographs taken from different angles and combined by computer into a composite representation of a slice of the brain's structure. *(Also called CAT scan.)*

**PET (positron emission tomography) scan** a visual display of brain activity that detects where a radioactive form of glucose goes while the brain performs a given task.

**MRI (magnetic resonance imaging)** a technique that uses magnetic fields and radio waves to produce computer-generated images of soft tissue. MRI scans show brain anatomy.

**Figure 11.2**
**The PET scan** To obtain a PET scan, researchers inject volunteers with a low and harmless dose of a short-lived radioactive sugar. Detectors around the person's head pick up the release of gamma rays from the sugar, which has concentrated in active brain areas. A computer then processes and translates these signals into a map of the brain at work.

Mark Harmel/Getty Images



Both photos from Daniel Weinberger, M.D., CBDB, NIMH

**Figure 11.3**
**MRI scan of a healthy individual (left) and a person with schizophrenia (right)** Note the enlarged ventricle, the fluid-filled brain region at the tip of the arrow in the image on the right.

(marked by the red arrows in **FIGURE 11.3**)—in some patients who have schizophrenia, a disabling psychological disorder.

A special application of MRI—**fMRI (functional MRI)**—can reveal the brain's functioning as well as its structure. Where the brain is especially active, blood goes. By comparing MRI scans taken less than a second apart, researchers can watch as specific brain areas activate, showing increased oxygen-laden bloodflow. As the person looks at a scene, for example, the fMRI machine detects blood rushing to the back of the brain, which processes visual information (see Figure 12.5, in the discussion of cortex functions in Module 12).

Such snapshots of the brain's changing activity are providing new insights—albeit sometimes overstated (Vul et al., 2009a,b)—into how the brain divides its labor. A mountain of recent fMRI studies suggests which brain areas are most active when people feel pain or rejection, listen to angry voices, think about scary things, feel happy, or become sexually excited. The technology enables a very crude sort of mind reading. After scanning 129 people's brains as they did eight different mental tasks (such as reading, gambling, or rhyming), neuroscientists were able, with 80 percent accuracy, to predict which of these mental activities people were doing (Poldrack et al., 2009). Other studies have explored brain activity associated with religious experience, though without settling the question of whether the brain is producing or perceiving God (Fingelkurts & Fingelkurts, 2009; Inzlicht et al., 2009; Kapogiannis et al., 2009).

**fMRI (functional MRI)** a technique for revealing bloodflow and, therefore, brain activity by comparing successive MRI scans. fMRI scans show brain function as well as its structure.

* * *

Today's techniques for peering into the thinking, feeling brain are doing for psychology what the microscope did for biology and the telescope did for astronomy. From them we have learned more about the brain in the last 30 years than in the previous 30,000. To be learning about the neurosciences now is like studying world geography while Magellan was exploring the seas. This truly is the golden age of brain science.

## Older Brain Structures

**11-2** What structures make up the brainstem, and what are the functions of the brainstem, thalamus, and cerebellum?

An animal's capacities come from its brain structures. In primitive animals, such as sharks, a not-so-complex brain primarily regulates basic survival functions: breathing, resting, and feeding. In lower mammals, such as rodents, a more complex brain enables emotion and greater memory. In advanced mammals, such as humans, a brain that processes more information enables increased foresight as well.

**AP® Exam Tip**

Your author, David Myers, is about to take you on a journey through your brain. Focus on the name of each part, its location within the brain, and what it does. Then it's time to practice, practice, practice.

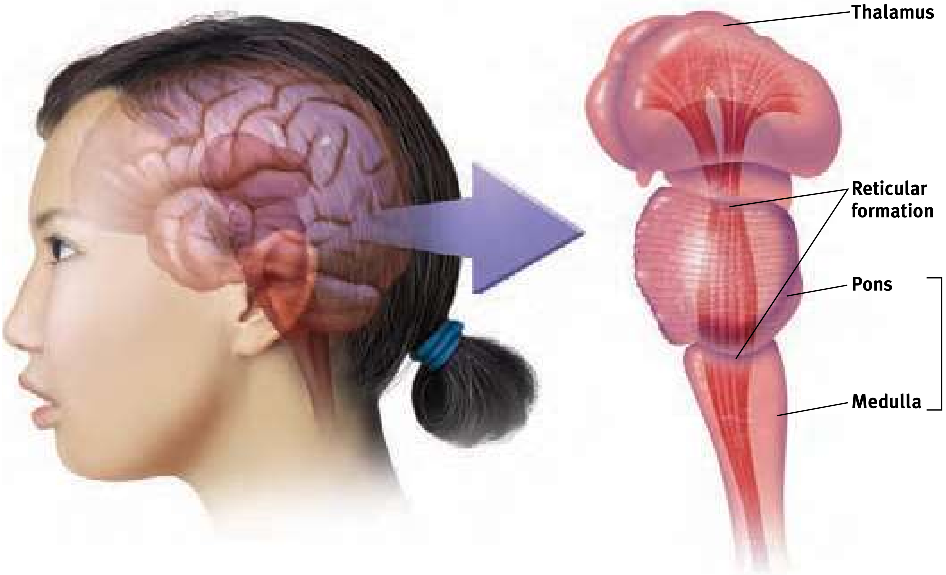



**Figure 11.4**
**The brainstem and thalamus** The brainstem, including the pons and medulla, is an extension of the spinal cord. The thalamus is attached to the top of the brainstem. The reticular formation passes through both structures.

**brainstem** the oldest part and central core of the brain, beginning where the spinal cord swells as it enters the skull; the brainstem is responsible for automatic survival functions.

**medulla** [muh-DUL-uh] the base of the brainstem; controls heartbeat and breathing.

**thalamus** [THAL-uh-muss] the brain's sensory control center, located on top of the brainstem; it directs messages to the sensory receiving areas in the cortex and transmits replies to the cerebellum and medulla.

This increasing complexity arises from new brain systems built on top of the old, much as the Earth's landscape covers the old with the new. Digging down, one discovers the fossil remnants of the past—brainstem components performing for us much as they did for our distant ancestors. Let's start with the brain's basement and work up to the newer systems.

## The Brainstem

The brain's oldest and innermost region is the **brainstem.** It begins where the spinal cord swells slightly after entering the skull. This slight swelling is the **medulla** (**FIGURE 11.4**). Here lie the controls for your heartbeat and breathing. As some brain-damaged patients in a vegetative state illustrate, we need no higher brain or conscious mind to orchestrate our heart's pumping and lungs' breathing. The brainstem handles those tasks.

Just above the medulla sits the *pons,* which helps coordinate movements. If a cat's brainstem is severed from the rest of the brain above it, the animal will still breathe and live—and even run, climb, and groom (Klemm, 1990). But cut off from the brain's higher regions, it won't *purposefully* run or climb to get food.

The brainstem is a crossover point, where most nerves to and from each side of the brain connect with the body's opposite side (**FIGURE 11.5**). This peculiar cross-wiring is but one of the brain's many surprises.

## The Thalamus

Sitting atop the brainstem is the **thalamus,** a pair of egg-shaped structures that act as the brain's sensory control center (Figure 11.4). The thalamus receives information from all the senses except smell and routes it to the higher brain regions that deal with seeing, hearing, tasting, and touching. The thalamus also receives some of the higher brain's replies, which it then directs to the medulla and to the cerebellum (see the next page). Think of the thalamus as being to sensory information what London is to England's trains: a hub through which traffic passes en route to various destinations.


**Figure 11.5**
**The body's wiring** Nerves from the left side of the brain are mostly linked to the right side of the body, and vice versa.

## The Reticular Formation

**reticular formation** a nerve network that travels through the brainstem and thalamus and plays an important role in controlling arousal.

Inside the brainstem, between your ears, lies the **reticular** ("netlike") **formation,** a neuron network that extends from the spinal cord right up through the thalamus. As the spinal cord's sensory input flows up to the thalamus, some of it travels through the reticular formation, which filters incoming stimuli and relays important information to other brain areas.

In 1949, Giuseppe Moruzzi and Horace Magoun discovered that electrically stimulating the reticular formation of a sleeping cat almost instantly produced an awake, alert animal. When Magoun *severed* a cat's reticular formation without damaging the nearby sensory pathways, the effect was equally dramatic: The cat lapsed into a coma from which it never awakened. The conclusion? The reticular formation enables arousal.

## The Cerebellum

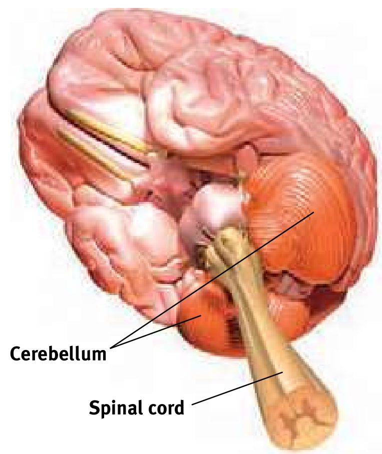
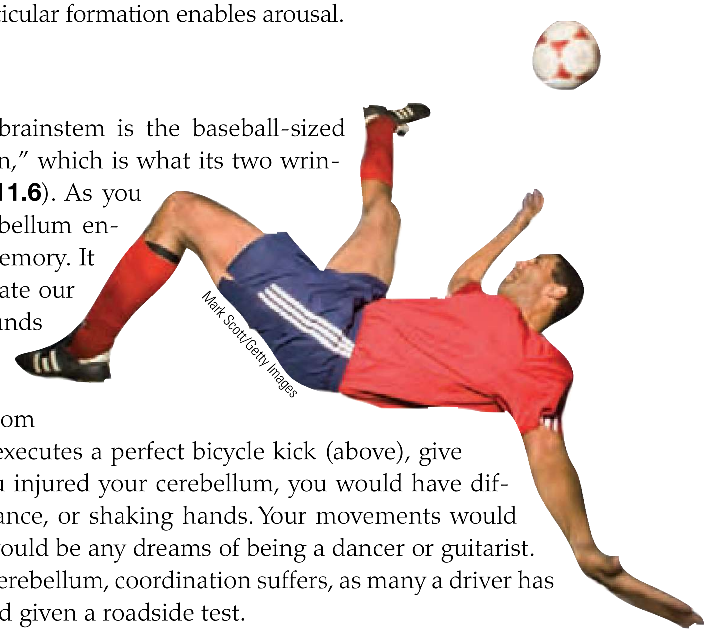



Figure 11.6
**The brain's organ of agility** Hanging at the back of the brain, the cerebellum coordinates our voluntary movements.




Extending from the rear of the brainstem is the baseball-sized **cerebellum,** meaning "little brain," which is what its two wrinkled halves resemble (**FIGURE 11.6**). As you will see in Module 32, the cerebellum enables nonverbal learning and memory. It also helps us judge time, modulate our emotions, and discriminate sounds and textures (Bower & Parsons, 2003). And it coordinates voluntary movement (with assistance from the pons). When a soccer player executes a perfect bicycle kick (above), give his cerebellum some credit. If you injured your cerebellum, you would have difficulty walking, keeping your balance, or shaking hands. Your movements would be jerky and exaggerated. Gone would be any dreams of being a dancer or guitarist. Under alcohol's influence on the cerebellum, coordination suffers, as many a driver has learned after being pulled over and given a roadside test.

* * *

*Note:* These older brain functions all occur without any conscious effort. This illustrates another of our recurring themes: *Our brain processes most information outside of our awareness.* We are aware of the *results* of our brain's labor (say, our current visual experience) but not of *how* we construct the visual image. Likewise, whether we are asleep or awake, our brainstem manages its life-sustaining functions, freeing our newer brain regions to think, talk, dream, or savor a memory.

**cerebellum** [sehr-uh-BELL-um] the "little brain" at the rear of the brainstem; functions include processing sensory input, coordinating movement output and balance, and enabling nonverbal learning and memory.

**limbic system** neural system (including the *hippocampus, amygdala,* and *hypothalamus*) located below the cerebral hemispheres; associated with emotions and drives.

## The Limbic System

**11-3** What are the limbic system's structures and functions?

We've considered the brain's oldest parts, but we've not yet reached its newest and highest regions, the *cerebral hemispheres* (the two halves of the brain). Between the oldest and newest brain areas lies the **limbic system** (*limbus* means "border"). This system contains the *amygdala,* the *hypothalamus,* and the *hippocampus* (**FIGURE 11.7**). The hippocampus processes conscious memories. Animals or humans who lose their hippocampus to surgery or injury also lose their ability to form new memories of facts and events. Module 31 explains how our two-track mind processes our memories. For now, let's look at the limbic system's links to emotions such as fear and anger, and to basic motives such as those for food and sex.

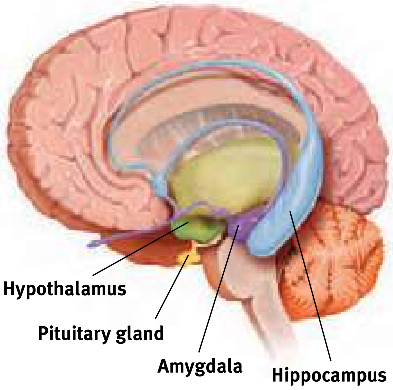



**Figure 11.7**
**The limbic system** This neural system sits between the brain's older parts and its cerebral hemispheres. The limbic system's hypothalamus controls the nearby pituitary gland.

**amygdala** [uh-MIG-duh-la] two lima-bean-sized neural clusters in the limbic system; linked to emotion.

**hypothalamus** [hi-po-THAL-uh-muss] a neural structure lying below *(hypo)* the thalamus; it directs several maintenance activities (eating, drinking, body temperature), helps govern the endocrine system via the pituitary gland, and is linked to emotion and reward.

### THE AMYGDALA

Research has linked the **amygdala,** two lima-bean-sized neural clusters, to aggression and fear. In 1939, psychologist Heinrich Klüver and neurosurgeon Paul Bucy surgically removed a rhesus monkey's amygdala, turning the normally ill-tempered animal into the most mellow of creatures. In studies with other wild animals, including the lynx, wolverine, and wild rat, researchers noted the same effect.

What then might happen if we electrically stimulated the amygdala of a normally placid domestic animal, such as a cat? Do so in one spot and the cat prepares to attack, hissing with its back arched, its pupils dilated, its hair on end. Move the electrode only slightly within the amygdala, cage the cat with a small mouse, and now it cowers in terror.

These and other experiments have confirmed the amygdala's role in rage and fear, including the perception of these emotions and the processing of emotional memories (Anderson & Phelps, 2000; Poremba & Gabriel, 2001). But we must be careful. The brain is not neatly organized into structures that correspond to our behavior categories. When we feel or act in aggressive or fearful ways, there is neural activity in many levels of our brain. Even within the limbic system, stimulating structures other than the amygdala can evoke aggression or fear. If you charge your cell phone's dead battery, you can activate the phone and make a call. Yet the battery is merely one link in an integrated system.

Jane Burton/Dorling Kindersley/Getty Images

**Aggression as a brain state** Back arched and fur fluffed, this fierce cat is ready to attack. Electrical stimulation of a cat's amygdala provokes angry reactions, suggesting the amygdala's role in aggression. Which ANS division is activated by such stimulation?

ANSWER: The cat would be aroused via its sympathetic nervous system.

### THE HYPOTHALAMUS

Just below *(hypo)* the thalamus is the **hypothalamus** (**FIGURE 11.8** on the next page), an important link in the command chain governing bodily maintenance. Some neural clusters in the hypothalamus influence hunger; others regulate thirst, body temperature, and sexual behavior. Together, they help maintain a steady internal state.

As the hypothalamus monitors the state of your body, it tunes into your blood chemistry and any incoming orders from other brain parts. For example, picking up signals from your brain's cerebral cortex that you are thinking about sex, your hypothalamus will secrete hormones. These hormones will in turn trigger the adjacent "master gland," your pituitary (see Figure 11.7), to influence your sex glands to release their hormones. These will intensify the thoughts of sex in your cerebral cortex. (Once again, we see the interplay between the nervous and endocrine systems: The brain influences the endocrine system, which in turn influences the brain.)

**AP® Exam Tip**

If you ever have to make a guess about brain parts on the AP® exam, the hypothalamus isn't a bad bet. Even though it's small, it has many functions.

ISM/Phototake

**Figure 11.8**

**The hypothalamus** This small but important structure, colored yellow/orange in this MRI scan photograph, helps keep the body's internal environment in a steady state.

A remarkable discovery about the hypothalamus illustrates how progress in science often occurs—when curious, open-minded investigators make an unexpected observation. Two young McGill University neuropsychologists, James Olds and Peter Milner (1954), were trying to implant an electrode in a rat's reticular formation when they made a magnificent mistake: They placed the electrode incorrectly (Olds, 1975). Curiously, as if seeking more stimulation, the rat kept returning to the location where it had been stimulated by this misplaced electrode. On discovering that they had actually placed the device in a region of the hypothalamus, Olds and Milner realized they had stumbled upon a brain center that provides pleasurable rewards (Olds, 1975).

In a meticulous series of experiments, Olds (1958) went on to locate other "pleasure centers," as he called them. (What the rats actually experience only they know, and they aren't telling. Rather than attribute human feelings to rats, today's scientists refer to *reward centers,* not "pleasure centers.") When allowed to press pedals to trigger their own stimulation in these areas, rats would sometimes do so at a feverish pace—up to 7000 times per hour—until they dropped from exhaustion. Moreover, to get this stimulation, they would even cross an electrified floor that a starving rat would not cross to reach food (**FIGURE 11.9**).

Other limbic system reward centers, such as the *nucleus accumbens* in front of the hypothalamus, were later discovered in many other species, including dolphins and monkeys. In fact, animal research has revealed both a general dopamine-related reward system and specific centers associated with the pleasures of eating, drinking, and sex. Animals, it seems, come equipped with built-in systems that reward activities essential to survival.

Contemporary researchers are experimenting with new ways of using limbic stimulation to control animals' actions in future applications, such as search-and-rescue operations. By rewarding rats for turning left or right, one research team trained previously caged rats to navigate natural environments (Talwar et al., 2002; **FIGURE 11.10**). By pressing buttons on a laptop, the researchers were then able to direct the rat—which carried a receiver, power source, and video camera on a backpack—to turn on cue, climb trees, scurry along branches, and turn around and come back down.

Do humans have limbic centers for pleasure? Indeed we do. To calm violent patients, one neurosurgeon implanted electrodes in such areas. Stimulated patients reported mild pleasure; unlike Olds' rats, however, they were not driven to a frenzy (Deutsch, 1972; Hooper & Teresi, 1986).

Experiments have also revealed the effects of a dopamine-related reward system in people. One research team had people rate the desirability of different vacation destinations. Then, after receiving either a dopamine-increasing drug or a sugar pill, they imagined themselves vacationing at half the locations. A day later, when presented with pairs of vacation spots they

> "If you were designing a robot vehicle to walk into the future and survive, . . . you'd wire it up so that behavior that ensured the survival of the self or the species—like sex and eating—would be naturally reinforcing."
> -Candace Pert (1986)

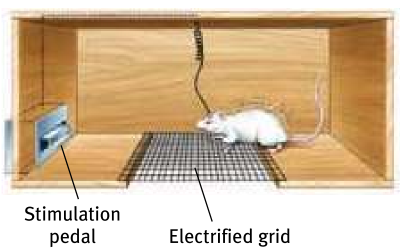



**Figure 11.9**

**Rat with an implanted electrode** With an electrode implanted in a reward center of its hypothalamus, the rat readily crosses an electrified grid, accepting the painful shocks, to press a pedal that sends electrical impulses to that center.

**Figure 11.10**

**Ratbot on a pleasure cruise** When stimulated by remote control, a rat could be guided to navigate across a field and even up a tree.

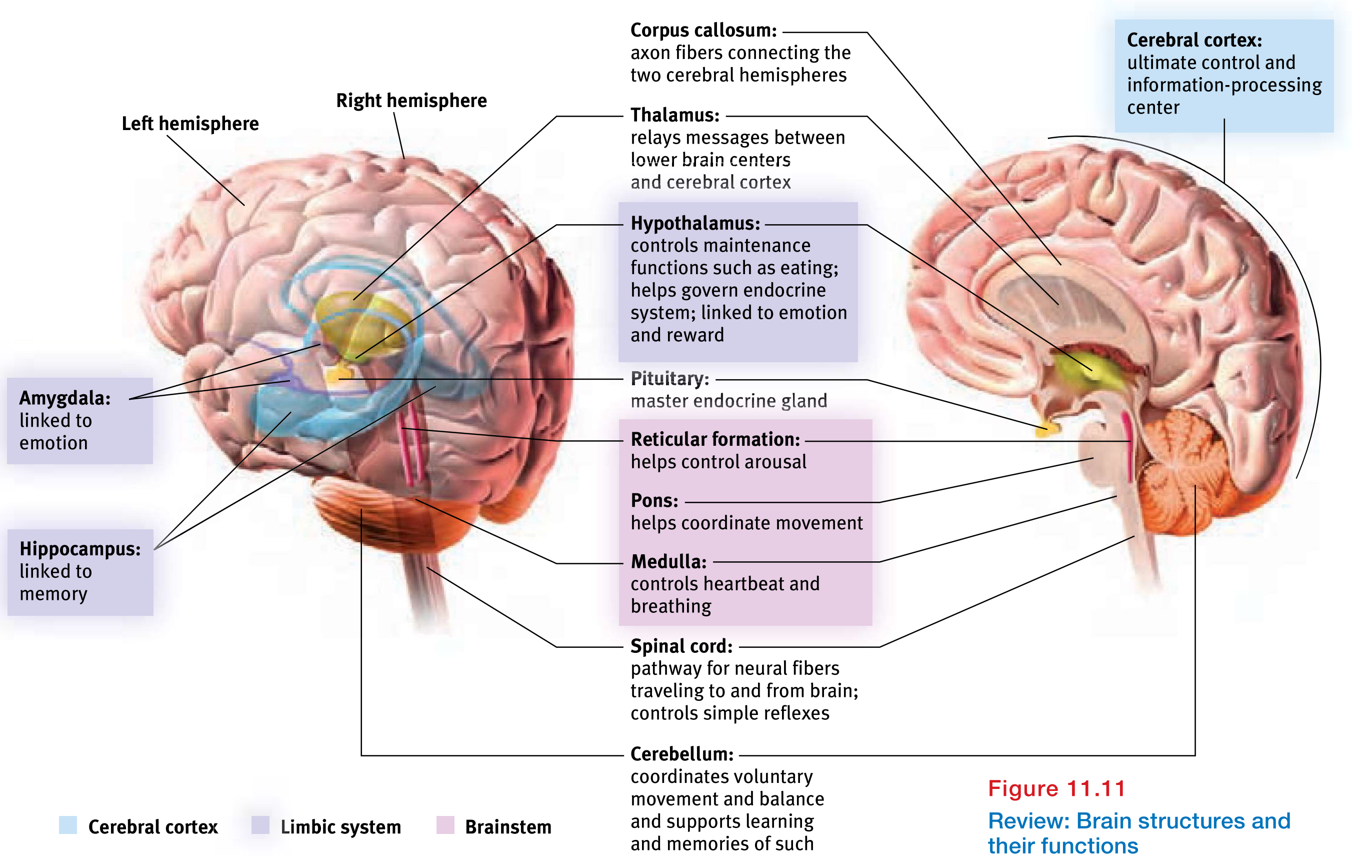



**Figure 11.11**
**Review: Brain structures and their functions**

had initially rated equally, only the dopamine takers preferred the places they had imagined under dopamine's influence (Sharot et al., 2009). The participants, it seems, associated the imagined experiences with dopamine-induced pleasant feelings.

Some researchers believe that addictive disorders, such as substance use disorders and binge eating, may stem from malfunctions in natural brain systems for pleasure and well-being. People genetically predisposed to this *reward deficiency syndrome* may crave whatever provides that missing pleasure or relieves negative feelings (Blum et al., 1996).

* * *

**FIGURE 11.11** locates the brain areas we've discussed, as well as the *cerebral cortex,* our next topic.

## Before You Move On

### ▶ ASK YOURSELF

If one day researchers discover how to stimulate human limbic centers to produce as strong a reaction as found in other animals, do you think this process could be used to reduce the incidence of substance use? Could such use have any negative consequences?

### ▶ TEST YOURSELF

Within what brain region would damage be most likely to disrupt your ability to skip rope? Your ability to sense tastes or sounds? In what brain region would damage perhaps leave you in a coma? Without the very breath and heartbeat of life?

*Answers to the Test Yourself questions can be found in Appendix E at the end of the book.*

# Module 11 Review

### 11-1 How do neuroscientists study the brain's connections to behavior and mind?

- Case studies and *lesioning* first revealed the general effects of brain damage.
- Modern electrical, chemical, or magnetic stimulation has also revealed aspects of information processing in the brain.
- *CT* and *MRI* scans show anatomy. *EEG, PET,* and *fMRI (functional MRI)* recordings reveal brain function.

### 11-2 What structures make up the brainstem, and what are the functions of the brainstem, thalamus, and cerebellum?

- The *brainstem,* the oldest part of the brain, is responsible for automatic survival functions. Its components are the *medulla* (which controls heartbeat and breathing), the pons (which helps coordinate movements), and the *reticular formation* (which affects arousal).
- The *thalamus,* sitting above the brainstem, acts as the brain's sensory control center. The *cerebellum,* attached to the rear of the brainstem, coordinates muscle movement and balance and also helps process sensory information.

### 11-3 What are the limbic system's structures and functions?

- The *limbic system* is linked to emotions, memory, and drives.
- Its neural centers include the hippocampus (which processes conscious memories); the *amygdala* (involved in responses of aggression and fear); and the *hypothalamus* (involved in various bodily maintenance functions, pleasurable rewards, and the control of the endocrine system).
- The pituitary (the"master gland") controls the hypothalamus by stimulating it to trigger the release of hormones.

## Multiple-Choice Questions

**1.** Computer-enhanced X-rays used to create brain images are known as

a. position emission tomography scans.
b. functional magnetic resonance images.
c. computed tomography scans.
d. electroencephalograms.
e. magnetic resonance images.

**2.** What part of the brain triggers the release of adrenaline to boost heart rate when you're afraid?

a. Amygdala
b. Thalamus
c. Medulla
d. Hippocampus
e. Hypothalamus

**3.** A gymnast falls and hits her head on the floor. She attempts to continue practicing, but has trouble maintaining balance. What part of her brain has probably been affected?

a. Reticular formation
b. Cerebellum
c. Amygdala
d. Frontal lobe
e. Brainstem

**4.** Which of the following scanning techniques measures glucose consumption as an indicator of brain activity?

a. CT
b. MRI
c. fMRI
d. PET
e. EEG

**5.** Which of the following is sometimes referred to as the brain's train hub, because it directs incoming sensory messages (with the exception of smell) to their proper places in the brain?

a. Hypothalamus
b. Pituitary
c. Cerebellum
d. Limbic system
e. Thalamus

**6.** Which of the following brain areas is responsible for regulating thirst?

a. Reticular activating system
b. Amygdala
c. Hypothalamus
d. Hippocampus
e. Brainstem

**7.** The hypothalamus is a(n) __________ center for the brain.

a. positioning
b. aggression
c. balance
d. memory
e. reward

**8.** Which of the following's primary function is processing memories?

a. Cerebral cortex
b. Medulla
c. Corpus callosum
d. Hippocampus
e. Hypothalamus

## Practice FRQs

**1.** Following a brain injury, Mike struggles to control his emotions and has difficulty establishing new memories. What parts of Mike's brain have most likely been affected by his injury?

### Answer

***1 point:*** Damage to the amygdala would make it difficult for Mike to control his emotions.

***1 point:*** Damage to the hippocampus would affect Mike's ability to establish new memories.

**2.** Identify the role of each of the following in listening to and taking notes during a psychology lecture.

- Hippocampus
- Cerebellum
- Cerebral cortex

***(3 points)***

# Module 12

## The Cerebral Cortex

Ed Kashi/Corbis

### Module Learning Objectives

**12-1** Identify the various regions of the cerebral cortex, and describe their functions.

**12-2** Discuss the brain's ability to reorganize itself, and define neurogenesis.

**12-1** What are the functions of the various cerebral cortex regions?

Older brain networks sustain basic life functions and enable memory, emotions, and basic drives. Newer neural networks within the *cerebrum*—the hemispheres that contribute 85 percent of the brain's weight—form specialized work teams that enable our perceiving, thinking, and speaking. Like other structures above the brainstem (including the thalamus, hippocampus, and amygdala), the cerebral hemispheres come as a pair. Covering those hemispheres, like bark on a tree, is the **cerebral cortex,** a thin surface layer of interconnected neural cells. It is your brain's thinking crown, your body's ultimate control and information-processing center.

As we move up the ladder of animal life, the cerebral cortex expands, tight genetic controls relax, and the organism's adaptability increases. Frogs and other small-cortex amphibians operate extensively on preprogrammed genetic instructions. The larger cortex of mammals offers increased capacities for learning and thinking, enabling them to be more adaptable. What makes us distinctively human mostly arises from the complex functions of our cerebral cortex.

**FYI**

The people who first dissected and labeled the brain used the language of scholars—Latin and Greek. Their words are actually attempts at graphic description: For example, *cortex* means "bark," *cerebellum* is "little brain," and *thalamus* is "inner chamber."

## Structure of the Cortex

If you opened a human skull, exposing the brain, you would see a wrinkled organ, shaped somewhat like the meat of an oversized walnut. Without these wrinkles, a flattened cerebral cortex would require triple the area—roughly that of a large pizza. The brain's left and right hemispheres are filled mainly with axons connecting the cortex to the brain's other regions. The cerebral cortex—that thin surface layer—contains some 20 to 23 billion nerve cells and 300 trillion synaptic connections (de Courten-Myers, 2005). Being human takes a lot of nerve.

Supporting these billions of nerve cells are nine times as many spidery **glial cells** ("glue cells"). Neurons are like queen bees; on their own they cannot feed or sheathe themselves. Glial cells are worker bees. They provide nutrients and insulating myelin, guide neural connections, and mop up ions and neurotransmitters. Glia may also play a role in learning and thinking. By "chatting" with neurons they may participate in information transmission and memory (Fields, 2009; Miller, 2005).

**cerebral** [seh-REE-bruhl] **cortex** the intricate fabric of interconnected neural cells covering the cerebral hemispheres; the body's ultimate control and information-processing center.

**glial cells (glia)** cells in the nervous system that support, nourish, and protect neurons; they may also play a role in learning and thinking.

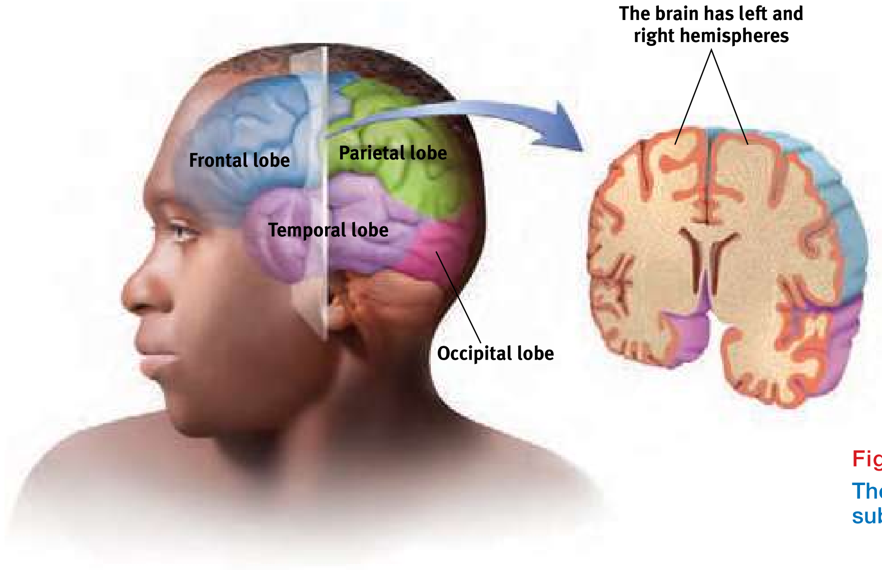



Figure 12.1
The cortex and its basic subdivisions

In more complex animal brains, the proportion of glia to neurons increases. A postmortem analysis of Einstein's brain did not find more or larger-than-usual neurons, but it did reveal a much greater concentration of glial cells than found in an average Albert's head (Fields, 2004).

Each hemisphere's cortex is subdivided into four *lobes,* separated by prominent *fissures,* or folds (**FIGURE 12.1**). Starting at the front of your brain and moving over the top, there are the **frontal lobes** (behind your forehead), the **parietal lobes** (at the top and to the rear), and the **occipital lobes** (at the back of your head). Reversing direction and moving forward, just above your ears, you find the **temporal lobes.** Each of the four lobes carries out many functions, and many functions require the interplay of several lobes.

**frontal lobes** portion of the cerebral cortex lying just behind the forehead; involved in speaking and muscle movements and in making plans and judgments.

**parietal** [puh-RYE-uh-tuhl] **lobes** portion of the cerebral cortex lying at the top of the head and toward the rear; receives sensory input for touch and body position.

**occipital** [ahk-SIP-uh-tuhl] **lobes** portion of the cerebral cortex lying at the back of the head; includes areas that receive information from the visual fields.

**temporal lobes** portion of the cerebral cortex lying roughly above the ears; includes the auditory areas, each receiving information primarily from the opposite ear.

**motor cortex** an area at the rear of the frontal lobes that controls voluntary movements.

## Functions of the Cortex

More than a century ago, surgeons found damaged cortical areas during autopsies of people who had been partially paralyzed or speechless. This rather crude evidence did not prove that specific parts of the cortex control complex functions like movement or speech. After all, if the entire cortex controlled speech and movement, damage to almost any area might produce the same effect. A TV with its power cord cut would go dead, but we would be fooling ourselves if we thought we had "localized" the picture in the cord.

### Motor Functions

Scientists had better luck in localizing simpler brain functions. For example, in 1870, German physicians Gustav Fritsch and Eduard Hitzig made an important discovery: Mild electrical stimulation to parts of an animal's cortex made parts of its body move. The effects were selective: Stimulation caused movement only when applied to an arch-shaped region at the back of the frontal lobe, running roughly ear-to-ear across the top of the brain. Moreover, stimulating parts of this region in the left or right hemisphere caused movements of specific body parts on the *opposite* side of the body. Fritsch and Hitzig had discovered what is now called the **motor cortex.**

#### MAPPING THE MOTOR CORTEX

Lucky for brain surgeons and their patients, the brain has no sensory receptors. Knowing this, Otfrid Foerster and Wilder Penfield were able to map the motor cortex in hundreds of wide-awake patients by stimulating different cortical areas and observing the body's responses.

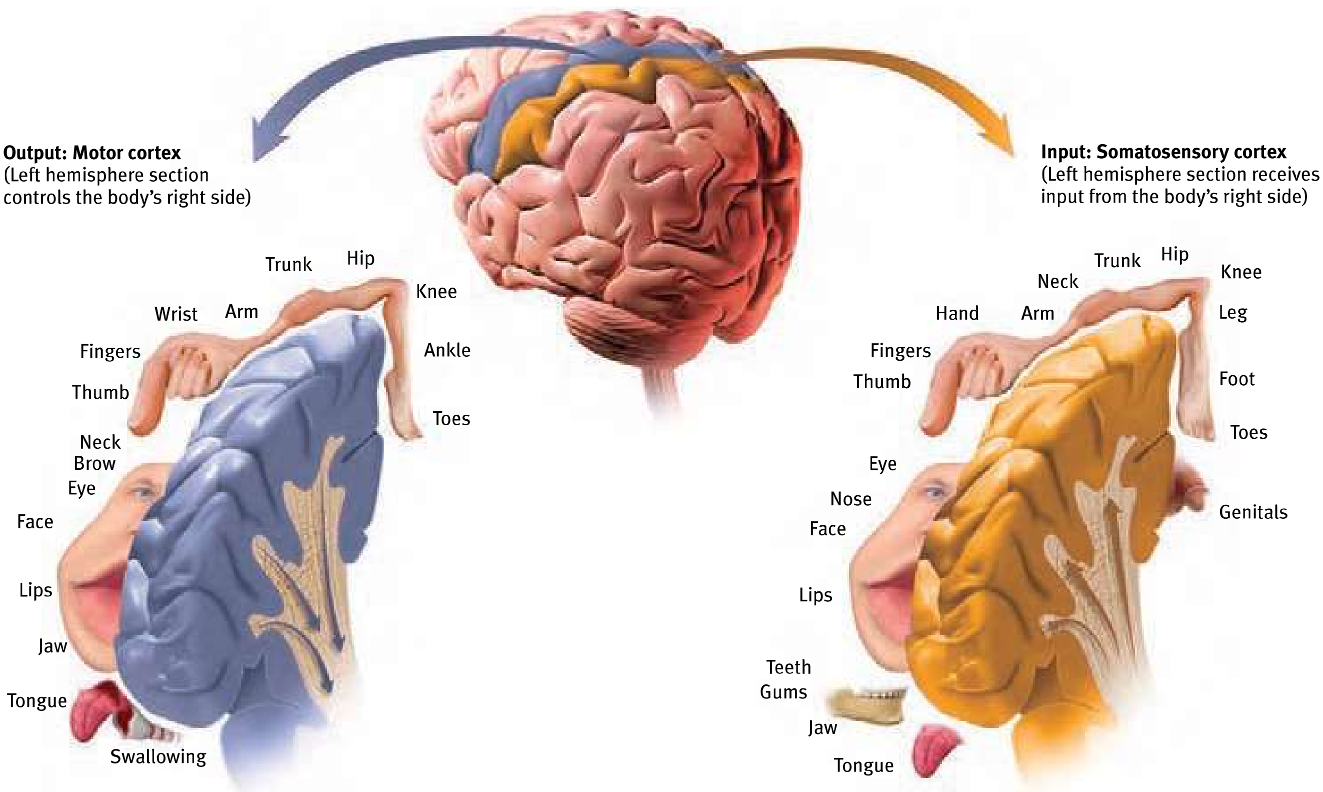



Figure 12.2

**Left hemisphere tissue devoted to each body part in the motor cortex and the somatosensory cortex** As you can see from this classic though inexact representation, the amount of cortex devoted to a body part in the motor cortex (in the frontal lobes) or in the somatosensory cortex (in the parietal lobes) is not proportional to that body part's size. Rather, the brain devotes more tissue to sensitive areas and to areas requiring precise control. Thus, the fingers have a greater representation in the cortex than does the upper arm.

They discovered that body areas requiring precise control, such as the fingers and mouth, occupy the greatest amount of cortical space (**FIGURE 12.2**).

In one of his many demonstrations of motor behavior mechanics, Spanish neuroscientist José Delgado stimulated a spot on a patient's left motor cortex, triggering the right hand to make a fist. Asked to keep the fingers open during the next stimulation, the patient, whose fingers closed despite his best efforts, remarked, "I guess, Doctor, that your electricity is stronger than my will" (Delgado, 1969, p. 114).

More recently, scientists were able to predict a monkey's arm motion a tenth of a second *before* it moved—by repeatedly measuring motor cortex activity preceding specific arm movements (Gibbs, 1996). Such findings have opened the door to research on brain-controlled computers.

## BRAIN-COMPUTER INTERFACES

By eavesdropping on the brain, could we enable someone—perhaps a paralyzed person—to move a robotic limb? Could a *brain-computer interface* command a cursor to write an e-mail or search the Internet? To find out, Brown University brain researchers implanted 100 tiny recording electrodes in the motor cortexes of three monkeys (Nicolelis & Chapin, 2002; Serruya et al., 2002). As the monkeys used a joystick to move a cursor to follow a moving red target (to gain rewards), the researchers matched the brain signals with the arm movements. Then they programmed a computer to monitor the signals and operate the joystick. When a monkey merely thought about a move, the mind-reading computer moved the cursor with nearly the same proficiency as had the reward-seeking monkey. In follow-up experiments, two monkeys were trained to control a robot arm that could grasp and deliver food (Velliste et al., 2008), and then a human did the same (**FIGURE 12.3**).

Hochberg et al., 2012. Reach and grasp by people with tetraplegia using a neurally controlled robotic arm. Nature, 485, pp. 372–375

**Figure 12.3**
**Mind over matter** A series of strokes left Cathy paralyzed for 15 years, unable to make even simple arm movements. Now, thanks to a tiny, 96-electrode implant in her brain's motor cortex, she is learning to direct a robotic arm with her thoughts (Hochberg et al., 2012).

Clinical trials of such *cognitive neural prosthetics* are now under way with people who have suffered paralysis or amputation (Andersen et al., 2010; Nurmikko et al., 2010). The first patient, a paralyzed 25-year-old man, was able to mentally control a TV, draw shapes on a computer screen, and play video games—all thanks to an aspirin-sized chip with 100 microelectrodes recording activity in his motor cortex (Hochberg et al., 2006). If everything psychological is also biological—if, for example, every thought is also a neural event—then microelectrodes perhaps could detect thoughts well enough to enable people to control events, as suggested by **FIGURE 12.4** on the next page.

## Sensory Functions

If the motor cortex sends messages out to the body, where does the cortex receive the incoming messages? Wilder Penfield also identified the cortical area that specializes in receiving information from the skin senses and from the movement of body parts. This area at the front of the parietal lobes, parallel to and just behind the motor cortex, we now call the **somatosensory cortex** (Figure 12.2). Stimulate a point on the top of this band of tissue and a person may report being touched on the shoulder; stimulate some point on the side and the person may feel something on the face.

**somatosensory cortex** area at the front of the parietal lobes that registers and processes body touch and movement sensations.

The more sensitive the body region, the larger the somatosensory cortex area devoted to it (Figure 12.2). Your supersensitive lips project to a larger brain area than do your toes, which is one reason we kiss with our lips rather than touch toes. Rats have a large area of the brain devoted to their whisker sensations, and owls to their hearing sensations.

Scientists have identified additional areas where the cortex receives input from senses other than touch. At this moment, you are receiving visual information in the visual cortex in your occipital lobes, at the very back of your brain (**FIGURES 12.5** and **12.6** on the next page). A bad enough bash there would make you blind. Stimulated there, you might see flashes of light or dashes of color. (In a sense, we *do* have eyes in the back of our head!) From your occipital lobes, visual information goes to other areas that specialize in tasks such as identifying words, detecting emotions, and recognizing faces.

Any sound you now hear is processed by your auditory cortex in your temporal lobes (just above your ears; see Figure 12.6). Most of this auditory information travels

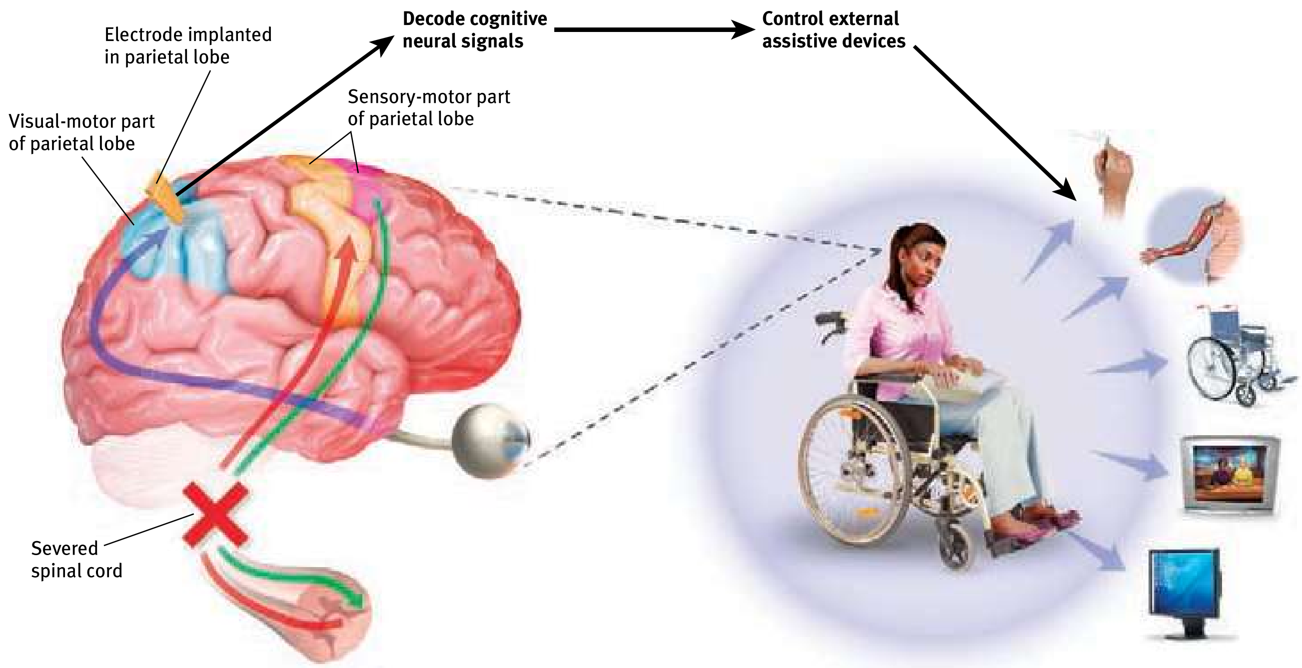



**Figure 12.4**
**Brain-computer interaction** A patient with a severed spinal cord has electrodes planted in a parietal lobe region involved with planning to reach out one's arm. The resulting signal can enable the patient to move a robotic limb, stimulate muscles that activate a paralyzed limb, navigate a wheelchair, control a TV, and use the Internet. (Graphic adapted from Andersen et al., 2010.)

a circuitous route from one ear to the auditory receiving area above your opposite ear. If stimulated there, you might hear a sound. MRI scans of people with schizophrenia reveal active auditory areas in the temporal lobes during auditory hallucinations (Lennox et al., 1999). Even the phantom ringing sound experienced by people with hearing loss is—if heard in one ear—associated with activity in the temporal lobe on the brain's opposite side (Muhlnickel, 1998).

Courtesy of V.P. Clark, K. Keill, J. Ma. Maisog, S. Courtney, L. G. Ungerleider, and J. V. Haxby, National Institutes of Health

**Figure 12.5**
**The brain in action** This fMRI (functional MRI) scan shows the visual cortex in the occipital lobes activated (color representation of increased bloodflow) as a research participant looks at a photo. When the person stops looking, the region instantly calms down.

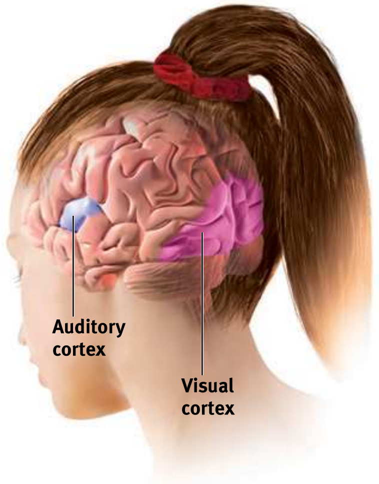



**Figure 12.6**
**The visual cortex and auditory cortex** The visual cortex of the occipital lobes at the rear of your brain receives input from your eyes. The auditory cortex, in your temporal lobes—above your ears—receives information from your ears.

## Association Areas

So far, we have pointed out small cortical areas that either receive sensory input or direct muscular output. Together, these occupy about one-fourth of the human brain's thin, wrinkled cover. What, then, goes on in the vast regions of the cortex? In these **association areas** (the peach-colored areas in **FIGURE 12.7**), neurons are busy with higher mental functions—many of the tasks that make us human.

**association areas** areas of the cerebral cortex that are not involved in primary motor or sensory functions; rather, they are involved in higher mental functions such as learning, remembering, thinking, and speaking.

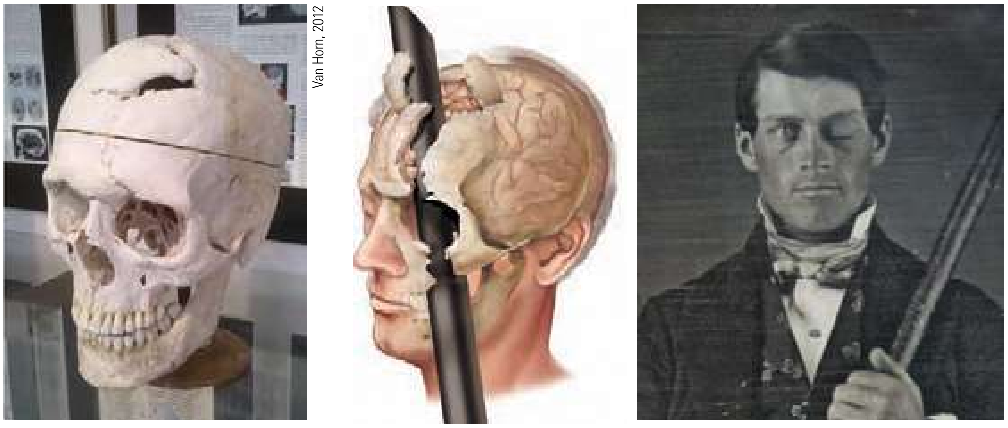
Electrically probing an association area won't trigger any observable response. So, unlike the sensory and motor areas, association area functions cannot be neatly mapped. Their silence has led to what Donald McBurney (1996, p. 44) has called "one of the hardiest weeds in the garden of psychology": the claim that we ordinarily use only 10 percent of our brains. (If true, wouldn't this imply a 90 percent chance that a bullet to your brain would land in an unused area?) Surgically lesioned animals and brain-damaged humans bear witness that association areas are not dormant. Rather, these areas interpret, integrate, and act on sensory information and link it with stored memories—a very important part of thinking.

Association areas are found in all four lobes. The *prefrontal cortex* in the forward part of the frontal lobes enables judgment, planning, and processing of new memories. People with damaged frontal lobes may have intact memories, high scores on intelligence tests, and great cake-baking skills. Yet they would not be able to plan ahead to *begin* baking a cake for a birthday party (Huey et al., 2006).


**Figure 12.7**
**Areas of the cortex in four mammals** More intelligent animals have increased "uncommitted" or association areas of the cortex. These vast areas of the brain are responsible for interpreting, integrating, and acting on sensory information and linking it with stored memories.

Frontal lobe damage also can alter personality and remove a person's inhibitions. Consider the classic case of railroad worker Phineas Gage. One afternoon in 1848, Gage, then 25 years old, was packing gunpowder into a rock with a tamping iron. A spark ignited the gunpowder, shooting the rod up through his left cheek and out the top of his skull, leaving his frontal lobes massively damaged (**FIGURE 12.8** on the next page). To everyone's amazement, he was immediately able to sit up and speak, and after the wound healed he returned to work. But the affable, soft-spoken man was now irritable, profane, and dishonest. This person, said his friends, was "no longer Gage." Although his mental abilities and memories were intact, his personality was not. (Although Gage lost his job, he did, over time, adapt to his injury and find work as a stagecoach driver [Macmillan & Lena, 2010].)

More recent studies of people with damaged frontal lobes have revealed similar impairments. Not only may they become less inhibited (without the frontal lobe brakes on their impulses), but their moral judgments may seem unrestrained by normal emotions. Would you advocate pushing someone in front of a runaway boxcar to save five others? Most people do not, but those with damage to a brain area behind the eyes often do (Koenigs et al., 2007). With their frontal lobes ruptured, people's moral compass seems to disconnect from their behavior.



Van Horn, 2012

Collection of Jack and Beverly Wilgus

(a) (b)

**Figure 12.8**
**A blast from the past**
(a) Gage's skull was kept as a medical record. Using measurements and modern neuroimaging techniques, researchers have reconstructed the probable path of the rod through Gage's brain (Damasio et al., 1994). (b) This recently discovered photo shows Gage after his accident. The image has been reversed to show the features correctly. (Early photos, such as this one, were actually mirror images.)

Association areas also perform other mental functions. In the parietal lobes, parts of which were large and unusually shaped in Einstein's normal-weight brain, they enable mathematical and spatial reasoning (Witelson et al., 1999). In patients undergoing brain surgery, stimulation of one parietal lobe area produced a feeling of wanting to move an upper limb, the lips, or the tongue (but without any actual movement). With increased stimulation, patients falsely believed they actually had moved. Curiously, when surgeons stimulated a different association area near the motor cortex in the frontal lobes, the patients did move but had no awareness of doing so (Desmurget et al., 2009). These head-scratching findings suggest that our perception of moving flows not from the movement itself, but rather from our intention and the results we expected.

Yet another association area, on the underside of the right temporal lobe, enables us to recognize faces. If a stroke or head injury destroyed this area of your brain, you would still be able to describe facial features and to recognize someone's gender and approximate age, yet be strangely unable to identify the person as, say, Lady Gaga, or even your grandmother.

Nevertheless, we should be wary of using pictures of brain "hot spots" to create a new phrenology that locates complex functions in precise brain areas (Uttal, 2001). Complex mental functions don't reside in any one place. There is no one spot in a rat's small association cortex that, when damaged, will obliterate its ability to learn or remember a maze.

Similarly, the acquisition, development, and use of language depends on both specialized neural networks and their integration. Nineteenth-century research by French physician Paul Broca and German investigator Carl Wernicke led to the discovery of specialized language brain areas. Damage to *Broca's area* disrupts speaking, while damage to *Wernicke's area* disrupts understanding. Today's neuroscience has shown that language functions are distributed across other brain areas as well.

**FYI**

For information on how distinct neural networks in your brain coordinate to enable language, see Module 36.

Memory, language, and attention result from the synchronized activity among distinct brain areas (Knight, 2007). Ditto for religious experience. Reports of more than 40 distinct brain regions becoming active in different religious states, such as praying and meditating, indicate that there is no simple "God spot" (Fingelkurts & Fingelkurts, 2009). The big lesson: *Our mental experiences arise from coordinated brain activity.*

## The Brain's Plasticity

**12-2** To what extent can a damaged brain reorganize itself, and what is neurogenesis?

Our brains are sculpted not only by our genes but also by our experiences. MRI scans show that well-practiced pianists have a larger-than-usual auditory cortex area that encodes piano sounds (Bavelier et al., 2000; Pantev et al., 1998). In Unit IX, we'll focus more on how experience molds the brain. For now, let's turn to another aspect of the brain's **plasticity:** its ability to modify itself after damage.

**plasticity** the brain's ability to change, especially during childhood, by reorganizing after damage or by building new pathways based on experience.

Some of the effects of brain damage described earlier can be traced to two hard facts: (1) Severed neurons, unlike cut skin, usually do not regenerate. (If your spinal cord were severed, you would probably be permanently paralyzed.) And (2) some brain functions seem preassigned to specific areas. One newborn who suffered damage to temporal lobe facial recognition areas later remained unable to recognize faces (Farah et al., 2000). But there is good news: Some of the brain's neural tissue can *reorganize* in response to damage. Under the surface of our awareness, the brain is constantly changing, building new pathways as it adjusts to little mishaps and new experiences.

Plasticity may also occur after serious damage, especially in young children (Kolb, 1989; see also **FIGURE 12.9**). Constraint-induced therapy aims to rewire brains and improve the dexterity of a brain-damaged child or even an adult stroke victim (Taub, 2004). By restraining a fully functioning limb, therapists force patients to use the "bad" hand or leg, gradually reprogramming the brain. One stroke victim, a surgeon in his fifties, was put to work cleaning tables, with his good arm and hand restrained. Slowly, the bad arm recovered its skills. As damaged-brain functions migrated to other brain regions, he gradually learned to write again and even to play tennis (Doidge, 2007).

The brain's plasticity is good news for those who are blind or deaf. Blindness or deafness makes unused brain areas available for other uses (Amedi et al., 2005). If a blind person uses one finger to read Braille, the brain area dedicated to that finger expands as the sense of touch invades the visual cortex that normally helps people see (Barinaga, 1992a; Sadato et al., 1996). Plasticity also helps explain why some studies find that deaf people have enhanced peripheral vision (Bosworth & Dobkins, 1999). In those people whose native language is sign, the temporal lobe area normally dedicated to hearing waits in vain for stimulation. Finally, it looks for other signals to process, such as those from the visual system.

Similar reassignment may occur when disease or damage frees up other brain areas normally dedicated to specific functions. If a slow-growing left hemisphere tumor disrupts language (which resides mostly in the left hemisphere), the right hemisphere may compensate (Thiel et al., 2006). If a finger is amputated, the somatosensory cortex that received its input will begin to receive input from the adjacent fingers, which then become more sensitive (Fox, 1984).

Although the brain often attempts self-repair by reorganizing existing tissue, it sometimes attempts to mend itself by producing new brain cells. This process, known as

MIKE THEILER/UPI/ Newscom

**Figure 12.9**

**Brain plasticity** Although the brains of young children show the greatest ability to reorganize and adapt to damage, adult brains also have some capacity for self-repair. Former Arizona Congresswoman Gabrielle Giffords lost her ability to speak after suffering a left-hemisphere gunshot wound. Her medical care included music therapy, where she worked on forming words to familiar songs such as "Happy Birthday." Giffords has since partly recovered her speaking ability. Two years after the shooting, she was able to speak as a surprise witness at a 2013 U.S. Senate hearing on gun legislation.

**neurogenesis** the formation of new neurons.

**neurogenesis,** has been found in adult mice, birds, monkeys, and humans (Jessberger et al., 2008). These baby neurons originate deep in the brain and may then migrate elsewhere and form connections with neighboring neurons (Aimone et al., 2010; Gould, 2007).

Master stem cells that can develop into any type of brain cell have also been discovered in the human embryo. If mass-produced in a lab and injected into a damaged brain, might neural stem cells turn themselves into replacements for lost brain cells? Might we someday be able to rebuild damaged brains, much as we reseed damaged lawns? Might new drugs spur the production of new nerve cells? Stay tuned. Today's biotech companies are hard at work on such possibilities. In the meantime, we can all benefit from other natural promoters of neurogenesis, such as exercise, sleep, and nonstressful but stimulating environments (Iso et al., 2007; Pereira et al., 2007; Stranahan et al., 2006).

## Before You Move On

**▶ ASK YOURSELF**

Has what you have learned about how our brains enable our minds affected your view of human nature?

**▶ TEST YOURSELF**

Try moving your right hand in a circular motion, as if polishing a table. Then start your right foot doing the same motion, synchronized with your hand. Now reverse the right foot's motion, but not the hand's. Finally, try moving the *left* foot opposite to the right hand.

1. Why is reversing the right foot's motion so hard?
2. Why is it easier to move the left foot opposite to the right hand?

*Answers to the Test Yourself questions can be found in Appendix E at the end of the book.*

# Module 12 Review

### 12-1 What are the functions of the various cerebral cortex regions?

- The *cerebral cortex* has two hemispheres, and each hemisphere has four lobes: the *frontal, parietal, occipital,* and *temporal.* Each lobe performs many functions and interacts with other areas of the cortex.
- *Glial cells* support, nourish, and protect neurons and may also play a role in learning and thinking.
- The *motor cortex,* at the rear of the frontal lobes, controls voluntary movements.
- The *somatosensory cortex,* at the front of the parietal lobes, registers and processes body touch and movement sensations.
- Body parts requiring precise control or those that are especially sensitive occupy the greatest amount of space in the motor cortex and somatosensory cortex, respectively.
- Most of the brain's cortex—the major portion of each of the four lobes—is devoted to uncommitted *association areas,* which integrate information involved in learning, remembering, thinking, and other higher-level functions.
- Our mental experiences arise from coordinated brain activity.

### 12-2 To what extent can a damaged brain reorganize itself, and what is neurogenesis?

- If one hemisphere is damaged early in life, the other will pick up many of its functions by reorganizing or building new pathways. This *plasticity* diminishes later in life.
- The brain sometimes mends itself by forming new neurons, a process known as *neurogenesis.*

## Multiple-Choice Questions

**1.** Damage to which of the following could interfere with the ability to plan for the future?

a. Frontal lobe
b. Temporal lobe
c. Parietal lobe
d. Occipital lobe
e. Somatosensory cortex

**2.** In general, damage to _________ disrupts speaking, while damage to _________ disrupts understanding of language.

a. the frontal lobe; the occipital lobe
b. the temporal lobe; the frontal lobe
c. the occipital lobe; the temporal lobe
d. Wernicke's area; Broca's area
e. Broca's area; Wernicke's area

**3.** Stimulation at a point on which of the following may cause a person to report being touched on the knee?

a. Motor cortex
b. Cerebellum
c. Somatosensory cortex
d. Temporal lobe
e. Thalamus

**4.** George can move his hand to sign a document because the _________, located in the _________ lobe of the brain, allows him to activate the proper muscles.

a. somatosensory cortex; temporal
b. somatosensory cortex; parietal
c. motor cortex; parietal
d. somatosensory cortex; frontal
e. motor cortex; frontal

**5.** The most noticeable difference between human brains and other mammalian brains is the size of the

a. association areas.
b. frontal lobe.
c. glial cells.
d. reticular activating system.
e. visual cortex.

**6.** Cognitive neural prosthetics are placed in the brain to help control parts of the

a. motor cortex.
b. auditory cortex.
c. somatosensory cortex.
d. visual cortex.
e. parietal lobe.

## Practice FRQs

**1.** Doctors sometimes have to remove a portion of the brain to control life-threatening seizures. Describe what the results of the removal of a portion of the motor cortex would be and explain how this procedure might be affected by brain plasticity.

### Answer

***1 point:*** Removing part of the motor cortex will result in paralysis in the parts of the body associated with the removed tissue.

***1 point:*** Because of brain plasticity, the person's brain may be able to change and reorganize new pathways based on experience. This is more likely if the person is a child.

**2.** Anthony attends a high school band concert. First, identify and explain which two lobes of his brain are most important for watching and listening to the concert. Second, explain which lobe of the brain is most responsible for analyzing the music and finding personal meaning.

***(3 points)***