# Module 20

## Hearing


Leland Bobbé/CORBIS

### Module Learning Objectives

**20-1** Describe the characteristics of air pressure waves, and explain the process by which the ear transforms sound energy into neural messages.

**20-2** Discuss the theories that help us understand pitch perception.

**20-3** Describe how we locate sounds.

**20-1** What are the characteristics of air pressure waves that we hear as sound, and how does the ear transform sound energy into neural messages?

Like our other senses, our **audition,** or hearing, is highly adaptive. We hear a wide range of sounds, but the ones we hear best are those sounds with frequencies in a range corresponding to that of the human voice. Those with normal hearing are acutely sensitive to faint sounds, an obvious boon for our ancestors' survival when hunting or being hunted, or for detecting a child's whimper. (If our ears were much more sensitive, we would hear a constant hiss from the movement of air molecules.)

**audition** the sense or act of hearing.

We are also remarkably attuned to variations in sounds. We easily detect differences among thousands of possible human voices: Walking between classes, we immediately recognize the voice of a friend behind us. A fraction of a second after a spoken word stimulates the ear's receptors, millions of neurons have simultaneously coordinated in extracting the essential features, comparing them with past experience, and identifying the stimulus (Freeman, 1991).

**AP® Exam Tip**

Pay attention to how many pages are devoted to each of the senses. Not only does this represent the complexity of the sensory system, it also represents how likely you are to find questions about that system on the AP® exam. More pages are devoted to vision than hearing, and vision questions are somewhat more likely to appear on the exam.

But not everyone has this ability. Some years ago, on a visit to my childhood home, I communicated with my then 80-year-old mother by writing on her erasable "magic pad." Four years earlier she had transitioned from hearing loss to complete deafness by giving up her now useless hearing aids.

"Do you hear anything?" I wrote.

"No," she answered, her voice still strong although she could not hear it. "Last night your Dad came in and found the TV blasting. Someone had left the volume way up; I didn't hear a thing." (Indeed, my father later explained, he recently tested her by sneaking up while she was reading and giving a loud clap just behind her ear. Her eye never wavered from the page.)

What is it like, I wondered. "A silent world?"

"Yes," she replied. "It's a silent world."

And for her, with human connections made difficult, it became a socially isolated world. "Not having understood what was said in a group," she reminisced, "I would chime in and say the same thing someone else had just said—and everyone would laugh. I would be so embarrassed, I wanted to fall through the floor." Increasingly, her way of coping was to avoid getting out onto the floor in the first place. She shied away from public events and found excuses to avoid people who didn't understand.

Our exchange left me wondering: Will I—having inherited her progressive hearing loss—also become socially isolated? Or, aided by today's better technology, can I keep my private vow not to repeat her past? Hearing allows mind-to-mind communication and enables connection. Yet many of us can and do connect despite hearing loss—with help from technology, lip-reading, and signing. For me, it's worth the effort. Communicating with others affirms our humanity as social creatures.

So, how does hearing normally work? How do we harvest meaning from the air pressure waves sent from another's mouth?

## The Stimulus Input: Sound Waves

**The sounds of music** A violin's short, fast waves create a high pitch, a cello's longer, slower waves a lower pitch. Differences in the waves' height, or amplitude, also create differing degrees of loudness. (To review the physical properties of light and sound waves, see Figure 18.2 in Module 18.)

Dennis MacDonald/Photo Edit

Draw a bow across a violin, and you will unleash the energy of sound waves. Jostling molecules of air, each bumping into the next, create waves of compressed and expanded air, like the ripples on a pond circling out from a tossed stone. As we swim in our ocean of moving air molecules, our ears detect these brief air pressure changes. (Exposed to a loud, low bass sound—perhaps from a bass guitar or a cello—we can also *feel* the vibration. We hear by both air and bone conduction.)

Like light waves, sound waves vary in shape. The *amplitude* of sound waves determines their *loudness.* Their length, or **frequency,** determines the **pitch** we experience. Long waves have low frequency—and low pitch. Short waves have high frequency—and high pitch. Sound waves produced by a violin are much shorter and faster than those produced by a cello or a bass guitar.

**AP® Exam Tip**

Note that both light and sound travel in waves. In each case, the amplitude and length of the waves are important.

We measure sounds in *decibels,* with zero decibels representing the absolute threshold for hearing. Every 10 decibels correspond to a tenfold increase in sound intensity. Thus, normal conversation (60 decibels) is 10,000 times more intense than a 20-decibel whisper. And a temporarily tolerable 100-decibel passing subway train is 10 billion times more intense than the faintest detectable sound.

## The Ear

The intricate process that transforms vibrating air into nerve impulses, which our brain decodes as sounds, begins when sound waves enter the outer ear. A mechanical chain reaction begins as the visible *outer ear* channels the waves through the auditory canal to the *eardrum,* a tight membrane, causing it to vibrate (**FIGURE 20.1** on the next page). In the **middle ear** three tiny bones (the *hammer, anvil,* and *stirrup*) pick up the vibrations and transmit them to the **cochlea,** a snail-shaped tube in the **inner ear.** The incoming vibrations cause the cochlea's membrane (the *oval window*) to vibrate, jostling the fluid that fills the tube. This motion causes ripples in the *basilar membrane,* bending the *hair cells* lining its surface, not unlike the wind bending a wheat field. Hair cell movement triggers impulses in the adjacent nerve cells. Axons of those cells converge to form the *auditory nerve,* which sends neural messages (via the thalamus) to the *auditory cortex* in the brain's temporal lobe. From vibrating air to fluid waves to electrical impulses to the brain: Voila! We hear.

**frequency** the number of complete wavelengths that pass a point in a given time (for example, per second).

**pitch** a tone's experienced highness or lowness; depends on frequency.

**middle ear** the chamber between the eardrum and cochlea containing three tiny bones (hammer, anvil, and stirrup) that concentrate the vibrations of the eardrum on the cochlea's oval window.

**cochlea** [KOHK-lee-uh] a coiled, bony, fluid-filled tube in the inner ear; sound waves traveling through the cochlear fluid trigger nerve impulses.

**inner ear** the innermost part of the ear, containing the cochlea, semicircular canals, and vestibular sacs.

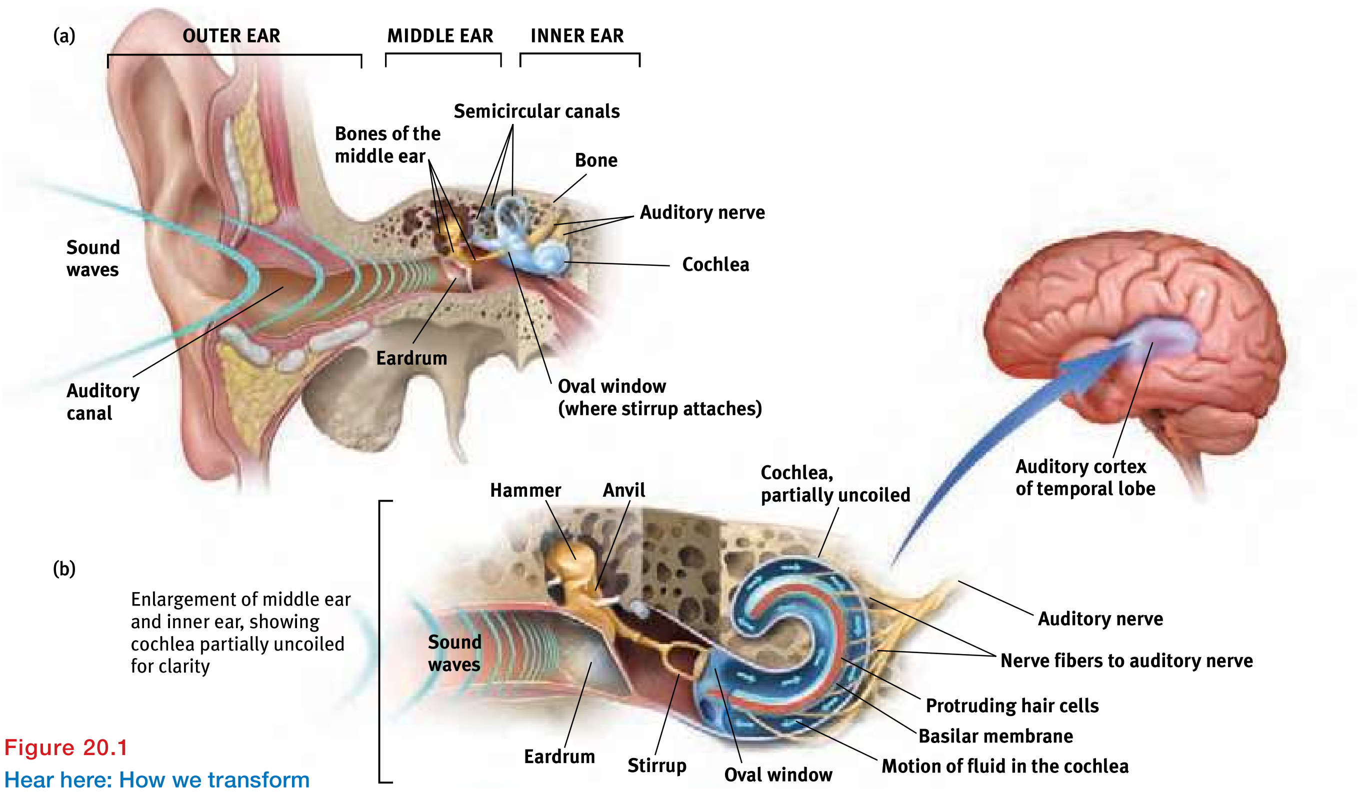
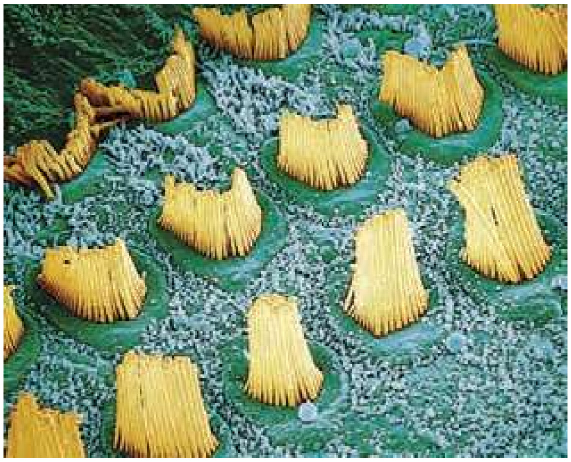



**Figure 20.1**

**Hear here: How we transform sound waves into nerve impulses that our brain interprets** (a) The outer ear funnels sound waves to the eardrum. The bones of the middle ear (hammer, anvil, and stirrup) amplify and relay the eardrum's vibrations through the oval window into the fluid-filled cochlea. (b) As shown in this detail of the middle and inner ear, the resulting pressure changes in the cochlear fluid cause the basilar membrane to ripple, bending the hair cells on its surface. Hair cell movements trigger impulses at the base of the nerve cells, whose fibers converge to form the auditory nerve. That nerve sends neural messages to the thalamus and on to the auditory cortex.

My vote for the most intriguing part of the hearing process is the hair cells—"quivering bundles that let us hear" thanks to their "extreme sensitivity and extreme speed" (Goldberg, 2007). A cochlea has 16,000 of them, which sounds like a lot until we compare that with an eye's 130 million or so photoreceptors. But consider their responsiveness. Deflect the tiny bundles of *cilia* on the tip of a hair cell by the width of an atom—the equivalent of displacing the top of the Eiffel Tower by half an inch—and the alert hair cell, thanks to a special protein at its tip, triggers a neural response (Corey et al., 2004).



Susumu Nishinaga/Science Source

**Be kind to your inner ear's hair cells** When vibrating in response to sound, the hair cells shown here lining the cochlea produce an electrical signal.

Damage to the cochlea's hair cell receptors or their associated nerves can cause **sensorineural hearing loss** (or nerve deafness). (A less common form of hearing loss is **conduction hearing loss,** caused by damage to the mechanical system that conducts sound waves to the cochlea.) Occasionally, disease causes sensorineural hearing loss, but more often the culprits are biological changes linked with heredity, aging, and prolonged exposure to ear-splitting noise or music.

**sensorineural hearing loss** hearing loss caused by damage to the cochlea's receptor cells or to the auditory nerves; also called *nerve deafness*.

**conduction hearing loss** hearing loss caused by damage to the mechanical system that conducts sound waves to the cochlea.

Hair cells have been likened to carpet fibers. Walk around on them and they will spring back with a quick vacuuming. But leave a heavy piece of furniture on them for a long time and they may never rebound. As a general rule, if we cannot talk over a noise, it is potentially harmful, especially if prolonged and repeated (Roesser, 1998). Such experiences are common when sound exceeds 100 decibels, as happens in venues from frenzied sports arenas to bagpipe bands to personal music coming through our earphones near maximum volume (**FIGURE 20.2**). Ringing of the ears after exposure to loud machinery or music indicates that we have been bad to our unhappy hair cells. As pain alerts us to possible bodily harm, ringing of the ears alerts us to possible hearing damage. It is hearing's equivalent of bleeding.

The rate of teen hearing loss, now 1 in 5, has risen by one-third since the early 1990s (Shargorodsky et al., 2010). Teen boys more than teen girls or adults blast themselves with loud volumes for long periods (Zogby, 2006). Males' greater noise exposure may help explain why men's hearing tends to be less acute than women's. But male or female, those who spend many hours in a loud nightclub, behind a power mower, or above a jackhammer should wear earplugs. "Condoms or, safer yet, abstinence," say sex educators. "Earplugs or walk away," say hearing educators.

AP Photo/Mark J. Terrill

**That Baylen may hear** When Super Bowl-winning quarterback Drew Brees celebrated New Orleans' 2010 victory amid pandemonium, he used ear muffs to protect the vulnerable hair cells of his son, Baylen.

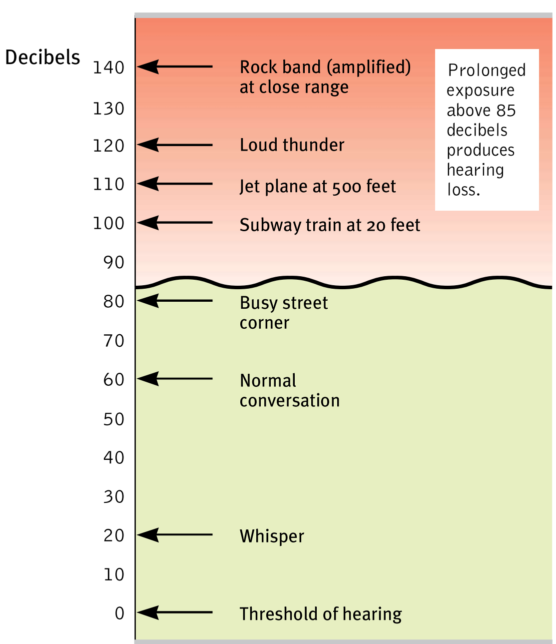
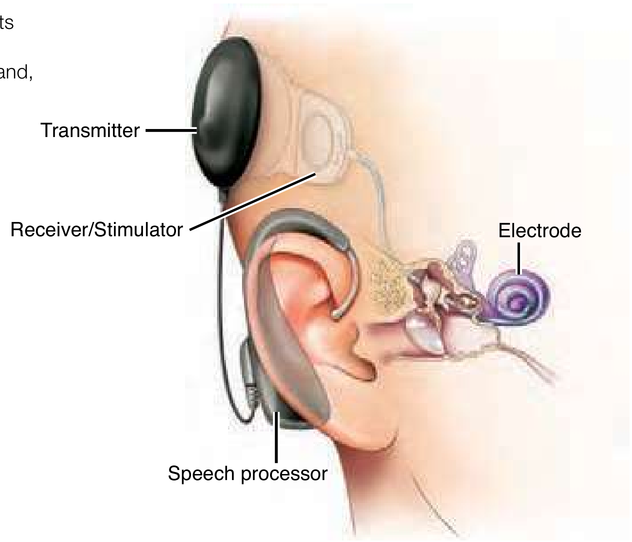



**Figure 20.2**
**The intensity of some common sounds**

Mark Holloway/Getty Images

**Hardware for hearing** Cochlear implants work by translating sounds into electrical signals that are transmitted to the cochlea and, via the auditory nerve, on to the brain.




**cochlear implant** a device for converting sounds into electrical signals and stimulating the auditory nerve through electrodes threaded into the cochlea.

For now, the only way to restore hearing for people with nerve deafness is a sort of bionic ear—a **cochlear implant**, which, by 2009, had been given to 188,000 people worldwide (NIDCD, 2011). This electronic device translates sounds into electrical signals that, wired into the cochlea's nerves, convey information about sound to the brain. Cochlear implants given to deaf kittens and human infants seem to trigger an "awakening" of the pertinent brain area (Klinke et al., 1999; Sirenteanu, 1999). They can help children become proficient in oral communication (especially if they receive them as preschoolers or even before age 1) (Dettman et al., 2007; Schorr et al., 2005).

The latest cochlear implants also can help restore hearing for most adults. However, the implants will not enable normal hearing in adults if their brain never learned to process sound during childhood. Similarly, cochlear implants did not enable hearing in deaf-from-birth cats that received them when fully grown rather than as 8-week-old kittens (Ryugo et al., 2010).

## Perceiving Loudness

How do we detect loudness? It is not, as I would have guessed, from the intensity of a hair cell's response. Rather, a soft, pure tone activates only the few hair cells attuned to its frequency. Given louder sounds, neighboring hair cells also respond. Thus, the brain can interpret loudness from the *number* of activated hair cells.

**FYI**

Experiments are also under way to restore vision—with a bionic retina (a 2-millimeter-diameter microchip with photoreceptors that stimulate damaged retinal cells), and with a video camera and computer that stimulate the visual cortex. In test trials, both devices have enabled blind people to gain partial sight (Boahen, 2005; Steenhuysen, 2002).

If a hair cell loses sensitivity to soft sounds, it may still respond to loud sounds. This helps explain another surprise: Really loud sounds may seem loud to people with or without normal hearing. As a person with hearing loss, I used to wonder what really loud music must sound like to people with normal hearing. Now I realize it sounds much the same; where we differ is in our sensation of soft sounds. This is why we hard-of-hearing people do not want *all* sounds (loud and soft) amplified. We like sound *compressed*—which means harder-to-hear sounds are amplified more than loud sounds (a feature of today's digital hearing aids).

## Perceiving Pitch

**20-2** What theories help us understand pitch perception?

How do we know whether a sound is the high-frequency, high-pitched chirp of a bird or the low-frequency, low-pitched roar of a truck? Current thinking on how we discriminate pitch, like current thinking on how we discriminate color, combines two theories.

- Hermann von Helmholtz's **place theory** presumes that we hear different pitches because different sound waves trigger activity at different places along the cochlea's basilar membrane. Thus, the brain determines a sound's pitch by recognizing the specific place (on the membrane) that is generating the neural signal. When Nobel laureate-to-be Georg von Békésy (1957) cut holes in the cochleas of guinea pigs and human cadavers and looked inside with a microscope, he discovered that the cochlea vibrated, rather like a shaken bedsheet, in response to sound. High frequencies produced large vibrations near the beginning of the cochlea's membrane. Low frequencies vibrate more of the membrane, including near the end. But a problem remains: Place theory can explain how we hear high-pitched sounds but not low-pitched sounds. The neural signals generated by low-pitched sounds are not so neatly localized on the basilar membrane.
- **Frequency theory** suggests an alternative: The brain reads pitch by monitoring the frequency of neural impulses traveling up the auditory nerve. The whole basilar membrane vibrates with the incoming sound wave, triggering neural impulses to the brain at the same rate as the sound wave. If the sound wave has a frequency of 100 waves per second, then 100 pulses per second travel up the auditory nerve. But again, a problem remains: An individual neuron cannot fire faster than 1000 times per second. How, then, can we sense sounds with frequencies above 1000 waves per second (roughly the upper third of a piano keyboard)?
- Enter the *volley principle:* Like soldiers who alternate firing so that some can shoot while others reload, neural cells can alternate firing. By firing in rapid succession, they can achieve a *combined frequency* above 1000 waves per second. Thus, place theory best explains how we sense *high pitches,* frequency theory best explains how we sense *low pitches,* and some combination of place and frequency seems to handle the *pitches in the intermediate range.*

**place theory** in hearing, the theory that links the pitch we hear with the place where the cochlea's membrane is stimulated.

**frequency theory** in hearing, the theory that the rate of nerve impulses traveling up the auditory nerve matches the frequency of a tone, thus enabling us to sense its pitch.

## Locating Sounds

**20-3** How do we locate sounds?

Why don't we have one big ear—perhaps above our one nose? "All the better to hear you with," as the wolf said to Red Riding Hood. As the placement of our eyes allows us to sense visual depth, so the placement of our two ears allows us to enjoy stereophonic ("three-dimensional") hearing.

Two ears are better than one for at least two reasons. If a car to the right honks, your right ear receives a more *intense* sound, and it receives sound slightly *sooner* than your left ear (**FIGURE 20.3**). Because sound travels 750 miles per hour and our ears are but 6 inches apart, the intensity difference and the time lag are extremely small. A just noticeable difference in the direction of two sound sources corresponds to a time difference of just 0.000027 second! Lucky for us, our supersensitive auditory system can detect such minute differences (Brown & Deffenbacher, 1979; Middlebrooks & Green, 1991).

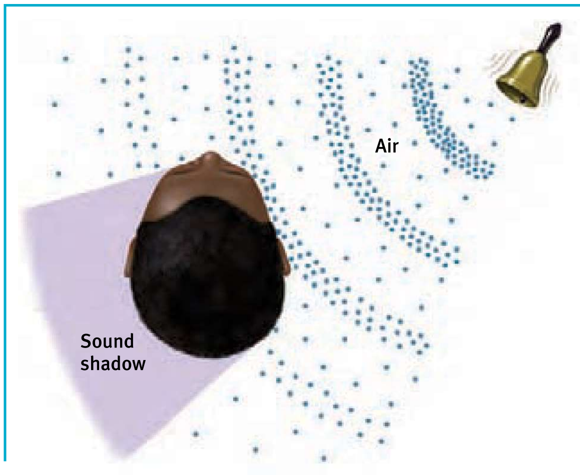



**Figure 20.3** **How we locate sounds** Sound waves strike one ear sooner and more intensely than the other. From this information, our nimble brain computes the sound's location. As you might therefore expect, people who lose all hearing in one ear often have difficulty locating sounds.

## Before You Move On

### ► ASK YOURSELF

If you are a hearing person, imagine that you had been born deaf. Do you think your life would be different?

### ► TEST YOURSELF

What are the basic steps in transforming sound waves into perceived sound?

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

# Module 20 Review

### 20-1 What are the characteristics of air pressure waves that we hear as sound, and how does the ear transform sound energy into neural messages?

- Sound waves are bands of compressed and expanded air. Our ears detect these changes in air pressure and transform them into neural impulses, which the brain decodes as sound.
- Sound waves vary in amplitude, which we perceive as differing loudness, and in *frequency,* which we experience as differing *pitch.*
- The outer ear is the visible portion of the ear. The *middle ear* is the chamber between the eardrum and *cochlea.*
- The *inner ear* consists of the cochlea, semicircular canals, and vestibular sacs.
- Through a mechanical chain of events, sound waves traveling through the auditory canal cause tiny vibrations in the eardrum. The bones of the middle ear (the *hammer, anvil,* and *stirrup*) amplify the vibrations and relay them to the fluid-filled cochlea. Rippling of the basilar membrane, caused by pressure changes in the cochlear fluid, causes movement of the tiny hair cells, triggering neural messages to be sent (via the thalamus) to the auditory cortex in the brain.
- *Sensorineural hearing loss* (or nerve deafness) results from damage to the cochlea's hair cells or their associated nerves. *Conduction hearing loss* results from damage to the mechanical system that transmits sound waves to the cochlea. *Cochlear implants* can restore hearing for some people.

### 20-2 What theories help us understand pitch perception?

- *Place theory* explains how we hear high-pitched sounds, and *frequency theory* explains how we hear low-pitched sounds. (A combination of the two theories (the volley principle) explains how we hear pitches in the middle range.)
  - *Place theory* proposes that our brain interprets a particular pitch by decoding the place where a sound wave stimulates the cochlea's basilar membrane.
  - *Frequency theory* proposes that the brain deciphers the frequency of the neural impulses traveling up the auditory nerve to the brain.

### 20-3 How do we locate sounds?

- Sound waves strike one ear sooner and more intensely than the other. The brain analyzes the minute differences in the sounds received by the two ears and computes the sound's source.

## Multiple-Choice Questions

**1.** What type of hearing loss is due to damage to the mechanism that transmits sound waves to the cochlea?

a. Sensorineural
b. Window-related
c. Conduction
d. Cochlear
e. Basilar

**2.** Pitch depends on which of the following?

a. Amplitude of a sound wave
b. Number of hair cells stimulated
c. Strength of nerve impulses traveling up the auditory nerve
d. Number of sound waves that reach the ear in a given time
e. Decibels of a sound wave

**3.** Which of the following reflects the notion that pitch is related to the number of impulses traveling up the auditory nerve in a unit of time?

a. Place theory
b. Frequency theory
c. Volley principle
d. Sound localization
e. Stereophonic hearing

**4.** The three small bones of the ear are located in the

a. cochlea.
b. outer ear.
c. inner ear.
d. middle ear.
e. auditory nerve.

## Practice FRQs

**1.** Describe two parts of the ear that transmit sound waves before they reach the hair cells.

### Answer

Students may describe any two of the following:

***1 point:*** The eardrum, a tight membrane separating the middle ear from the outer ear.

***1 point:*** The three bones in the middle ear that transmit sound waves between the eardrum and the cochlea.

***1 point:*** The oval window, the point at which vibrations enter the cochlea.

***1 point:*** The cochlea, where the fluid inside vibrates and the hair cells are stimulated.

**2.** What roles do the outer, middle, and inner ear play in helping a person hear a song on the radio?

***(3 points)***

# Module 21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## The Other Senses

### Module Learning Objectives

**21-1** Describe the sense of touch.

**21-2** Discuss how we best understand and control pain.

**21-3** Describe the senses of taste and smell.

**21-4** Explain how we sense our body's position and movement.

**21-5** Describe how our senses interact.

Although our brain gives seeing and hearing priority in the allocation of cortical tissue, extraordinary happenings occur within our four other senses—our senses of touch, taste, smell, and body position and movement. Sharks and dogs rely on their extraordinary sense of smell, aided by large brain areas devoted to this system. Without our own senses of touch, taste, smell, and body position and movement, we humans would also be seriously handicapped, and our capacities for enjoying the world would be seriously diminished.

## Touch

**21-1** How do we sense touch?

"Touch is both the alpha and omega of affection." -William James (1890)

Although not the first sense to come to mind, touch is vital. Right from the start, touch is essential to our development. Infant rats deprived of their mother's grooming produce less growth hormone and have a lower metabolic rate—a good way to keep alive until the mother returns, but a reaction that stunts growth if prolonged. Infant monkeys allowed to see, hear, and smell—but not touch—their mother become desperately unhappy; those separated by a screen with holes that allow touching are much less miserable. As we will see in Module 46, premature human babies gain weight faster and go home sooner if they are stimulated by hand massage. As lovers, we yearn to touch—to kiss, to stroke, to snuggle. And even strangers, touching only the other's forearms and separated by a curtain, can communicate anger, fear, disgust, love, gratitude, and sympathy at levels well above chance (Hertenstein et al., 2006).

Humorist Dave Barry may be right to jest that your skin "keeps people from seeing the inside of your body, which is repulsive, and it prevents your organs from falling onto the ground." But skin does much more. Our "sense of touch" is actually a mix of distinct skin senses for pressure, warmth, cold, and pain. Touching various spots on the skin with a soft hair, a warm or cool wire, and the point of a pin reveals that some spots are especially sensitive to pressure, others to warmth, others to cold, still others to pain. Other skin sensations are variations of the basic four (*pressure, warmth, cold,* and *pain*):

- Stroking adjacent pressure spots creates a tickle.
- Repeated gentle stroking of a pain spot creates an itching sensation.
- Touching adjacent cold and pressure spots triggers a sense of wetness, which you can experience by touching dry, cold metal.
- Stimulating nearby cold and warm spots produces the sensation of hot (**FIGURE 21.1**).

Touch sensations involve more than tactile stimulation, however. A self-produced tickle produces less somatosensory cortex activation than does the same tickle from something or someone else (Blakemore et al., 1998). (The brain is wise enough to be most sensitive to unexpected stimulation.)


**Figure 21.1**
**Warm + cold = hot** When ice-cold water passes through one coil and comfortably warm water through another, we perceive the combined sensation as burning hot.

# Pain

**21-2** How can we best understand and control pain?

Be thankful for occasional pain. Pain is your body's way of telling you something has gone wrong. Drawing your attention to a burn, a break, or a sprain, pain orders you to change your behavior—"Stay off that turned ankle!" The rare people born without the ability to feel pain may experience severe injury or even die before early adulthood. Without the discomfort that makes us occasionally shift position, their joints fail from excess strain, and without the warnings of pain, the effects of unchecked infections and injuries accumulate (Neese, 1991).

More numerous are those who live with chronic pain, which is rather like an alarm that won't shut off. The suffering of those with persistent or recurring backaches, arthritis, headaches, and cancer-related pain, prompts two questions: What is pain? How might we control it?

**"Pain is a gift"** So said a doctor studying 13-year-old Ashlyn Blocker. Ashlyn has a rare genetic mutation that prevents her feeling pain. At birth she didn't cry. As a child, she ran around for two days on a broken ankle. She has put her hands on a hot machine and burned the flesh off. And she has reached into boiling water to retrieve a dropped spoon. "Everyone in my class asks me about it, and I say, 'I can feel pressure, but I can't feel pain.' *Pain!* I cannot feel it!" (Heckert, 2010).
Jeff Riedel/Contour by Getty Images

## Understanding Pain

Our pain experiences vary widely. Women are more pain sensitive than men are (Wickelgren, 2009). Individual pain sensitivity varies, too, depending on genes, physiology, experience, attention, and surrounding culture (Gatchel et al., 2007; Reimann et al., 2010). Thus, feeling pain reflects both bottom-up sensations and top-down processes.

### BIOLOGICAL INFLUENCES

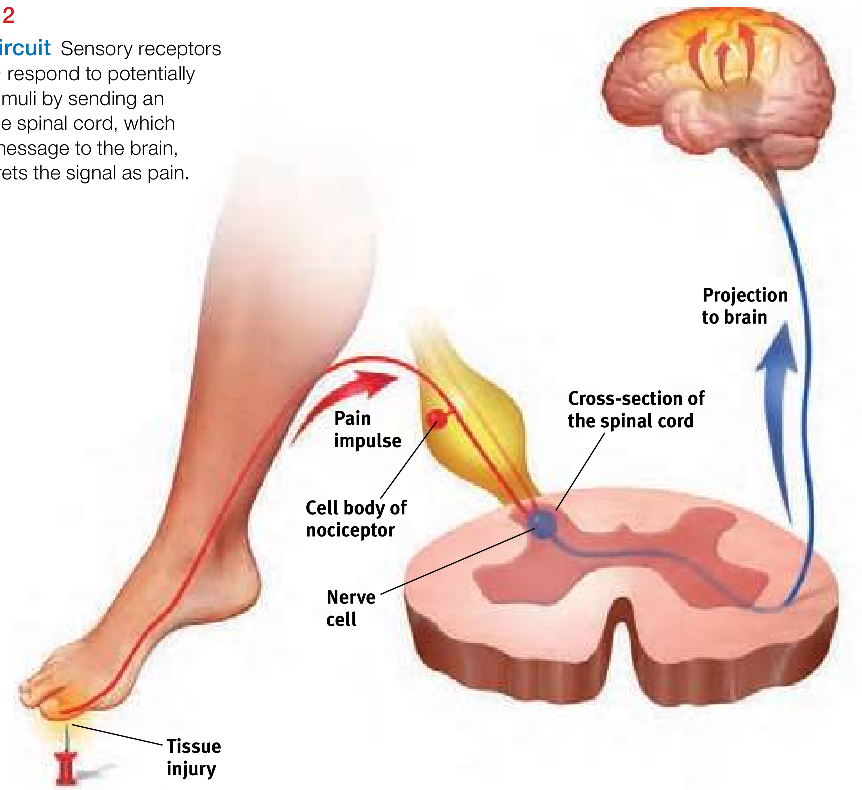
There is no one type of stimulus that triggers pain (as light triggers vision). Instead, there are different *nociceptors*—sensory receptors that detect hurtful temperatures, pressure, or chemicals (**FIGURE 21.2** on the next page).

Although no theory of pain explains all available findings, psychologist Ronald Melzack and biologist Patrick Wall's (1965, 1983) classic **gate-control theory** provides a useful model. The spinal cord contains small nerve fibers that conduct most pain signals, and larger fibers that conduct most other sensory signals. Melzack and Wall theorized that the spinal cord contains a neurological "gate." When tissue is injured, the small fibers activate and open the gate, and you feel pain. Large-fiber activity closes the gate, blocking pain signals and preventing them from reaching the brain. Thus, one way to treat chronic pain is to

**gate-control theory** the theory that the spinal cord contains a neurological "gate" that blocks pain signals or allows them to pass on to the brain. The "gate" is opened by the activity of pain signals traveling up small nerve fibers and is closed by activity in larger fibers or by information coming from the brain.

Figure 21.2

**The pain circuit** Sensory receptors *(nociceptors)* respond to potentially damaging stimuli by sending an impulse to the spinal cord, which passes the message to the brain, which interprets the signal as pain.




stimulate (by massage, electric stimulation, or acupuncture) "gate-closing" activity in the large neural fibers (Wall, 2000).

But pain is not merely a physical phenomenon of injured nerves sending impulses to a definable brain area—like pulling on a rope to ring a bell. Melzack and Wall noted that brain-to-spinal-cord messages can also close the gate, helping to explain some striking influences on pain. When we are distracted from pain (a psychological influence) and soothed by the release of our naturally painkilling *endorphins* (a biological influence), our experience of pain diminishes. Sports injuries may go unnoticed until the after-game shower. People who carry a gene that boosts the availability of endorphins are less bothered by pain, and their brain is less responsive to pain (Zubieta et al., 2003). Others carry a mutated gene that disrupts pain circuit neurotransmission and experience little pain (Cox et al., 2006). Such discoveries may point the way toward new pain medications that mimic these genetic effects.

The brain can also create pain, as it does in people's experiences of *phantom limb sensations,* when it misinterprets the spontaneous central nervous system activity that occurs in the absence of normal sensory input. As the dreamer may see with eyes closed, so some 7 in 10 amputees may feel pain or movement in nonexistent limbs (Melzack, 1992, 2005). (An amputee may also try to step off a bed onto a phantom limb or to lift a cup with a phantom hand.) Even those born without a limb sometimes perceive sensations from the absent arm or leg. The brain, Melzack (1998) surmises, comes prepared to anticipate "that it will be getting information from a body that has limbs."

A similar phenomenon occurs with other senses. People with hearing loss often experience the sound of silence: phantom sounds—a ringing-in-the-ears sensation known as *tinnitus.* Those who lose vision to glaucoma, cataracts, diabetes, or macular degeneration may experience phantom sights—nonthreatening hallucinations (Ramachandran & Blakeslee, 1998). Some with nerve damage have had taste phantoms, such as ice water seeming sickeningly sweet (Goode, 1999). Others have experienced phantom smells, such as nonexistent rotten food. The point to remember: *We feel, see, hear, taste, and smell with our brain,* which can sense even without functioning senses.

## PSYCHOLOGICAL INFLUENCES

The psychological effects of distraction are clear in the stories of athletes who, focused on winning, play through the pain. We also seem to edit our *memories* of pain, which often differ from the pain we actually experienced. In experiments, and after medical procedures, people overlook a pain's duration. Their memory snapshots instead record two factors: their pain's *peak* moment (which can lead them to recall variable pain, with peaks, as worse [Stone et al., 2005]), and how much pain they felt at the *end.*

In one experiment, researchers asked people to immerse one hand in painfully cold water for 60 seconds, and then the other hand in the same painfully cold water for 60 seconds followed by a slightly less painful 30 seconds more (Kahneman et al., 1993). Which experience would you expect to recall as most painful? Curiously, when asked which trial they would prefer to repeat, most preferred the longer trial, with more net pain—but less pain at the end. Physicians have used this principle with patients undergoing colon exams—lengthening the discomfort by a minute, but lessening its intensity (Kahneman, 1999). Although the extended milder discomfort added to their net pain experience, patients experiencing this taper-down treatment later recalled the exam as less painful than did those whose pain ended abruptly. (If, at the end of a painful root canal, the oral surgeon asks if you'd like to go home or to have a few more minutes of milder discomfort, there's a case to be made for prolonging your hurt.)


**Playing with pain** In a 2012 NFL game, Dallas Cowboys quarterback Tony Romo cracked a rib after colliding with an opposing player. He continued playing through the pain, which reclaimed his attention after the game's end.

"When belly with bad pains doth swell, It matters naught what else goes well." -SADI, *THE GULISTAN*, 1258

"Pain is increased by attending to it." -CHARLES DARWIN, *EXPRESSION OF EMOTIONS IN MAN AND ANIMALS*, 1872

## SOCIAL-CULTURAL INFLUENCES

Our perception of pain also varies with our social situation and our cultural traditions. We tend to perceive more pain when others also seem to be experiencing pain (Symbaluk et al., 1997). This may help explain other apparent social aspects of pain, as when pockets of Australian keyboard operators during the mid-1980s suffered outbreaks of severe pain during typing or other repetitive work—without any discernible physical abnormalities (Gawande, 1998). Sometimes the pain in sprain is mainly in the brain—literally. When feeling empathy for another's pain, a person's own brain activity may partly mirror that of the other's brain in pain (Singer et al, 2004).

Thus, our perception of pain is a biopsychosocial phenomenon (**FIGURE 21.3**). Viewing pain this way can help us better understand how to cope with pain and treat it.

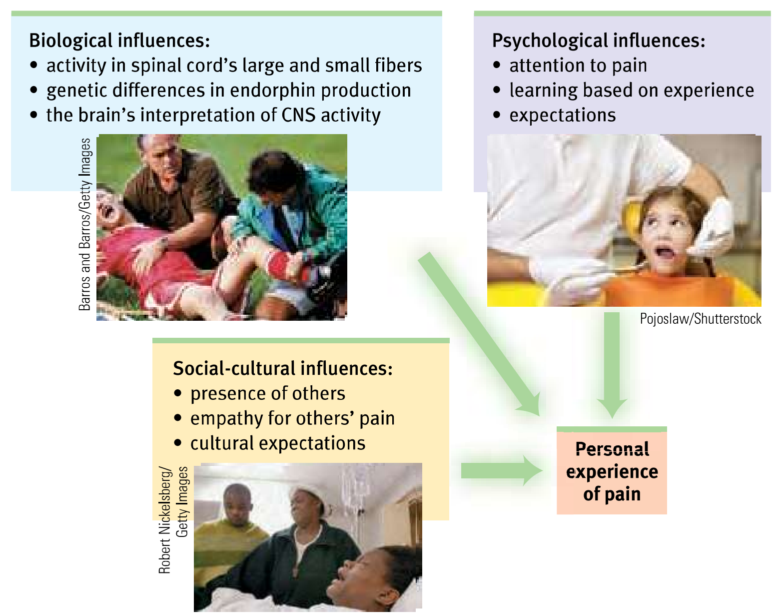



**Figure 21.3**
**Biopsychosocial approach to pain** Our experience of pain is much more than neural messages sent to the brain.

Gary Conner/Phototake

**Acupuncture: A jab well done** This acupuncturist is attempting to help this woman gain relief from back pain by using needles on points of the patient's hand.

## Controlling Pain

If pain is where body meets mind—if it is both a physical and a psychological phenomenon—then it should be treatable both physically and psychologically. Depending on the type of symptoms, pain control clinics select one or more therapies from a list that includes drugs, surgery, acupuncture, electrical stimulation, massage, exercise, hypnosis, relaxation training, and thought distraction.

Even an inert placebo can help, by dampening the central nervous system's attention and responses to painful experiences—mimicking analgesic drugs (Eippert et al., 2009; Wager, 2005). After being injected in the jaw with a stinging saltwater solution, men in one experiment received a placebo said to relieve pain, and they immediately felt better. Being given fake pain-killing chemicals caused the brain to dispense real ones, as indicated by activity in an area that releases natural pain-killing opiates (Scott et al., 2007; Zubieta et al., 2005). "Believing becomes reality," noted one commentator (Thernstrom, 2006), as "the mind unites with the body."

Another experiment pitted two placebos—fake pills and pretend acupuncture—against each other (Kaptchuk et al., 2006). People with persistent arm pain (270 of them) received either sham acupuncture (with trick needles that retracted without puncturing the skin) or blue cornstarch pills that looked like pills often prescribed for strain injury. A fourth of those receiving the nonexistent needle pricks and 31 percent of those receiving the pills complained of side effects, such as painful skin or dry mouth and fatigue. After two months, both groups were reporting less pain, with the fake acupuncture group reporting the greater pain drop.

Distracting people with pleasant images *("Think of a warm, comfortable environment")* or drawing their attention away from the painful stimulation *("Count backward by 3s")* is an especially effective way to activate pain-inhibiting circuits and to increase pain tolerance (Edwards et al., 2009). A well-trained nurse may distract needle-shy patients by chatting with them and asking them to look away when inserting the needle. For burn victims receiving excruciating wound care, an even more effective distraction comes from immersion in a computer-generated 3-D world, like the snow scene in **FIGURE 21.4**. Functional MRI (fMRI) scans reveal that playing in the virtual reality reduces the brain's pain-related activity (Hoffman, 2004). Because pain is in the brain, diverting the brain's attention may bring relief.

**Figure 21.4**
**Virtual-reality pain control** For burn victims undergoing painful skin repair, an escape into virtual reality can powerfully distract attention, thus reducing pain and the brain's response to painful stimulation. The fMRI scans on the right illustrate a lowered pain response when the patient is distracted.


Image by Todd Richards and Aric Bills, U.W., © Hunter Hoffman, www.vrpain.com
Image by Todd Richards and Aric Bills, U.W., © Hunter Hoffman, www.vrpain.com
Image by Todd Richards and Aric Bills, U.W., © Hunter Hoffman, www.vrpain.com

## Taste

**21-3** How do we experience taste and smell?

Like touch, our sense of taste involves several basic sensations. Taste's sensations were once thought to be sweet, sour, salty, and bitter, with all others stemming from mixtures of these four (McBurney & Gent, 1979). Then, as investigators searched for specialized nerve fibers for the four taste sensations, they encountered a receptor for what we now know is a fifth—the savory meaty taste of *umami,* best experienced as the flavor enhancer monosodium glutamate (MSG), often used in Chinese and Thai food.

Evolutionary psychologists explain that tastes exist for more than our pleasure (see **TABLE 21.1**). Pleasureful tastes attracted our ancestors to energy- or protein-rich foods that enabled their survival. Aversive tastes deterred them from new foods that might be toxic. We see the inheritance of this biological wisdom in today's 2- to 6-year-olds, who are typically fussy eaters, especially when offered new meats or bitter-tasting vegetables, such as spinach and brussels sprouts (Cooke et al., 2003). Meat and plant toxins were both potentially dangerous sources of food poisoning for our ancestors, especially for children. Given repeated small tastes of disliked new foods, children will, however, typically begin to accept them (Wardle et al., 2003). (Module 38 will explore cultural influences on our taste preferences.)

**Table 21.1 The Survival Functions of Basic Tastes**

| Taste | Indicates |
|---|---|
| *Sweet* | Energy source |
| *Salty* | Sodium essential to physiological processes |
| *Sour* | Potentially toxic acid |
| *Bitter* | Potential poisons |
| *Umami* | Proteins to grow and repair tissue |

(Adapted from Cowart, 2005.)

Taste is a chemical sense. Inside each little bump on the top and sides of your tongue are 200 or more taste buds, each containing a pore that catches food chemicals. Into each taste bud pore, 50 to 100 taste receptor cells project antenna-like hairs that sense food molecules. Some receptors respond mostly to sweet-tasting molecules, others to salty-, sour-, umami-, or bitter-tasting ones. It doesn't take much to trigger a response that alerts your brain's temporal lobe. If a stream of water is pumped across your tongue, the addition of a concentrated salty or sweet taste for but one-tenth of a second will get your attention (Kelling & Halpern, 1983). When a friend asks for "just a taste" of your soft drink, you can squeeze off the straw after a mere instant.

Taste receptors reproduce themselves every week or two, so when you burn your tongue with hot pizza, it hardly matters. However, as you grow older, the number of taste buds decreases, as does taste sensitivity (Cowart, 1981). (No wonder adults enjoy strong-tasting foods that children resist.) Smoking and alcohol use accelerate these declines. Those who lose their sense of taste report that food tastes like "straw" and is hard to swallow (Cowart, 2005).

Essential as taste buds are, there's more to taste than meets the tongue. Expectations can influence taste. When told a sausage roll was "vegetarian," people in one experiment found it decidedly inferior to its identical partner labeled "meat" (Allen et al., 2008). In another experiment, when adults were told that a wine cost $90 rather than its real $10 price, they reported it tasting better and a brain area that responds to pleasant experiences showed more activity (Plassmann et al., 2008).

Lauren Burke/Jupiterimages

## Smell

Life begins with an inhale and ends with an exhale. Between birth and death, you will daily inhale and exhale nearly 20,000 breaths of life-sustaining air, bathing your nostrils in a stream of scent-laden molecules. The resulting experiences of smell *(olfaction)* are strikingly intimate: You inhale something of whatever or whoever it is you smell.

Like taste, smell is a chemical sense. We smell something when molecules of a substance carried in the air reach a tiny cluster of 20 million receptor cells at the top of each

**Try This**

Impress your friends with your new word for the day: People unable to see are said to experience blindness. People unable to hear experience deafness. People unable to smell experience *anosmia.*

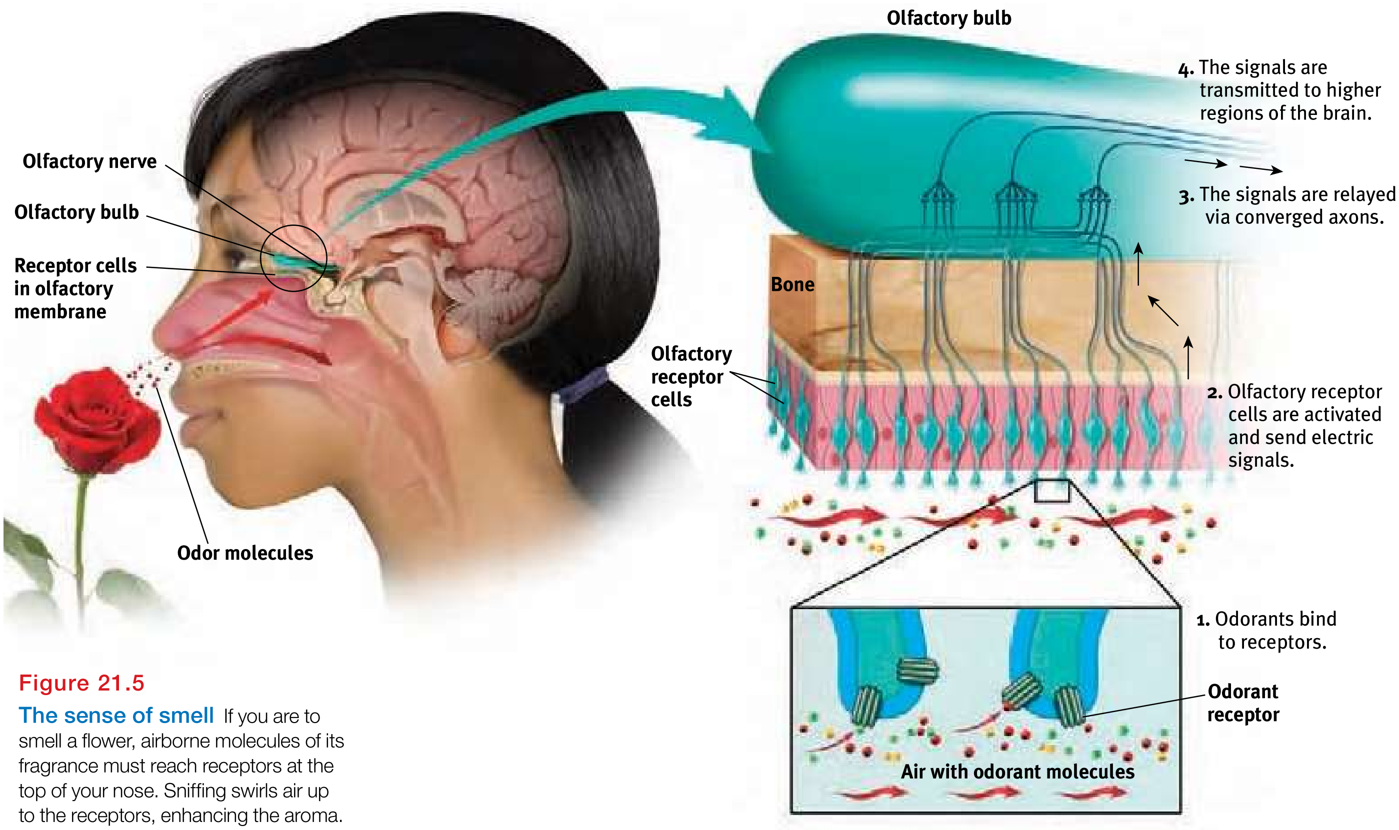



Figure 21.5

**The sense of smell** If you are to smell a flower, airborne molecules of its fragrance must reach receptors at the top of your nose. Sniffing swirls air up to the receptors, enhancing the aroma. The receptor cells send messages to the brain's olfactory bulb, and then onward to the temporal lobe's primary smell cortex and to the parts of the limbic system involved in memory and emotion.

nasal cavity (**FIGURE 21.5**). These olfactory receptor cells, waving like sea anemones on a reef, respond selectively—to the aroma of a cake baking, to a wisp of smoke, to a friend's fragrance. Instantly, they alert the brain through their axon fibers. Being an old, primitive sense, olfactory neurons bypass the brain's sensory control center, the thalamus.

Research has shown that even nursing infants and their mothers have a literal chemistry to their relationship: They quickly learn to recognize each other's scents (McCarthy, 1986). Aided by smell, a mother fur seal returning to a beach crowded with pups will find her own. Our human sense of smell is less acute than our senses of seeing and hearing. Looking out across a garden, we see its forms and colors in exquisite detail and hear a variety of birds singing, yet we smell little of it without sticking our nose into the blossoms.

Odor molecules come in many shapes and sizes—so many, in fact, that it takes many different receptors to detect them. A large family of genes designs the 350 or so receptor proteins that recognize particular odor molecules (Miller, 2004). Linda Buck and Richard Axel (1991) discovered (in work for which they received a 2004 Nobel Prize) that these receptor proteins are embedded on the surface of nasal cavity neurons. As a key slips into a lock, so odor molecules slip into these receptors. Yet we don't seem to have a distinct receptor for each detectable odor. This suggests that some odors trigger a combination of receptors, in patterns that are interpreted by the olfactory cortex. As the English alphabet's 26 letters can combine to form many words, so odor molecules bind to different receptor arrays, producing the 10,000 odors we can detect (Malnic et al., 1999). It is the combinations of olfactory receptors, which activate different neuron patterns, that allow us to distinguish between the aromas of fresh-brewed and hours-old coffee (Zou et al., 2005).

Tish1/Shutterstock

For humans, the attractiveness of smells depends on learned associations (Herz, 2001). As babies nurse, their preference for the smell of their mother's breast builds. So, too, with other associations. As good experiences are linked with a particular scent, people come to like that scent, which helps explain why people in the United States tend to like the smell of wintergreen (which they associate with candy and gum) more than do those in Great Britain (where it often is associated with medicine). In another example of odors evoking unpleasant emotions, researchers frustrated Brown University students with a rigged computer game in a scented room (Herz et al., 2004). Later, if exposed to the same odor while working on a verbal task, the students' frustration was rekindled and they gave up sooner than others exposed to a different odor or no odor.


**The nose knows** Humans have some 20 million olfactory receptors. A bloodhound has 220 million (Herz, 2007).

Though it's difficult to recall odors by name, we have a remarkable capacity to recognize long-forgotten odors and their associated memories (Engen, 1987; Schab, 1991). The smell of the sea, the scent of a perfume, or an aroma of a favorite relative's kitchen can bring to mind a happy time. It's a phenomenon the British travel agent chain Lunn Poly understood well. To evoke memories of lounging on sunny, warm beaches, the company once piped the aroma of coconut suntan oil into its shops (Fracassini, 2000).

Our brain's circuitry helps explain an odor's power to evoke feelings and memories (**FIGURE 21.6**). A hotline runs between the brain area receiving information from the nose and the brain's ancient limbic centers associated with memory and emotion. Thus, when put in a foul-smelling room, people expressed harsher judgments of immoral acts (such as lying or keeping a found wallet) and more negative attitudes toward gay men (Inbar et al., 2011; Schnall et al., 2008).

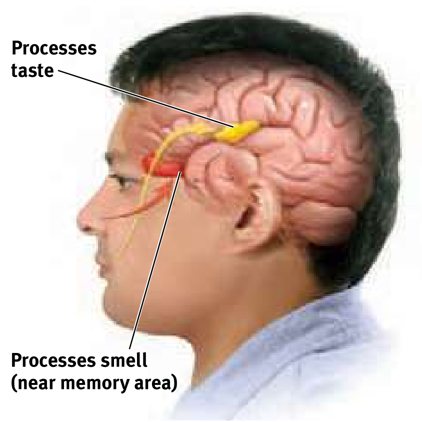



**Figure 21.6**
**Taste, smell, and memory** Information from the taste buds (yellow arrow) travels to an area between the frontal and temporal lobes of the brain. It registers in an area not far from where the brain receives information from our sense of smell, which interacts with taste. The brain's circuitry for smell (red area) also connects with areas involved in memory storage, which helps explain why a smell can trigger a memory.

## Body Position and Movement

**21-4** How do we sense our body's position and movement?

Important sensors in your joints, tendons, and muscles enable your **kinesthesia**—your sense of the position and movement of your body parts. By closing your eyes or plugging your ears you can momentarily imagine being without sight or sound. But what would it be like to live without touch or kinesthetic sense—without, therefore, being able to sense the positions of your limbs when you wake during the night? Ian Waterman of Hampshire, England, knows. In 1972, at age 19, Waterman contracted a rare viral infection that destroyed the nerves enabling his sense of light touch and of body position and movement. People with this condition report feeling disembodied, as though their body is dead, not real, not theirs (Sacks, 1985). With prolonged practice, Waterman has learned to walk and eat—by visually focusing on his limbs and directing them accordingly. But if the lights go out, he crumples to the floor (Azar, 1998). Even for the rest of us, vision interacts with kinesthesia. Stand with your right heel in front of your left toes. Easy. Now close your eyes and you will probably wobble.

A companion **vestibular sense** monitors your head's (and thus your body's) position and movement. The biological gyroscopes for this sense of equilibrium are in your inner ear. The *semicircular canals,* which look like a three-dimensional pretzel (Figure 20.1a), and the *vestibular sacs,* which connect the canals with the cochlea, contain fluid that moves when your head rotates or tilts. This movement stimulates hairlike receptors, which send

**kinesthesia** [kin-ehs-THEE-see-a] the system for sensing the position and movement of individual body parts.

**vestibular sense** the sense of body movement and position, including the sense of balance.



**Bodies in space** These high school competitive cheer team members can thank their inner ears for the information that enables their brains to monitor their bodies' position so expertly.

messages to the cerebellum at the back of the brain, thus enabling you to sense your body position and to maintain your balance.

If you twirl around and then come to an abrupt halt, neither the fluid in your semicircular canals nor your kinesthetic receptors will immediately return to their neutral state. The dizzy aftereffect fools your brain with the sensation that you're still spinning. This illustrates a principle that underlies perceptual illusions: Mechanisms that normally give us an accurate experience of the world can, under special conditions, fool us. Understanding how we get fooled provides clues to how our perceptual system works.

## Sensory Interaction

**21-5** How do our senses interact?

Our senses are not totally separate information channels. In interpreting the world, our brain blends their inputs. Consider what happens to your sense of taste if you hold your nose, close your eyes, and have someone feed you various foods. A slice of apple may be indistinguishable from a chunk of raw potato. A piece of steak may taste like cardboard. Without their smells, a cup of cold coffee may be hard to distinguish from a glass of Gatorade. To savor a taste, we normally breathe the aroma through our nose—which is why eating is not much fun when you have a bad cold. Smell can also change our perception of taste: A drink's strawberry odor enhances our perception of its sweetness. Even touch can influence taste. Depending on its texture, a potato chip "tastes" fresh or stale (Smith, 2011). This is **sensory interaction** at work—the principle that one sense may influence another. Smell + texture + taste = flavor.

**sensory interaction** the principle that one sense may influence another, as when the smell of food influences its taste.

Vision and hearing may similarly interact. An almost imperceptible flicker of light is more easily visible when accompanied by a short burst of sound (Kayser, 2007). And a sound may be easier to hear with a visual cue. If I (as a person with hearing loss) watch a video with simultaneous captioning, I have no trouble hearing the words I am seeing (and may therefore think I don't need the captioning). If I then turn off the captioning, I suddenly realize I do need it. The eyes guide the ears (**FIGURE 21.7**).

But what do you suppose happens if the eyes and the ears disagree? What if we *see* a speaker saying one syllable while we *hear* another? Surprise: We may perceive a third syllable that blends both inputs. Seeing the mouth movements for *ga* while hearing *ba* we may perceive *da.* This phenomenon is known as the *McGurk effect,* after its discoverers, psychologist Harry McGurk and his assistant John MacDonald (1976).

Touch also interacts with our other senses. In detecting events, the brain can combine simultaneous touch and visual signals, thanks to neurons projecting from the somatosensory cortex back to the visual cortex (Macaluso et al., 2000). Touch even interacts with hearing. In one experiment, researchers blew a puff of air (such as our mouths produce when saying *pa* and *ta*) on the neck or hands as people heard either these sounds or the more airless sounds *ba* or *da*. To my surprise (and yours?), the people more often misheard

**Figure 21.7**
**Sensory interaction** When a hard-of-hearing listener sees an animated face forming the words being spoken at the other end of a phone line, the words become easier to understand (Knight, 2004). The eyes guide the ears.

*ba* or *da* as *pa* or *ta* when played with the faint puff (Gick & Derrick, 2009). Thanks to sensory interaction, they were hearing with their skin.

Our brain even blends our tactile and social judgments:

- After holding a warm drink rather than a cold one, people are more likely to rate someone more warmly, feel closer to them, and behave more generously (IJzerman & Semin, 2009; Williams & Bargh, 2008). Physical warmth promotes social warmth.
- After being given the cold shoulder by others in an experiment, people judge the room as colder than do those treated warmly (Zhong & Leonardelli, 2008). Social exclusion literally feels cold.
- Holding a heavy rather than light clipboard makes job candidates seem more important. Holding rough objects makes social interactions seem more difficult (Ackerman et al., 2010).
- When leaning to the left—by sitting in a left- rather than right-leaning chair, or squeezing a hand-grip with their left hand, or using a mouse with their left hand—people lean more left in their expressed political attitudes (Oppenheimer & Trail, 2010).

These examples of **embodied cognition** illustrate how brain circuits processing our bodily sensations connect with brain circuits responsible for cognition.

**embodied cognition** in psychological science, the influence of bodily sensations, gestures, and other states on cognitive preferences and judgments.

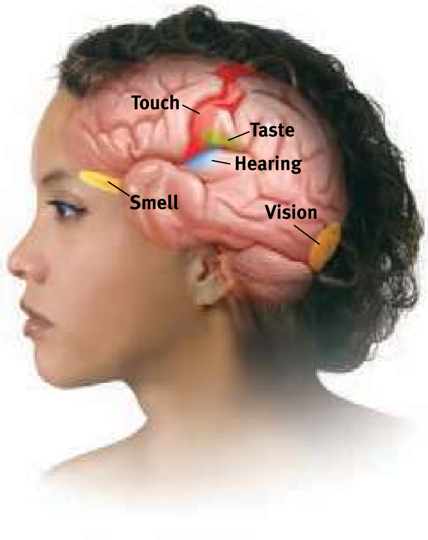
So, the senses interact: As we attempt to decipher our world, our brain blends inputs from multiple channels. For many people, an odor, perhaps of mint or chocolate, can evoke a sensation of taste (Stevenson & Tomiczek, 2007). But in a few select individuals, the senses become joined in a phenomenon called *synesthesia,* where one sort of sensation (such as hearing sound) produces another (such as seeing color). Thus, hearing music may activate color-sensitive cortex regions and trigger a sensation of color (Brang et al., 2008; Hubbard et al., 2005). Seeing the number 3 may evoke a taste sensation (Ward, 2003).

* * *

For a summary of our sensory systems, see **TABLE 21.2**. The river of perception is fed by sensation, cognition, and emotion. And that is why we need biological, psychological, and social-cultural levels of analysis.

**Table 21.2 Summarizing the Senses**

| Sensory System | Source | Receptors |
|---|---|---|
| *Vision* | Light waves striking the eye | Rods and cones in the retina |
| *Hearing* | Sound waves striking the outer ear | Cochlear hair cells in the inner ear |
| *Touch* | Pressure, warmth, cold, pain on the skin | Skin receptors detect pressure, warmth, cold, and pain |
| *Taste* | Chemical molecules in the mouth | Basic tongue receptors for sweet, sour, salty, bitter, and umami |
| *Smell* | Chemical molecules breathed in through the nose | Millions of receptors at top of nasal cavity |
| *Body position—kinesthesia* | Any change in position of a body part, interacting with vision | Kinesthetic sensors all over the body |
| *Body movement—vestibular sense* | Movement of fluids in the inner ear caused by head/body movement | Hairlike receptors in the semicircular canals and vestibular sacs |



* * *

To feel awe, mystery, and a deep reverence for life, we need look no further than our own perceptual system and its capacity for organizing formless nerve impulses into colorful sights, vivid sounds, and evocative smells. As Shakespeare's Hamlet recognized, "There are more things in Heaven and Earth, Horatio, than are dreamt of in your philosophy." Within our ordinary sensory and perceptual experiences lies much that is truly extraordinary—surely much more than has so far been dreamt of in our psychology.

## Before You Move On

**▶ ASK YOURSELF**

Have you ever experienced a feeling that you think could be explained by embodied cognition?

**▶ TEST YOURSELF**

How does our system for sensing smell differ from our sensory systems for vision, touch, and taste?

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

# Module 21 Review

### 21-1 How do we sense touch?

- Our sense of touch is actually several senses—pressure, warmth, cold, and pain—that combine to produce other sensations, such as "hot."

### 21-2 How can we best understand and control pain?

- Pain reflects bottom-up sensations (such as input from nociceptors, the sensory receptors that detect hurtful temperatures, pressure, or chemicals) and top-down processes (such as experience, attention, and culture).
- One theory of pain is that a "gate" in the spinal cord either opens to permit pain signals traveling up small nerve fibers to reach the brain, or closes to prevent their passage.
- The biopsychosocial perspective views our perception of pain as the sum of biological, psychological, and social-cultural influences. Pain treatments often combine physical and psychological elements, including placebos and distractions.

### 21-3 How do we experience taste and smell?

- Taste and smell are chemical senses.
- Taste is a composite of five basic sensations—sweet, sour, salty, bitter, and umami—and of the aromas that interact with information from the taste receptor cells of the taste buds.
- There are no basic sensations for smell. We have some 20 million olfactory receptor cells, with about 350 different receptor proteins.
- Odor molecules trigger combinations of receptors, in patterns that the olfactory cortex interprets. The receptor cells send messages to the brain's olfactory bulb, then to the temporal lobe, and to parts of the limbic system.

### 21-4 How do we sense our body's position and movement?

- Through *kinesthesia*, we sense the position and movement of our body parts.
- We monitor our body's position and movement, and maintain our balance with our *vestibular sense.*

### 21-5 How do our senses interact?

- Our senses can influence one another. This *sensory interaction* occurs, for example, when the smell of a favorite food amplifies its taste.
- *Embodied cognition* is the influence of bodily sensations, gestures, and other states on cognitive preferences and judgments.

## Multiple-Choice Questions

**1.** Sensing the position and movement of individual body parts is an example of which sense?

a. Kinesthetic
b. Vestibular
c. Auditory
d. Umami
e. Olfactory

**2.** Which of the following is the best example of kinesthesia?

a. Awareness of the smell of freshly brewed coffee
b. Ability to feel pressure on your arm
c. Ability to hear a softly ticking clock
d. Ability to calculate where a kicked soccer ball will land from the moment it leaves your foot
e. Awareness of the position of your arms when swimming the backstroke

**3.** Which of the following is the best example of sensory interaction?

a. Finding that despite its delicious aroma, a weird-looking meal tastes awful
b. Finding that food tastes bland when you have a bad cold
c. Finding it difficult to maintain your balance when you have an ear infection
d. Finding that the cold pool water doesn't feel so cold after a while
e. All of these are examples.

**4.** Which of the following is most closely associated with hairlike receptors in the semicircular canals?

a. Body position
b. Smell
c. Hearing
d. Pain
e. Touch

## Practice FRQs

**1.** Describe the receptor cells for taste and smell.

### Answer

***1 point:*** Taste: Receptor cells in the tongue detect sweet, sour, salty, bitter, and umami.

***1 point:*** Smell: Olfactory cells line the top of the nasal cavity.

**2.** Briefly explain the biopsychosocial perspective on pain and pain treatment.

***(2 points)***

# Unit IV Review

## Key Terms and Concepts to Remember

sensation, p. 152
perception, p. 152
bottom-up processing, p. 152
top-down processing, p. 152
selective attention, p. 152
inattentional blindness, p. 154
change blindness, p. 154
transduction, p. 155
psychophysics, p. 155
absolute threshold, p. 156
signal detection theory, p. 156
subliminal, p. 157
priming, p. 157
difference threshold, p. 158
Weber's law, p. 158
sensory adaptation, p. 159
perceptual set, p. 163
extrasensory perception (ESP), p. 167
parapsychology, p. 167
wavelength, p. 171
hue, p. 172
intensity, p. 172
pupil, p. 172
iris, p. 172
lens, p. 172
retina, p. 172
accommodation, p. 172
rods, p. 173
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optic nerve, p.173
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parallel processing, p. 176
Young-Helmholtz trichromatic (three-color) theory, p. 178
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perceptual constancy, p. 186
color constancy, p. 187
perceptual adaptation, p. 191
audition, p. 194
frequency, p. 195
pitch, p. 195
middle ear, p. 195
cochlea [KOHK-lee-uh], p. 195
inner ear, p. 195
sensorineural hearing loss, p. 197
conduction hearing loss, p. 197
cochlear implant, p. 198
place theory, p. 199
frequency theory, p. 199
gate-control theory, p. 203
kinesthesia [kin-ehs-THEE-see-a], p. 209
vestibular sense, p. 209
sensory interaction, p. 210
embodied cognition, p. 211

## Key Contributors to Remember

Gustav Fechner, p. 156
Ernst Weber, p. 158
David Hubel, p. 175
Torsten Wiesel, p. 175

## AP® Exam Practice Questions

### Multiple-Choice Questions

**1.** What is the purpose of the iris?

a. To focus light on the retina
b. To process color
c. To allow light into the eye
d. To enable night vision
e. To detect specific shapes

**2.** Neurons that fire in response to specific edges, lines, angles, and movements are called what?

a. Rods
b. Cones
c. Ganglion cells
d. Feature detectors
e. Bipolar cells

**3.** Signal detection theory is most closely associated with which perception process?

a. Vision
b. Sensory adaptation
c. Absolute thresholds
d. Smell
e. Context effects

**4.** Which of the following represents perceptual constancy?

a. We recognize the taste of McDonald's food each time we eat it.
b. In photos of people, the people almost always are perceived as figure and everything else as ground.
c. We know that the color of a printed page has not changed as it moves from sunlight into shadow.
d. From the time they are very young, most people can recognize the smell of a dentist's office.
e. The cold water in a lake doesn't seem so cold after you have been swimming in it for a few minutes.

**5.** Our tendency to see faces in clouds and other ambiguous stimuli is partly based on what perception principle?

a. Selective attention
b. ESP
c. Perceptual set
d. Shape constancy
e. Bottom-up processing

**6.** The process by which rods and cones change electromagnetic energy into neural messages is called what?

a. Adaptation
b. Accommodation
c. Parallel processing
d. Transduction
e. Perceptual setting

**7.** Which of the following is most likely to influence our memory of a painful event?

a. The overall length of the event
b. The intensity of pain at the end of the event
c. The reason for the pain
d. The amount of rest you've had in the 24 hours preceding the event
e. The specific part of the body that experiences the pain

**8.** Frequency theory relates to which element of the hearing process?

a. Rate at which the basilar membrane vibrates
b. Number of fibers in the auditory nerve
c. Point at which the basilar membrane exhibits the most vibration
d. Decibel level of a sound
e. Number of hair cells in each cochlea

**9.** Which of the following best represents an absolute threshold?

a. A guitar player knows that his D string has just gone out of tune.
b. A photographer can tell that the natural light available for a photograph has just faded slightly.
c. Your friend amazes you by correctly identifying unlabeled glasses of Coke and Pepsi.
d. A cook can just barely taste the salt she has added to her soup.
e. Your mom throws out the milk because she says the taste is "off."

**10.** Which of the following describes a perception process that the Gestalt psychologists would have been interested in?

a. Depth perception and how it allows us to survive in the world
b. Why we see an object near us as closer rather than larger
c. How an organized whole is formed out of its component pieces
d. What the smallest units of perception are
e. The similarities between shape constancy and size constancy

**11.** Which perception process are the hammer, anvil, and stirrup involved in?

a. Processing intense colors
b. Processing information related to our sense of balance
c. Supporting a structural frame to hold the eardrum
d. Transmitting sound waves to the cochlea
e. Holding hair cells that enable hearing

**12.** Which of the following might result from a disruption of your vestibular sense?

a. Inability to detect the position of your arm without looking at it
b. Loss of the ability to detect bitter tastes
c. Dizziness and a loss of balance
d. An inability to detect pain
e. Loss of color vision

**13.** When we go to the movies, we see smooth continuous motion rather than a series of still images because of which process?

a. The phi phenomenon
b. Perceptual set
c. Stroboscopic movement
d. Relative motion
e. Illusory effect

**14.** Two monocular depth cues are most responsible for our ability to know that a jet flying overhead is at an elevation of several miles. One cue is relative size. What is the other?

a. Relative motion
b. Retinal disparity
c. Interposition
d. Light and shadow
e. Linear perspective

**15.** Which of the following phrases accurately describes top-down processing?

a. The entry-level data captured by our various sensory systems
b. The effect that our experiences and expectations have on perception
c. Our tendency to scan a visual field from top to bottom
d. Our inclination to follow a predetermined set of steps to process sound
e. The fact that information is processed by the higher regions of the brain before it reaches the lower brain

## Free-Response Questions

**1.** While listening to the orchestra as she dances the lead role in *Swan Lake*, a ballerina concludes her performance with a pirouette, spinning around several times before leaping into the arms of her dance partner.

Discuss how the ballerina relied on the following and how each is important.

- Kinesthetic sense
- Vestibular sense
- Semicircular canals
- Hearing

### Rubric for Free Response Question 1

***1 point:*** Kinesthesia will allow the ballerina to sense the position of different parts of her body as she dances the role. Thus, she will know that she is to start by facing the audience and, although she has spun around several times, she will always be aware of where the audience is, and where to put her feet and arms in order to accomplish the choreography. Page 209

***1 point:*** The vestibular sense enables the dancer to sense her body position and to maintain her balance. Pages 209–210

***1 point:*** Semicircular canals near her inner ear help the ballerina maintain her sense of balance. She needs this balance as she leaps and spins, and her training allows her to use her vestibular sense to maintain balance rather than become dizzy. Pages 195 and 209

***1 point:*** The ballerina's sense of hearing allows her to perceive the music and to dance to the correct rhythm of each piece of music. Pages 194–199

**2.** Ester is walking to her chemistry class when she notices someone in the distance suddenly duck into a dark doorway. She is suspicious and starts to chase the figure, but misjudges the distance and accidentally runs into the door. She falls down but quickly recovers, and laughs when she discovers that the mystery person is her roommate, who was avoiding Ester, because she had borrowed Ester's favorite sweater without permission and was afraid Ester might be angry.

Use the following terms to explain the perceptual processes involved in this scenario.

- Gate-control theory
- Vestibular sense
- Selective attention
- Signal detection theory
- Binocular cues
- Perceptual set

***(6 points)***

**3.** Describe, from the beginning of the process to the end, how your brain is perceiving the words you are reading right now. Use the following terms in your answer.

- Transduction
- Top-down processing
- Retina
- Pupil
- Occipital lobe
- Rods
- Feature detectors

***(7 points)***

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