# Unit IV

# Sensation and Perception

## Modules



"I have perfect vision," explains my colleague, Heather Sellers, an acclaimed writer and teacher. Her vision may be fine, but there is a problem with her perception. She cannot recognize faces.

In her memoir, *You Don't Look Like Anyone I Know,* Sellers (2010) tells of awkward moments resulting from her lifelong *prosopagnosia*—face blindness.

> In college, on a date at the Spaghetti Station, I returned from the bathroom and plunked myself down in the wrong booth, facing the wrong man. I remained unaware he was not my date even as my date (a stranger to me) accosted Wrong Booth Guy, and then stormed out of the Station. I can't distinguish actors in movies and on television. I do not recognize myself in photos or videos. I can't recognize my stepsons in the soccer pick-up line; I failed to determine which husband was mine at a party, in the mall, at the market.

Her inability to recognize faces means that people sometimes perceive her as snobby or aloof. "Why did you walk past me?" a neighbor might later ask. Similar to those of us with hearing loss who fake hearing during trite social conversation, Sellers sometimes fakes recognition. She often smiles at people she passes, in case she knows them. Or she pretends to know the person with whom she is talking. (To avoid the stress associated with such perception failures, people with serious hearing loss or with prosopagnosia often shy away from busy social situations.) But there is an upside: When encountering someone who previously irritated her, she typically won't feel ill will, because she doesn't recognize the person.

Unlike Sellers, most of us have (as Module 18 explains) a functioning area on the underside of our brain's right hemisphere that helps us recognize a familiar human face as soon as we detect it—in only one-seventh of a second (Jacques & Rossion, 2006). This ability illustrates a broader principle. *Nature's sensory gifts enable each animal to obtain essential information.* Some examples:

- Frogs, which feed on flying insects, have cells in their eyes that fire only in response to small, dark, moving objects. A frog could starve to death knee-deep in motionless flies. But let one zoom by and the frog's "bug detector" cells snap awake.
- Male silkworm moths' odor receptors can detect one-billionth of an ounce of sex attractant per second released by a female one mile away. That is why silkworms continue to be.
- Human ears are most sensitive to sound frequencies that include human voices, especially a baby's cry.

In this unit, we'll look more closely at what psychologists have learned about how we sense and perceive the world around us.

# Module 16

## Basic Principles of Sensation and Perception

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### Module Learning Objectives

16-1 Contrast *sensation* and *perception*, and explain the difference between *bottom-up* and *top-down processing*.

16-2 Discuss how much information we can consciously attend to at once.

16-3 Identify the three steps that are basic to all our sensory systems.

16-4 Distinguish between *absolute* and *difference thresholds*, and discuss whether we can sense and be affected by stimuli below the absolute threshold.

16-5 Explain the function of sensory adaptation.

**sensation** the process by which our sensory receptors and nervous system receive and represent stimulus energies from our environment.

**perception** the process of organizing and interpreting sensory information, enabling us to recognize meaningful objects and events.

**bottom-up processing** analysis that begins with the sensory receptors and works up to the brain's integration of sensory information.

**top-down processing** information processing guided by higher-level mental processes, as when we construct perceptions drawing on our experience and expectations.

**selective attention** the focusing of conscious awareness on a particular stimulus.

**16-1** What are *sensation* and *perception?* What do we mean by *bottom-up processing* and *top-down processing?*

Sellers' curious mix of "perfect vision" and face blindness illustrates the distinction between sensation and perception. When she looks at a friend, her **sensation** is normal: Her senses detect the same information yours would, and they transmit that information to her brain. And her **perception**—the processes by which her brain organizes and interprets sensory input—is almost normal. Thus, she may recognize people from their hair, gait, voice, or particular physique, just not their face. Her experience is much like the struggle you or I would have trying to recognize a specific penguin in a group of waddling penguins.

In our everyday experiences, sensation and perception blend into one continuous process. In this module, we slow down that process to study its parts, but in real life, our sensory and perceptual processes work together to help us decipher the world around us.

- Our **bottom-up processing** starts at the sensory receptors and works up to higher levels of processing.
- Our **top-down processing** constructs perceptions from the sensory input by drawing on our experience and expectations.

As our brain absorbs the information in **FIGURE 16.1**, bottom-up processing enables our sensory systems to detect the lines, angles, and colors that form the flower and leaves. Using top-down processing we interpret what our senses detect.

But *how* do we do it? How do we create meaning from the blizzard of sensory stimuli bombarding our bodies 24 hours a day? Meanwhile, in a silent, cushioned, inner world, our brain floats in utter darkness. By itself, it sees nothing. It hears nothing. It feels nothing. *So, how does the world out there get in?* To phrase the question scientifically: How do we construct our representations of the external world? How do a campfire's flicker, crackle, and smoky scent activate neural connections? And how, from this living neurochemistry, do we create our conscious experience of the fire's motion and temperature, its aroma and beauty? In search of answers to such questions, let's look at some processes that cut across all our sensory systems. To begin, where is the border between our conscious and unconscious awareness, and what stimuli cross that threshold?

## Selective Attention

**16-2** How much information do we consciously attend to at once?

Through **selective attention,** your awareness focuses, like a flashlight beam, on a minute aspect of all that you experience. By one estimate, your five senses take in 11,000,000 bits of information per second, of which you consciously process about 40 (Wilson, 2002). Yet your mind's unconscious track intuitively makes great use of the other 10,999,960 bits. Until reading this sentence, for example, you have been unaware that your shoes are pressing against your feet or that your nose is in your line of vision. Now, suddenly, your attentional spotlight shifts. Your feet feel encased, your nose stubbornly intrudes on the words before you. While focusing on these words, you've also been blocking other parts of your environment from awareness, though your peripheral vision would let you see them easily. You can change that. As you stare at the X below, notice what surrounds these sentences (the edges of the page, the desktop, the floor).

X

A classic example of selective attention is the *cocktail party effect*—your ability to attend to only one voice among many (while also being able to detect your own name in an unattended voice). This effect might have prevented an embarrassing and dangerous situation in

**Figure 16.1**

**What's going on here?** Our sensory and perceptual processes work together to help us sort out the complex images, including the hidden couple in Sandro Del-Prete's drawing, *The Flowering of Love.*


Sandro Del-Prete

2009, when two commercial airline pilots "lost track of time." Focused on their laptops and conversation, they ignored alarmed air traffic controllers' attempts to reach them as they overflew their Minneapolis destination by 150 miles. If only the controllers had known and spoken the pilots' names.

"Has a generation of texters, surfers, and twitterers evolved the enviable ability to process multiple streams of novel information in parallel? Most cognitive psychologists doubt it." -Steven Pinker, "Not at All," 2010

## Selective Attention and Accidents

Text or talk on the phone while driving, or attend to a music player or GPS, and your selective attention will shift back and forth between the road and its electronic competition. But when a demanding situation requires it, you'll probably give the road your full attention. You'll probably also blink less. When focused on a task, such as reading, people blink less than when their mind is wandering (Smilek et al., 2010). If you want to know whether your dinner companion is focused on what you're saying, watch for eyeblinks and hope there won't be too many.

We pay a toll for switching attentional gears, especially when we shift to complex tasks, like noticing and avoiding cars around us. The toll is a slight and sometimes fatal delay in coping (Rubenstein et al., 2001). About 28 percent of traffic accidents occur when people are chatting on cell phones or texting (National Safety Council, 2010). One study tracked long-haul truck drivers for 18 months. The video cameras mounted in their cabs showed they were at 23 times greater risk of a collision while texting (VTTI, 2009). Mindful of such findings, the United States in 2010 banned truckers and bus drivers from texting while driving (Halsey, 2010).

It's not just truck drivers who are at risk. One in four teen drivers with cell phones admit to texting while driving (Pew, 2009). Multitasking comes at a cost: fMRI scans offer a biological account of how multitasking distracts from brain resources allocated to driving. They show that brain activity in areas vital to driving decreases an average 37 percent when a driver is attending to conversation (Just et al., 2008).

**AP® Exam Tip**

You may wish to think about how the information on selective attention relates to something a little less dangerous: studying. The same principles apply. The more time you spend texting, tweeting, and Facebooking, the less focused you'll be on the material you're trying to master. A better strategy is to spend 25 minutes doing schoolwork and schoolwork alone. Then you can reward yourself with a few minutes of social networking.

Even hands-free cell-phone talking is more distracting than a conversation with passengers, who can see the driving demands and pause the conversation. When University of Sydney researchers analyzed phone records for the moments before a car crash, they found that cell-phone users (even with hands-free sets) were four times more at risk (McEvoy et al., 2005, 2007). Having a passenger increased risk only 1.6 times. This risk difference also appeared in an experiment that asked drivers to pull off at a freeway rest stop 8 miles ahead. Of drivers conversing with a passenger, 88 percent did so. Of those talking on a cell phone, 50 percent drove on by (Strayer & Drews, 2007).



*"I wasn't texting. I was building this ship in a bottle."*

SALLY FORTH




**Driven to distraction** In driving-simulation experiments, people whose attention is diverted by cell-phone conversation make more driving errors.

Most European countries and American states now ban hand-held cell phones while driving (Rosenthal, 2009). Engineers are also devising ways to monitor drivers' gaze and to direct their attention back to the road (Lee, 2009).

## Selective Inattention

At the level of conscious awareness, we are "blind" to all but a tiny sliver of visual stimuli. Researchers demonstrated this **inattentional blindness** dramatically by showing people a 1-minute video in which images of three black-shirted men tossing a basketball were superimposed over the images of three white-shirted players (Neisser, 1979; Becklen & Cervone, 1983). The viewers' supposed task was to press a key every time a black-shirted player passed the ball. Most focused their attention so completely on the game that they failed to notice a young woman carrying an umbrella saunter across the screen midway through the video (**FIGURE 16.2**). Seeing a replay of the video, viewers were astonished to see her (Mack & Rock, 2000). This inattentional blindness is a by-product of what we are really good at: focusing attention on some part of our environment.

In a repeat of the experiment, smart-aleck researchers Daniel Simons and Christopher Chabris (1999) sent a gorilla-suited assistant through the swirl of players. During its 5- to 9-second cameo appearance, the gorilla paused to thump its chest. Still, half the conscientious pass-counting viewers failed to see it. In another follow-up experiment, only 1 in 4 students engrossed in a cell-phone conversation while crossing a campus square noticed a clown-suited unicyclist in their midst (Hyman et al., 2010). (Most of those not on the phone *did* notice.) Attention is powerfully selective. Your conscious mind is in one place at a time.

Given that most people miss someone in a gorilla or clown suit while their attention is riveted elsewhere, imagine the fun that magicians can have by manipulating our selective attention. Misdirect people's attention and they will miss the hand slipping into the pocket. "Every time you perform a magic trick, you're engaging in experimental psychology," says Teller, a magician and master of mind-messing methods (2009).

**inattentional blindness** failing to see visible objects when our attention is directed elsewhere.

**change blindness** failing to notice changes in the environment.

Magicians also exploit a form of inattentional blindness called **change blindness.** By selectively riveting our attention on their left hand's dramatic act, we fail to notice changes made with their other hand. In laboratory experiments, viewers didn't notice that, after a brief visual interruption, a big Coke bottle had disappeared, a railing had risen, or clothing color had changed (Chabris & Simons, 2010; Resnick et al., 1997). Focused on giving directions to a construction worker, two out of three people also failed to notice when he was replaced by another worker during a staged interruption (**FIGURE 16.3**). Out of sight, out of mind.

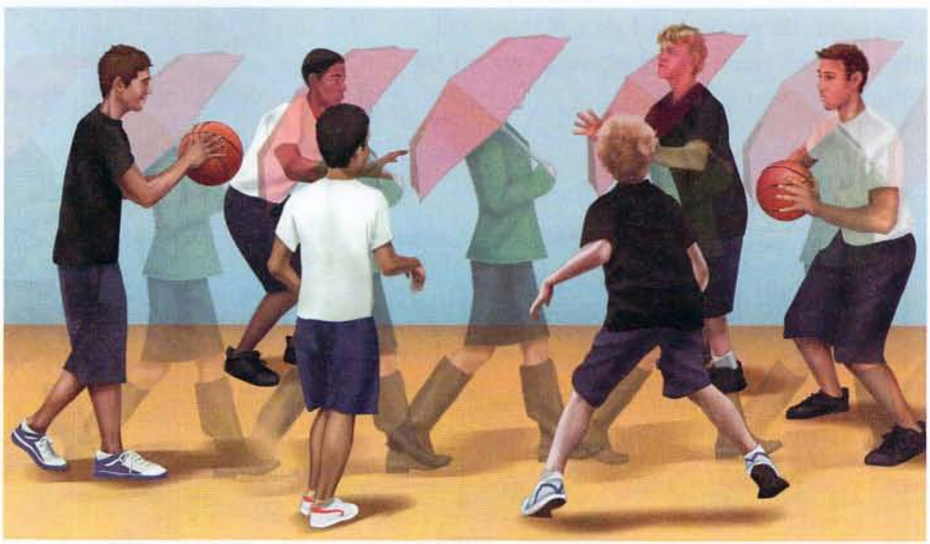

**Figure 16.2**

**Testing selective attention** In this classic experiment, viewers who were attending to basketball tosses among the black-shirted players usually failed to notice the umbrella-toting woman sauntering across the screen. (From Neisser, 1979.)

**Figure 16.3**

**Change blindness** While a man (white hair) provides directions to a construction worker, two experimenters rudely pass between them. During this interruption, the original worker switches places with another person wearing different-colored clothing. Most people, focused on their direction giving, do not notice the switch.

An equally astonishing form of inattention is *choice blindness.* At one Swedish supermarket, people tasted two jams, indicated their preference, and then tasted again their preferred jam and explained their preference. Fooled by trick jars (see **FIGURE 16.4**) most people didn't notice that they were actually "retasting" their *non*preferred jam.

Image is from the research paper by Lars Hall, Petter Johansson, and colleagues (2010).

**Figure 16.4**

**Marketplace magic** Prankster researchers Lars Hall, Petter Johansson, and colleagues (2010) invited people to sample two jams and pick one to retaste. By flipping the jars after putting the lids back on, the researchers actually induced people to "resample" their nonchosen jam. Yet, even when asked whether they noticed anything odd, most tasters were choice blind. Even when given markedly different jams, they usually failed to notice the switch.

Some stimuli, however, are so powerful, so strikingly distinct, that we experience *pop-out,* as when we notice an angry face in a crowd. We don't choose to attend to these stimuli; they draw our eye and demand our attention.

Our selective attention extends even into our sleep, as we will see.

## Transduction

### 16-3 What three steps are basic to all our sensory systems?

Every second of every day, our sensory systems perform an amazing feat: They convert one form of energy into another. Vision processes light energy. Hearing processes sound waves. All our senses

- *receive* sensory stimulation, often using specialized receptor cells.
- *transform* that stimulation into neural impulses.
- *deliver* the neural information to our brain.

The process of converting one form of energy into another that your brain can use is called **transduction.** Later in this unit, we'll focus on individual sensory systems. How do we see? Hear? Feel pain? Taste? Smell? Keep our balance? In each case, we'll consider these three steps—receiving, transforming, and delivering the information to the brain. We'll also see what **psychophysics** has discovered about the physical energy we can detect and its effects on our psychological experiences.

First, though, let's explore some strengths and weaknesses in our ability to detect and interpret stimuli in the vast sea of energy around us.

**transduction** conversion of one form of energy into another. In sensation, the transforming of stimulus energies, such as sights, sounds, and smells, into neural impulses our brain can interpret.

**psychophysics** the study of relationships between the physical characteristics of stimuli, such as their intensity, and our psychological experience of them.

# Thresholds

**16-4** What are the *absolute* and *difference thresholds,* and do stimuli below the absolute threshold have any influence on us?

At this moment, you and I are being struck by X-rays and radio waves, ultraviolet and infrared light, and sound waves of very high and very low frequencies. To all of these we are blind and deaf. Other animals with differing needs detect a world that lies beyond our experience. Migrating birds stay on course aided by an internal magnetic compass. Bats and dolphins locate prey using sonar, bouncing echoing sound off objects. Bees navigate on cloudy days by detecting invisible (to us) polarized light.

The shades on our own senses are open just a crack, allowing us a restricted awareness of this vast sea of energy. But for our needs, this is enough.

**absolute threshold** the minimum stimulation needed to detect a particular stimulus 50 percent of the time.

**signal detection theory** a theory predicting how and when we detect the presence of a faint stimulus *(signal)* amid background stimulation *(noise)*. Assumes that there is no single absolute threshold and that detection depends partly on a person's experience, expectations, motivation, and alertness.

## Absolute Thresholds

To some kinds of stimuli we are exquisitely sensitive. Standing atop a mountain on an utterly dark, clear night, most of us could see a candle flame atop another mountain 30 miles away. We could feel the wing of a bee falling on our cheek. We could smell a single drop of perfume in a three-room apartment (Galanter, 1962).

German scientist and philosopher Gustav Fechner (1801–1887) studied our awareness of these faint stimuli and called them our **absolute thresholds**—the minimum stimulation necessary to detect a particular light, sound, pressure, taste, or odor 50 percent of the time. To test your absolute threshold for sounds, a hearing specialist would expose each of your ears to varying sound levels. For each tone, the test would define where half the time you could detect the sound and half the time you could not. That 50-50 point would define your absolute threshold.

**Try This**

Try out this old riddle on a couple of friends. "You're driving a bus with 12 passengers. At your first stop, 6 passengers get off. At the second stop, 3 get off. At the third stop, 2 more get off but 3 new people get on. What color are the bus driver's eyes?" Do your friends detect the signal—who is the bus driver?—amid the accompanying noise?

Detecting a weak stimulus, or signal, depends not only on the signal's strength (such as a hearing-test tone) but also on our psychological state—our experience, expectations, motivation, and alertness. **Signal detection theory** predicts when we will detect weak signals (measured as our ratio of "hits" to "false alarms") **(FIGURE 16.5)**. Signal detection theorists seek to understand why people respond differently to the same stimuli (have you ever noticed that some teachers are much more likely than others to detect students texting during class?) and why the same person's reactions vary as circumstances change. Exhausted parents will notice the faintest whimper from a newborn's cradle while failing to notice louder, unimportant sounds. Lonely, anxious people at speed-dating events also respond with a low threshold and thus tend to be unselective in reaching out to potential dates (McClure et al., 2010).

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**Figure 16.5**

**Signal detection** What three factors will make it more likely that you correctly detect a text message?

ANSWER: (1) You are expecting a text message. (2) It is important that you see the text message and respond. (3) You are alert.

AJ Photo/Science Source

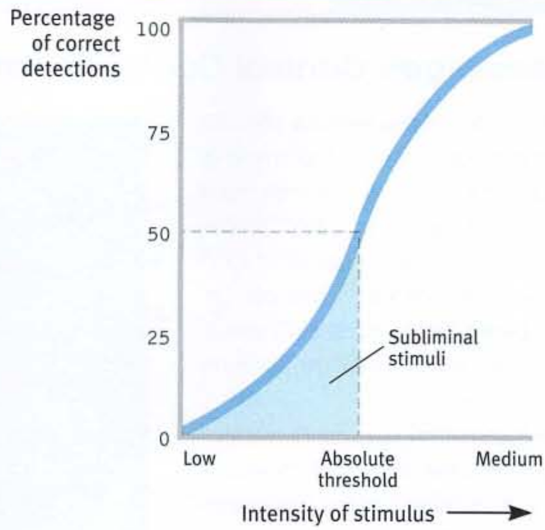



**Figure 16.6**
**Absolute threshold** Can I detect this sound? An *absolute threshold* is the intensity at which a person can detect a stimulus half the time. Hearing tests locate these thresholds for various frequency levels. Stimuli below your absolute threshold are subliminal.

Stimuli you cannot detect 50 percent of the time are **subliminal**—below your absolute threshold (**FIGURE 16.6**). Under certain conditions, you can be affected by stimuli so weak that you don't consciously notice them. An unnoticed image or word can reach your visual cortex and briefly **prime** your response to a later question. In a typical experiment, the image or word is quickly flashed, then replaced by a *masking stimulus* that interrupts the brain's processing before conscious perception (Van den Bussche et al., 2009). For example, one experiment subliminally flashed either emotionally positive scenes (kittens, a romantic couple) or negative scenes (a werewolf, a dead body) an instant before participants viewed slides of people (Krosnick et al., 1992). The participants consciously perceived either scene as only a flash of light. Yet the people somehow looked nicer if their image immediately followed unperceived kittens rather than an unperceived werewolf. As other experiments confirm, we can evaluate a stimulus even when we are not aware of it—and even when we are unaware of our evaluation (Ferguson & Zayas, 2009).

**subliminal** below one's absolute threshold for conscious awareness.

**priming** the activation, often unconsciously, of certain associations, thus predisposing one's perception, memory, or response.

"The heart has its reasons which reason does not know." -Pascal, *Pensées*, 1670

How do we feel or respond to what we do not know and cannot describe? An imperceptibly brief stimulus often triggers a weak response that *can* be detected by brain scanning (Blankenburg et al., 2003; Haynes & Rees, 2005, 2006). Only when the stimulus triggers synchronized activity in several brain areas does it reach consciousness (Dehaene, 2009). Once again we see the dual-track mind at work: *Much of our information processing occurs automatically, out of sight, off the radar screen of our conscious mind.*

So can we be controlled by subliminal messages? For more on that question, see Thinking Critically About: Can Subliminal Messages Control Our Behavior? on the next page.

## Difference Thresholds

To function effectively, we need absolute thresholds low enough to allow us to detect important sights, sounds, textures, tastes, and smells. We also need to detect small differences among stimuli. A musician must detect minute discrepancies when tuning an instrument. Students in the hallway must detect the sound of their friends' voices amid all the other voices. Even after living two years in Scotland, sheep *baa*'s all sound alike to my ears. But not to those of ewes, which I have observed streaking, after shearing, directly to the *baa* of their lamb amid the chorus of other distressed lambs.

Eric Isselée/Shutterstock

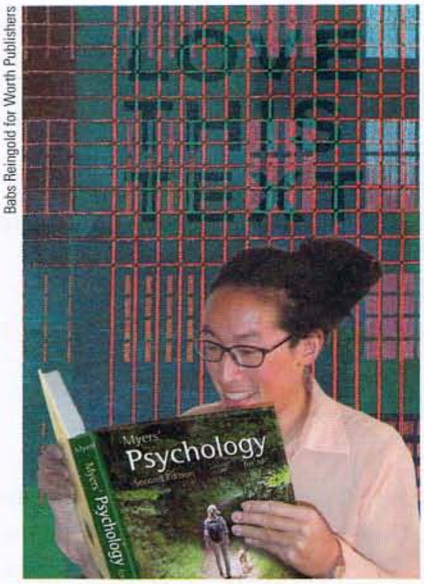
## Thinking Critically About

### Can Subliminal Messages Control Our Behavior?

Hoping to penetrate our unconscious, entrepreneurs offer audio and video programs to help us lose weight, stop smoking, or improve our memories. Soothing ocean sounds may mask messages we cannot consciously hear: "I am thin"; "Smoke tastes bad"; or "I do well on tests—I have total recall of information." Such claims make two assumptions: (1) We can unconsciously sense subliminal (literally, "below threshold") stimuli. (2) Without our awareness, these stimuli have extraordinary suggestive powers. Can we? Do they?

As we have seen, subliminal *sensation* is a fact. Remember that an "absolute" threshold is merely the point at which we can detect a stimulus *half the time*. At or slightly below this threshold, we will still detect the stimulus some of the time.

But does this mean that claims of subliminal *persuasion* are also facts? The near-consensus among researchers is *No*. The laboratory research reveals a *subtle, fleeting* effect. Priming thirsty people with the subliminal word *thirst* might therefore, for a moment, make a thirst-quenching beverage ad more persuasive (Strahan et al., 2002). Likewise, priming thirsty people with Lipton Iced Tea may increase their choosing the primed brand (Karremans et al., 2006; Veltkamp et al., 2011; Verwijmeren et al., 2011a,b). But the subliminal-message hucksters claim something different: a *powerful, enduring* effect on behavior.




Babs Reingold for Worth Publishers

**Subliminal persuasion?** Although subliminally presented stimuli *can* subtly influence people, experiments discount attempts at subliminal advertising and self-improvement. (The playful message here is not actually subliminal—because you can easily perceive it.)

To test whether subliminal recordings have this enduring effect, researchers randomly assigned university students to listen daily for 5 weeks to commercial subliminal messages claiming to improve either self-esteem or memory (Greenwald et al., 1991, 1992). But the researchers played a practical joke and switched half the labels. Some students who thought they were receiving affirmations of self-esteem were actually hearing the memory-enhancement message. Others got the self-esteem message but thought their memory was being recharged.

Were the recordings effective? Students' test scores for self-esteem and memory, taken before and after the 5 weeks, revealed no effects. Yet the students *perceived* themselves receiving the benefits they *expected*. Those who *thought* they had heard a memory recording *believed* their memories had improved. Those who thought they had heard a self-esteem recording believed their self-esteem had grown. (Reading this research, one hears echoes of the testimonies that ooze from ads for such products. Some customers, having bought what is not supposed to be heard [and having indeed not heard it!] offer testimonials like, "I really know that your recordings were invaluable in reprogramming my mind.")

Over a decade, Greenwald conducted 16 double-blind experiments evaluating subliminal self-help recordings. His results were uniform: Not one of the recordings helped more than a placebo (Greenwald, 1992). And placebos, you may remember, work only because we *believe* they will work.

The LORD is my shepherd;
I shall not want.
He maketh me to lie down
in green pastures:
he leadeth me
beside the still waters.
He restoreth my soul:
he leadeth me
in the paths of righteousness
for his name's sake.
Yea, though I walk through the valley
of the shadow of death,
I will fear no evil:
for thou art with me;
thy rod and thy staff
they comfort me.
Thou preparest a table before me
in the presence of mine enemies:
thou anointest my head with oil,
my cup runneth over.
Surely goodness and mercy
shall follow me
all the days of my life:
and I will dwell
in the house of the LORD
for ever.

**The difference threshold** In this computer-generated copy of the Twenty-third Psalm, each line of the typeface increases slightly. How many lines are required for you to experience a just noticeable difference?

The **difference threshold** (or the *just noticeable difference [jnd]*) is the minimum difference a person can detect between any two stimuli half the time. That difference threshold increases with the size of the stimulus. Thus, if you add 1 ounce to a 10-ounce weight, you will detect the difference; add 1 ounce to a 100-ounce weight and you probably will not.

In the nineteenth century, Ernst Weber noted something so simple and so widely applicable that we still refer to it as **Weber's law.** This law states that for an average person to perceive a difference, two stimuli must differ by a constant minimum *percentage* (not a constant *amount*). The exact proportion varies, depending on the stimulus. Two lights, for example, must differ in intensity by 8 percent. Two objects must differ in weight by 2 percent. And two tones must differ in frequency by only 0.3 percent (Teghtsoonian, 1971). For example, to be perceptibly different, a 50-ounce weight must differ from another by about an ounce, a 100-ounce weight by about 2 ounces.

**difference threshold** the minimum difference between two stimuli required for detection 50 percent of the time. We experience the difference threshold as a *just noticeable difference* (or *jnd*).

**Weber's law** the principle that, to be perceived as different, two stimuli must differ by a constant minimum percentage (rather than a constant amount).

**sensory adaptation** diminished sensitivity as a consequence of constant stimulation.

## Sensory Adaptation

### 16-5 What is the function of sensory adaptation?

Entering your neighbors' living room, you smell a musty odor. You wonder how they can stand it, but within minutes you no longer notice it. **Sensory adaptation** has come to your rescue. When we are constantly exposed to a stimulus that does not change, we become less aware of it because our nerve cells fire less frequently. (To experience sensory adaptation, move your watch up your wrist an inch: You will feel it—but only for a few moments.)

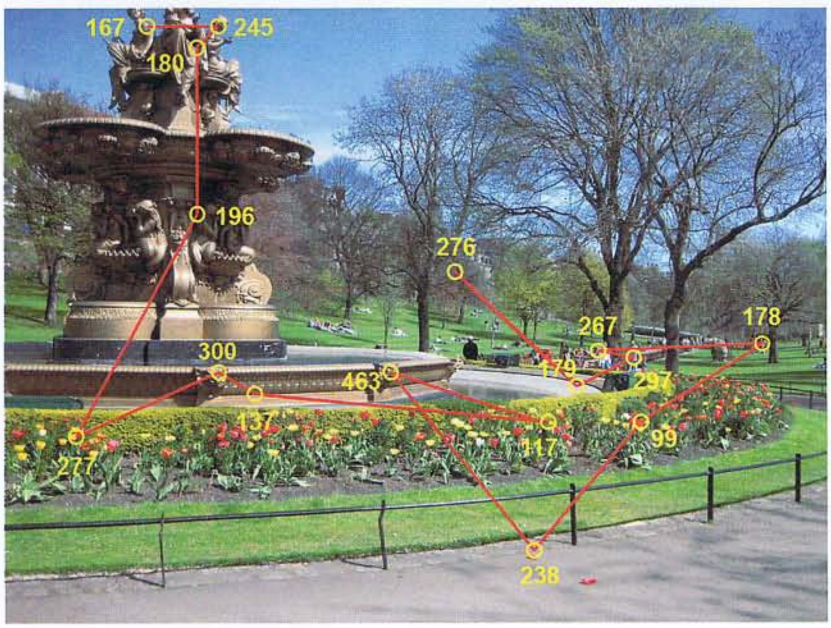
Why, then, if we stare at an object without flinching, does it *not* vanish from sight? Because, unnoticed by us, our eyes are always moving. This continual flitting from one spot to another ensures that stimulation on the eyes' receptors continually changes (**FIGURE 16.7**).

"We need above all to know about changes; no one wants or needs to be reminded 16 hours a day that his shoes are on."
-Neuroscientist David Hubel (1979)

What if we actually could stop our eyes from moving? Would sights seem to vanish, as odors do? To find out, psychologists have devised ingenious instruments that maintain a constant image on the eye's inner surface. Imagine that we have fitted a volunteer, Mary, with one of these instruments—a miniature projector mounted on a contact lens (**FIGURE 16.8a** on the next page). When Mary's eye moves, the image from the projector moves as well. So everywhere that Mary looks, the scene is sure to go.

If we project images through this instrument, what will Mary see? At first, she will see the complete image. But within a few seconds, as her sensory system begins to fatigue, things get weird. Bit by bit, the image vanishes, only to reappear and then disappear—often in fragments (Figure 16.8b).

Although sensory adaptation reduces our sensitivity, it offers an important benefit: freedom to focus on *informative* changes in our environment without being distracted by background chatter. Stinky or heavily perfumed classmates don't notice their odor because, like you and me, they adapt to what's constant and detect only change. Our sensory receptors




John M. Henderson

**Figure 16.7**
**The jumpy eye** Our gaze jumps from one spot to another every third of a second or so, as eye-tracking equipment illustrated in this photograph of Edinburgh's Princes Street Gardens (Henderson, 2007). The circles represent fixations, and the numbers indicate the time of fixation in milliseconds (300 milliseconds = three-tenths of a second).

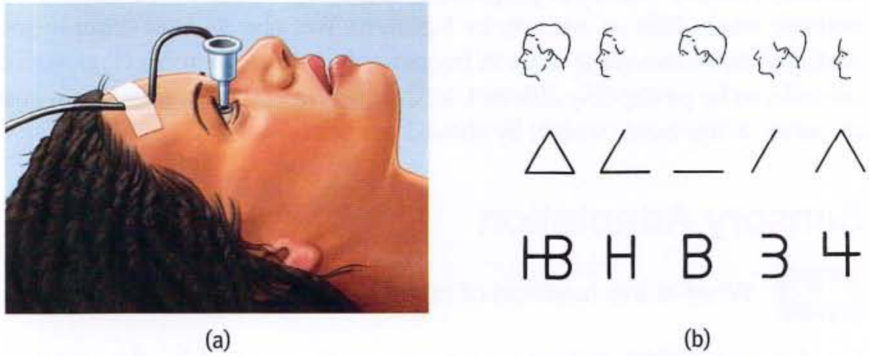



**Figure 16.8**

**Sensory adaptation: Now you see it, now you don't!**
(a) A projector mounted on a contact lens makes the projected image move with the eye. (b) Initially, the person sees the stabilized image, but soon she sees fragments fading and reappearing. (From "Stabilized images on the retina," by R. M. Pritchard. Copyright © 1961 Scientific American, Inc. All rights reserved.)

are alert to novelty; bore them with repetition and they free our attention for more important things. We will see this principle again and again: *We perceive the world not exactly as it is, but as it is useful for us to perceive it.*

Our sensitivity to changing stimulation helps explain television's attention-grabbing power. Cuts, edits, zooms, pans, sudden noises—all demand attention. The phenomenon is irresistible even to TV researchers. One noted that even during interesting conversations, "I cannot for the life of me stop from periodically glancing over to the screen" (Tannenbaum, 2002).

Sensory adaptation even influences our perceptions of emotions. By creating a 50-50 morphed blend of an angry and a scared face, researchers showed that our visual system adapts to a static facial expression by becoming less responsive to it (Butler et al., 2008) (**FIGURE 16.9**).

Sensory adaptation and sensory thresholds are important ingredients in our perceptions of the world around us. Much of what we perceive comes not just from what's "out there" but also from what's behind our eyes and between our ears.

**Figure 16.9**

**Emotion adaptation** Gaze at the angry face on the left for 20 to 30 seconds, then look at the center face (looks scared, yes?). Then gaze at the scared face on the right for 20 to 30 seconds, before returning to the center face (now looks angry, yes?).



## Before You Move On

### ▶ ASK YOURSELF

Can you recall a recent time when, your attention focused on one thing, you were oblivious to something else (perhaps to pain, to someone's approach, or to background music)?

### ▶ TEST YOURSELF

Explain how Heather Sellers' experience of prosopagnosia illustrates the difference between sensation and perception.

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

# Module 16 Review

**16-1** What are *sensation* and *perception?* What do we mean by *bottom-up processing* and *top-down processing?*

- *Sensation* is the process by which our sensory receptors and nervous system receive and represent stimulus energies from our environment. *Perception* is the process of organizing and interpreting this information, enabling recognition of meaningful events. Sensation and perception are actually parts of one continuous process.
- *Bottom-up processing* is sensory analysis that begins at the entry level, with information flowing from the sensory receptors to the brain. *Top-down processing* is information processing guided by high-level mental processes, as when we construct perceptions by filtering information through our experience and expectations.

**16-2** How much information do we consciously attend to at once?

- We *selectively attend* to, and process, a very limited portion of incoming information, blocking out much and often shifting the spotlight of our attention from one thing to another.
- Focused intently on one task, we often display *inattentional blindness* (including *change blindness*) to other events and changes around us.

**16-3** What three steps are basic to all our sensory systems?

- Our senses (1) receive sensory stimulation (often using specialized receptor cells); (2) transform that stimulation into neural impulses; and (3) deliver the neural information to the brain. *Transduction* is the process of converting one form of energy into another.
- Researchers in *psychophysics* study the relationships between stimuli's physical characteristics and our psychological experience of them.

**16-4** What are the *absolute* and *difference thresholds,* and do stimuli below the absolute threshold have any influence on us?

- Our *absolute threshold* for any stimulus is the minimum stimulation necessary for us to be consciously aware of it 50 percent of the time. *Signal detection theory* predicts how and when we will detect a faint stimulus amid background noise. Individual absolute thresholds vary, depending on the strength of the signal and also on our experience, expectations, motivation, and alertness.
- Our *difference threshold* (also called *just noticeable difference,* or *jnd*) is the difference we can discern between two stimuli 50 percent of the time. *Weber's law* states that two stimuli must differ by a constant percentage (not a constant amount) to be perceived as different.
- *Priming* shows that we can process some information from stimuli below our absolute threshold for conscious awareness. But the effect is too fleeting to enable people to exploit us with *subliminal* messages.

**16-5** What is the function of sensory adaptation?

- *Sensory adaptation* (our diminished sensitivity to constant or routine odors, sights, sounds, and touches) focuses our attention on informative changes in our environment.

## Multiple-Choice Questions

**1.** What occurs when experiences influence our interpretation of data?

a. Selective attention
b. Transduction
c. Bottom-up processing
d. Top-down processing
e. Signal detection theory

**2.** What principle states that to be perceived as different, two stimuli must differ by a minimum percentage rather than a constant amount?

a. Absolute threshold
b. Different threshold
c. Signal detection theory
d. Priming
e. Weber's law

**3.** What do we call the conversion of stimulus energies, like sights and sounds, into neural impulses?

a. Transduction
b. Perception
c. Priming
d. Signal detection theory
e. Threshold

**4.** Natalia is washing her hands and adjusts the faucet handle until the water feels just slightly hotter than it did before. Natalia's adjustment until she feels a difference is an example of

a. a subliminal stimulus.
b. an absolute threshold.
c. a difference threshold.
d. signal detection.
e. Weber's law.

**5.** Tyshane went swimming with friends who did not want to get into the pool because the water felt cold. Tyshane jumped in and after a few minutes declared, "It was cold when I first got in, but now my body is used to it. Come on in!" Tyshane's body became accustomed to the water due to

a. perceptual set.
b. absolute threshold.
c. difference threshold.
d. selective attention.
e. sensory adaptation.

## Practice FRQs

**1.** Explain how bottom-up and top-down processes work together to help us decipher the world around us..

### Answer

***1 point:*** Bottom-up processing starts at the sensory receptors and works up to higher levels of processing.

***1 point:*** Top-down processing constructs perceptions from the sensory input by drawing on our experience and expectations.

**2.** Marisol is planning a ski trip for spring break. Define absolute threshold and difference threshold, and explain how each one might play a role in her perception of the winter weather she will experience.

***(4 points)***

# Module 17

## Influences on Perception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### Module Learning Objectives

**17-1** Explain how our expectations, contexts, emotions, and motivation influence our perceptions.

**17-2** List the claims of ESP, and discuss the conclusions of most research psychologists after putting these claims to the test.

## Perceptual Set

**17-1** How do our expectations, contexts, emotions, and motivation influence our perceptions?

As everyone knows, to see is to believe. As we less fully appreciate, to believe is to see. Through experience, we come to expect certain results. Those expectations may give us a **perceptual set,** a set of mental tendencies and assumptions that greatly affects (top-down) what we perceive. Perceptual set can influence what we hear, taste, feel, and see.

**perceptual set** a mental predisposition to perceive one thing and not another.

Consider: Is the image in the center picture of **FIGURE 17.1** a young woman's profile or an old woman? What we see in such a drawing can be influenced by first looking at either of the two unambiguous versions (Boring, 1930).

Everyday examples of perceptual set abound. In 1972, a British newspaper published unretouched photographs of a "monster" in Scotland's Loch Ness—"the most amazing

**Figure 17.1**
**Perceptual set** Show a friend either the left or right image. Then show the center image and ask, "What do you see?" Whether your friend reports seeing a young woman's profile or an old woman may depend on which of the other two drawings was viewed first. In each of those images, the meaning is clear, and it will establish perceptual expectations.




pictures ever taken," stated the paper. If this information creates in you the same expectations it did in most of the paper's readers, you, too, will see the monster in a similar photo in **FIGURE 17.2**. But when a skeptical researcher approached the photos with different expectations, he saw a curved tree limb—as had others the day the photo was shot (Campbell, 1986). With this different perceptual set, you may now notice that the object is floating motionless, with ripples outward in all directions—hardly what we would expect of a lively monster. Once we have formed a wrong idea about reality, we have more difficulty seeing the truth.

Perceptual set can also affect what we hear. Consider the kindly airline pilot who, on a takeoff run, looked over at his depressed co-pilot and said, "Cheer up." Expecting to hear the usual "Gear up," the co-pilot promptly raised the wheels—before they left the ground (Reason & Mycielska, 1982).

**Figure 17.2**

**Believing is seeing** What do you perceive? Is this Nessie, the Loch Ness monster, or a log?



**Try This**

When shown the phrase

*Mary had a*
*a little lamb*

many people perceive what they expect, and miss the repeated word. Did you?

Perceptual set similarly affects taste. One experiment invited some bar patrons to sample free beer (Lee et al., 2006). When researchers added a few drops of vinegar to a brand-name beer, the tasters preferred it—unless they had been told they were drinking vinegar-laced beer. Then they expected, and usually experienced, a worse taste. In another experiment, preschool children, by a 6-to-1 margin, thought french fries tasted better when served in a McDonald's bag rather than a plain white bag (Robinson et al., 2007).

What determines our perceptual set? As Module 47 will explain, through experience we form concepts, or *schemas,* that organize and allow us to interpret unfamiliar information. Our pre-existing schemas for old women and young women, for monsters and tree limbs, all influence how we interpret ambiguous sensations with top-down processing.

"We hear and apprehend only what we already half know."
-Henry David Thoreau, *Journal*, 1860

In everyday life, stereotypes about gender (another instance of perceptual set) can color perception. Without the obvious cues of pink or blue, people will struggle over whether to call the new baby "he" or "she." But told an infant is "David," people (especially children) may perceive "him" as bigger and stronger than if the same infant is called "Diana" (Stern & Karraker, 1989). Some differences, it seems, exist merely in the eyes of their beholders.

## Context Effects

A given stimulus may trigger radically different perceptions, partly because of our differing perceptual set, but also because of the immediate context. Some examples:

**Culture and context effects** What is above the woman's head? In a classic study from nearly a half-century ago, most East Africans perceived the woman as balancing a metal box or can on her head and the family as sitting under a tree. Westerners, for whom corners and boxlike architecture were more common, were more likely to perceive the family as being indoors, with the woman sitting under a window. (Adapted from Gregory & Gombrich, 1973.)

- Imagine hearing a noise interrupted by the words "eel is on the wagon." Likely, you would actually perceive the first word as *wheel*. Given "eel is on the orange," you would hear *peel*. This curious phenomenon, discovered by Richard Warren, suggests that the brain can work backward in time to allow a later stimulus to determine how we perceive an earlier one. The context creates an expectation that, top-down, influences our perception (Grossberg, 1995).
- Does the pursuing dog in **FIGURE 17.3** look bigger than the one being pursued? If so, you are experiencing a context effect.
- How tall is the shorter player in **FIGURE 17.4**?

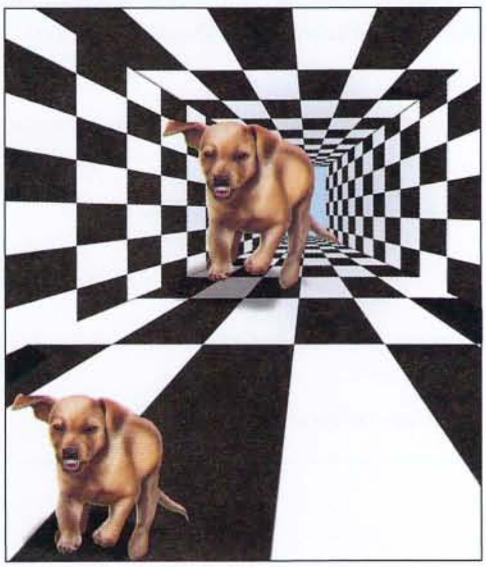


**Figure 17.3**

**The interplay between context and emotional perception** The context makes the pursuing dog look bigger than the pursued. It isn't.

Dennis Geppert/Holland Sentinel

**Figure 17.4**

**Big and "little"** The "little guy" shown here is actually a 6'9" former Hope College basketball center who would tower over most of us. But he seemed like a short player when matched in a semi-pro game against the world's tallest basketball player at that time, 7'9" Sun Ming Ming from China.

## Emotion and Motivation

Perceptions are influenced, top-down, not only by our expectations and by the context, but also by our emotions and motivation.

Hearing sad rather than happy music can predispose people to perceive a sad meaning in spoken homophonic words—*mourning* rather than *morning*, *die* rather than *dye*, *pain* rather than *pane* (Halberstadt et al., 1995).

Researchers (Proffitt, 2006a,b; Schnall et al., 2008) have demonstrated the power of emotions with other clever experiments showing that

- walking destinations look farther away to those who have been fatigued by prior exercise.
- a hill looks steeper to those who are wearing a heavy backpack or have just been exposed to sad, heavy classical music rather than light, bouncy music. As with so many of life's challenges, a hill also seems less steep to those with a friend beside them.
- a target seems farther away to those throwing a heavy rather than a light object at it.

"When you're hitting the ball, it comes at you looking like a grapefruit. When you're not, it looks like a blackeyed pea."
-Former Major League Baseball player George Scott

Even a softball appears bigger when you are hitting well, observed other researchers, after asking players to choose a circle the size of the ball they had just hit well or poorly (Witt & Proffitt, 2005). When angry, people more often perceive neutral objects as guns (Bauman & DeSteno, 2010).

Motives also matter. Desired objects, such as a water bottle when thirsty, seem closer (Balcetis & Dunning, 2010). This perceptual bias energizes our going for it. Our motives also direct our perception of ambiguous images.

Emotions color our social perceptions, too. Spouses who feel loved and appreciated perceive less threat in stressful marital events—"He's just having a bad day" (Murray et al., 2003). Professional referees, if told a soccer team has a history of aggressive behavior, will assign more penalty cards after watching videotaped fouls (Jones et al., 2002).

* * *

Emotion and motivation clearly influence how we perceive sensations. But what to make of extrasensory perception, which claims that perception can occur apart from sensory input? For more on that question, see Thinking Critically About: ESP—Perception Without Sensation?

## Before You Move On

### ▶ ASK YOURSELF

Can you recall a time when your expectations have predisposed how you perceived a person (or group of people)?

### ▶ TEST YOURSELF

What type of evidence shows that, indeed, "there is more to perception than meets the senses"?

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

## Thinking Critically About

### ESP—Perception Without Sensation?

**17-2** What are the claims of ESP, and what have most research psychologists concluded after putting these claims to the test?

Without sensory input, are we capable of **extrasensory perception (ESP)**? Are there indeed people—any people—who can read minds, see through walls, or foretell the future? Nearly half of Americans believe there are (AP, 2007; Moore, 2005).

The most testable and, for this unit, most relevant parapsychological concepts are

- *telepathy:* mind-to-mind communication.
- *clairvoyance:* perceiving remote events, such as a house on fire in another state.
- *precognition:* perceiving future events, such as an unexpected death in the next month.

Closely linked is *psychokinesis,* or "mind over matter," such as levitating a table or influencing the roll of a die. (The claim is illustrated by the wry request, "Will all those who believe in psychokinesis please raise my hand?")

If ESP is real, we would need to overturn the scientific understanding that we are creatures whose minds are tied to our physical brains and whose perceptual experiences of the world are built of sensations. Sometimes new evidence does overturn our scientific preconceptions. Science, as we will see throughout this book, offers us various surprises—about the extent of the unconscious mind, about the effects of emotions on health, about what heals and what doesn't, and much more.


Dan Piraro

Most research psychologists and scientists—including 96 percent of the scientists in the U.S. National Academy of Sciences—are skeptical that paranormal phenomena exist (McConnell, 1991). But reputable universities in many locations, including Great Britain, the Netherlands, and Australia, have added faculty chairs or research units in **parapsychology** (Turpin, 2005). These researchers perform scientific experiments searching for possible ESP and other paranormal phenomena. Before seeing how parapsychologists do research on ESP, let's consider some popular beliefs.

#### PREMONITIONS OR PRETENSIONS?

Can psychics see into the future? Although one might wish for a psychic stock forecaster, the tallied forecasts of "leading psychics" reveal meager accuracy. During the 1990s, the tabloid psychics were all wrong in predicting surprising events. (Madonna did not become a gospel singer, the Statue of Liberty did not lose both its arms in a terrorist blast, Queen Elizabeth did not abdicate her throne to enter a convent.) And the new-century psychics have missed the big-news events. Where were the psychics on 9/10 when we needed them? Why, despite a $50 million reward offered, could none of them help locate terrorist Osama bin Laden after the horror of 9/11, or step forward to predict the impending stock crashes in 2008? In 30 years, unusual predictions have almost never come true, and psychics have virtually never anticipated any of the year's headline events (Emory, 2004, 2006). In 2010, when a mine collapse trapped 33 miners, the Chilean government reportedly consulted four psychics. Their verdict? "They're all dead" (Kraul, 2010). But 69 days later, all 33 were rescued.

Moreover, the hundreds of psychic visions offered to police departments have been no more accurate than guesses made by others (Nickell, 1994, 2005; Radford, 2010; Reiser, 1982). But their sheer volume does increase the odds of an occasional correct guess, which psychics can then report to the media. Police departments are wise to all this. When researchers asked the police departments of America's 50 largest cities whether they ever had used psychics, 65 percent said *No* (Sweat & Durm, 1993). Of those that had, not one had found them helpful. Vague predictions can also later be interpreted ("retrofitted")

**extrasensory perception (ESP)** the controversial claim that perception can occur apart from sensory input; includes telepathy, clairvoyance, and precognition.

**parapsychology** the study of paranormal phenomena, including ESP and psychokinesis.

*(continued on next page)*

## Thinking Critically About *(continued)*

to match events that provide a perceptual set for "understanding" them. Nostradamus, a sixteenth-century French psychic, explained in an unguarded moment that his ambiguous prophecies "could not possibly be understood till they were interpreted after the event and by it."

Are the spontaneous "visions" of everyday people any more accurate? Do dreams, for example, foretell the future, as people from both Eastern and Western cultures tend to believe—making some people more reluctant to fly after dreaming of a plane crash (Morewedge & Norton, 2009)? Or do they only seem to do so when we recall or reconstruct them in light of what has already happened? Two Harvard psychologists tested the prophetic power of dreams after superhero aviator Charles Lindbergh's baby son was kidnapped and murdered in 1932, but before the body was discovered (Murray & Wheeler, 1937). When invited to report their dreams about the child, 1300 visionaries submitted dream reports. How many accurately envisioned the child dead? Five percent. And how many also correctly anticipated the body's location—buried among trees? Only 4 of the 1300. Although this number was surely no better than chance, to those 4 dreamers the accuracy of their apparent precognitions must have seemed uncanny.

Given the billions of events in the world each day, and given enough days, some stunning coincidences are sure to occur. By one careful estimate, chance alone would predict that more than a thousand times a day someone on Earth will think of another person and then within the next five minutes will learn of that person's death (Charpak & Broch, 2004). Thus, when explaining an astonishing event, we should "give chance a chance" (Lilienfeld, 2009). With enough time and people, the improbable becomes inevitable.

"To be sure of hitting the target, shoot first and call whatever you hit the target." -WRITER-ARTIST ASHLEIGH BRILLIANT, 1933

"A person who talks a lot is sometimes right." -SPANISH PROVERB

### PUTTING ESP TO EXPERIMENTAL TEST

When faced with claims of mind reading or out-of-body travel or communication with the dead, how can we separate bizarre ideas from those that sound strange but are true? At the heart of science is a simple answer: *Test them to see if they work.* If they do, so much the better for the ideas. If they don't, so much the better for our skepticism.

This scientific attitude has led both believers and skeptics to agree that what parapsychology needs is a reproducible phenomenon and a theory to explain it. Parapsychologist Rhea White (1998) spoke for many in saying that "the image of parapsychology that comes to my mind, based on nearly 44 years in the field, is that of a small airplane [that] has been perpetually taxiing down the runway of the Empirical Science Airport since 1882 . . . its movement punctuated occasionally by lifting a few feet off the ground only to bump back down on the tarmac once again. It has never taken off for any sustained flight."

How might we test ESP claims in a controlled, reproducible experiment? An experiment differs from a staged demonstration. In the laboratory, the experimenter controls what the "psychic" sees and hears. On stage, the psychic controls what the audience sees and hears.

The search for a valid and reliable test of ESP has resulted in thousands of experiments. After digesting data from 30 such studies, parapsychologist Lance Storm and his colleagues (2010a,b) concluded that, given participants with experience or belief in ESP, there is "consistent and reliable" parapsychological evidence. Psychologist Ray Hyman (2010), who has been scrutinizing parapsychological research since 1957, replies that if this is the best evidence, it fails to impress: "Parapsychology will achieve scientific acceptability only when it provides a positive theory with . . . independently replicable evidence. This is something it has yet to achieve after more than a century."

Daryl Bem (2011), a respected social psychologist, has been a skeptic of stage psychics; he once quipped that "a psychic is an actor playing the role of a psychic" (1984). Yet he has reignited hopes for replicable evidence with nine experiments that seemed to show people anticipating future events. In one,

"At the heart of science is an essential tension between two seemingly contradictory attitudes—an openness to new ideas, no matter how bizarre or counterintuitive they may be, and the most ruthless skeptical scrutiny of all ideas, old and new." -CARL SAGAN (1987)

Magician Harry Houdini after fooling Sir Arthur Conan Doyle with a pseudo-psychic trick: "Now I beg of you, Sir Arthur, do not jump to the conclusion that certain things you see are necessarily 'supernatural,' or with the work of 'spirits,' just because you cannot explain them." -QUOTED BY WILLIAM KALUSH AND LARRY SLOMAN, *THE SECRET LIFE OF HOUDINI*, 2007

## Thinking Critically About *(continued)*

when an erotic scene was about to appear on a screen in one of two randomly selected positions, Cornell University participants guessed right 53.1 percent of the time (beating 50 percent by a small but statistically significant margin). In another, people viewed a set of words, took a recall test of those words, and then rehearsed a randomly selected subset of those words. People better remembered the rehearsed words—even when the rehearsal took place *after* the recall test. The upcoming rehearsal—a future event—apparently affected their ability to recall words.

Bem wonders if his "anomalous" findings reflect an evolutionary advantage to those who can precognitively anticipate future dangers. Critics scoff. "If any of his claims were true," wrote cognitive scientist Douglas Hofstadter (2011), "then all of the bases underlying contemporary science would be toppled, and we would have to rethink everything about the nature of the universe." Moreover, if future events retroactively affect present feelings, then why can't people intuitively predict casino outcomes or stock market futures?

Despite Bem's research having survived critical reviews by a top-tier journal, other critics found the methods "badly flawed" (Alcock, 2011) or the statistical analyses "biased" (Wagenmakers et al., 2011). "A result—especially one of this importance—must recur several times in tests by independent and skeptical researchers to gain scientific credibility," observed astronomer David Helfand (2011). "I have little doubt that Professor Bem's experiments will fail this test."

Anticipating such skepticism, Bem has made his computer materials available to anyone who wishes to replicate his studies, and replications are now under way. One research team has already conducted five replications of Bem's recall experiments at various universities and found no precognition (Galak et al., 2011). Regardless of the outcomes, science will have done its work. It will have been open to a finding that challenges its own worldview, and then, through follow-up research, it will have assessed its validity. And that is how science sifts crazy-sounding ideas, leaving most on the historical waste heap while occasionally surprising us.

One skeptic, magician James Randi, has had a longstanding offer of $1 million to be given "to anyone who proves a genuine psychic power under proper observing conditions" (Randi, 1999; Thompson, 2010). French, Australian, and Indian groups have made similar offers of up to 200,000 euros (CFI, 2003). Large as these sums are, the scientific seal of approval would be worth far more. To refute those who say there is no ESP, one need only produce a single person who can demonstrate a single, reproducible ESP event. (To refute those who say pigs can't talk would take but one talking pig.) So far, no such person has emerged.


Courtesy of Claire Cole

**Testing psychic powers in the British population**
University of Hertfordshire psychologists created a "mind machine" to see if people can influence or predict a coin toss (Wiseman & Greening, 2002). Using a touch-sensitive screen, visitors to festivals around the country were given four attempts to call heads or tails. Using a random-number generator, a computer then decided the outcome. When the experiment concluded in January 2000, nearly 28,000 people had predicted 110,959 tosses—with 49.8 percent correct.

## Before You Move On

### ▶ ASK YOURSELF

Have you ever had what felt like an ESP experience? Can you think of an explanation other than ESP for that experience?

### ▶ TEST YOURSELF

What is the field of study that researches claims of extrasensory perception (ESP)?

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

# Module 17 Review

**17-1** How do our expectations, contexts, emotions, and motivation influence our perceptions?

- *Perceptual set* is a mental predisposition that functions as a lens through which we perceive the world.
- Our learned concepts (schemas) prime us to organize and interpret ambiguous stimuli in certain ways.
- Our physical and emotional context, as well as our motivation, can create expectations and color our interpretation of events and behaviors.

**17-2** What are the claims of ESP, and what have most research psychologists concluded after putting these claims to the test?

- *Parapsychology* is the study of paranormal phenomena, including *extrasensory perception (ESP)* and psychokinesis.
- The three most testable forms of ESP are telepathy (mind-to-mind communication), clairvoyance (perceiving remote events), and precognition (perceiving future events).
- Skeptics argue that (1) to believe in ESP, you must believe the brain is capable of perceiving without sensory input, and (2) researchers have been unable to replicate ESP phenomena under controlled conditions.

## Multiple-Choice Questions

**1.** What do we call a mental predisposition that influences our interpretation of a stimulus?

a. A context effect
b. Perceptual set
c. Extrasensory perception
d. Emotion
e. Motivation

**2.** Kimberly tells her brother to put on a suit on a warm summer day. Kimberly's brother knows to put on a swimsuit instead of a business suit because of

a. context.
b. ESP.
c. precognition.
d. bottom-up processing.
e. clairvoyance.

**3.** Which of the following is produced by perceptual set?

a. Not noticing that the songs change in a restaurant
b. Noticing a difference in the weight of a friend from one week to the next
c. Moving an arm quickly so that a mosquito flies away
d. Surprise at hearing an Oklahoma cowboy speak with a British accent
e. Not noticing a watch on your wrist as the day goes on

## Practice FRQs

**1.** Martha is convinced she has extrasensory perception. Explain what Martha's specific abilities would be if she had each of the following forms of ESP:

- Telepathy
- Clairvoyance
- Precognition

Then, briefly explain why you should doubt her claims.

### Answer

***1 point:*** Telepathy: Martha would be able to use mind-to-mind communication; that is, she is able to read someone's mind.

***1 point:*** Clairvoyance: Martha would be able to perceive things happening at a distance; that is, a cousin who lives in another state just burnt her hand on the oven, and Martha feels it.

***1 point:*** Precognition: Martha would be able to see future events happen; that is, she knows a pop quiz will take place next week.

***1 point:*** There has never been a conclusive scientific demonstration of extrasensory ability.

**2.** How can context effects, emotions, and motivation trigger different perceptions of a single stimulus?

*(3 points)*

# Module 18


## Vision

### Module Learning Objectives

**18-1** Describe the characteristics of visible light, and explain the process by which the eye transforms light energy into neural messages.

**18-2** Describe how the eye and brain process visual information.

**18-3** Discuss the theories that help us understand color vision.

**wavelength** the distance from the peak of one light or sound wave to the peak of the next. Electromagnetic wavelengths vary from the short blips of cosmic rays to the long pulses of radio transmission.

**18-1** What is the energy that we see as visible light, and how does the eye transform light energy into neural messages?

Our eyes receive light energy and transduce (transform) it into neural messages that our brain then processes into what we consciously see. How does such a taken-for-granted yet remarkable thing happen?

## The Stimulus Input: Light Energy

When you look at a bright red tulip, what strikes your eyes is not particles of the color red but pulses of electromagnetic energy that your visual system perceives as red. What we see as visible light is but a thin slice of the whole spectrum of electromagnetic energy, ranging from imperceptibly short gamma waves to the long waves of radio transmission (**FIGURE 18.1**). Other organisms are sensitive to differing portions of the spectrum. Bees, for instance, cannot see what we perceive as red but can see ultraviolet light.

Two physical characteristics of light help determine our sensory experience of them. Light's **wavelength**—the distance from one wave peak to the next

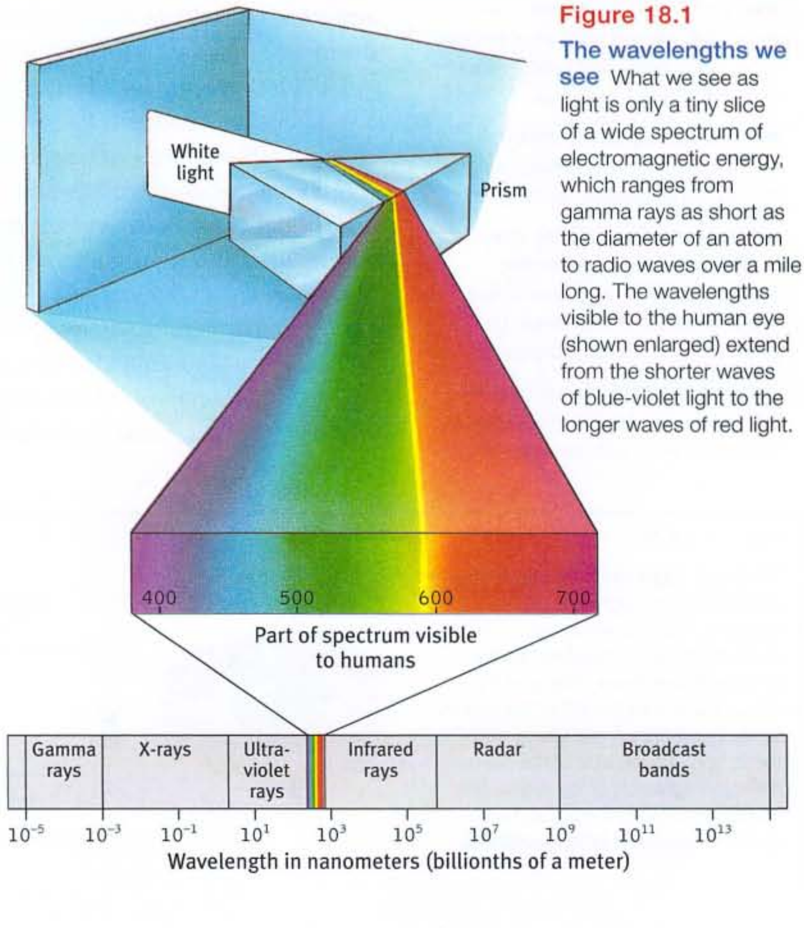



**Figure 18.1** **The wavelengths we see** What we see as light is only a tiny slice of a wide spectrum of electromagnetic energy, which ranges from gamma rays as short as the diameter of an atom to radio waves over a mile long. The wavelengths visible to the human eye (shown enlarged) extend from the shorter waves of blue-violet light to the longer waves of red light.

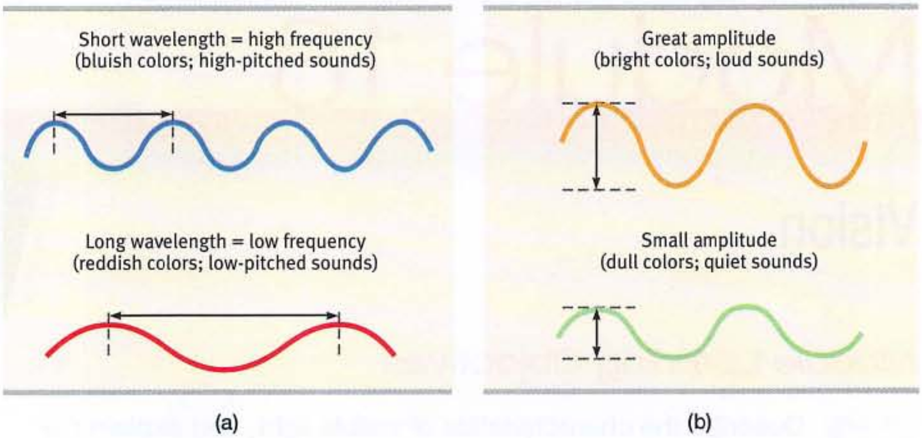



**Figure 18.2**

**The physical properties of waves** (a) Waves vary in *wavelength* (the distance between successive peaks). *Frequency,* the number of complete wavelengths that can pass a point in a given time, depends on the wavelength. The shorter the wavelength, the higher the frequency. Wavelength determines the perceived color of light (and also the *pitch* of sound). (b) Waves also vary in *amplitude* (the height from peak to trough). Wave amplitude determines the *brightness* of colors (and also the loudness of sounds).

**hue** the dimension of color that is determined by the wavelength of light; what we know as the color names *blue, green,* and so forth.

**intensity** the amount of energy in a light or sound wave, which we perceive as brightness or loudness, as determined by the wave's amplitude.

**pupil** the adjustable opening in the center of the eye through which light enters.

**iris** a ring of muscle tissue that forms the colored portion of the eye around the pupil and controls the size of the pupil opening.

**lens** the transparent structure behind the pupil that changes shape to help focus images on the retina.

**retina** the light-sensitive inner surface of the eye, containing the receptor rods and cones plus layers of neurons that begin the processing of visual information.

**accommodation** the process by which the eye's lens changes shape to focus near or far objects on the retina.

(**FIGURE 18.2a**)—determines its **hue** (the color we experience, such as the tulip's red petals or green leaves). **Intensity,** the amount of energy in light waves (determined by a wave's *amplitude,* or height), influences brightness (Figure 18.2b). To understand *how* we transform physical energy into color and meaning, we first need to understand vision's window, the eye.

## The Eye

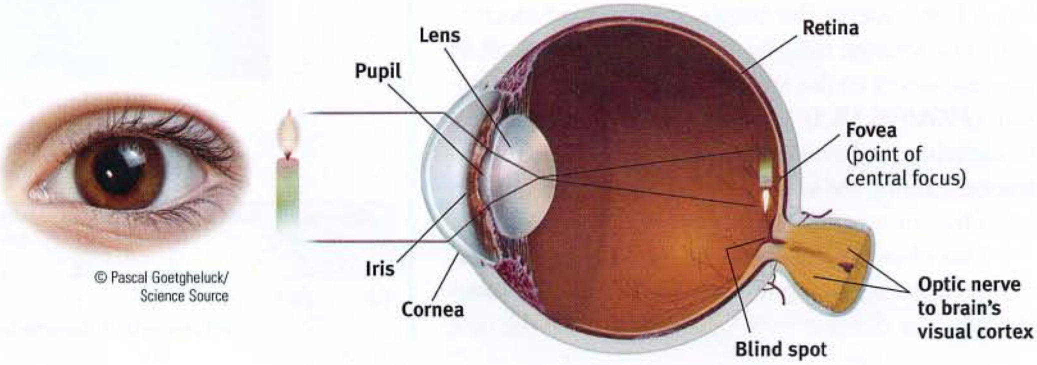
Light enters the eye through the *cornea,* which protects the eye and bends light to provide focus (**FIGURE 18.3**). The light then passes through the **pupil,** a small adjustable opening. Surrounding the pupil and controlling its size is the **iris,** a colored muscle that dilates or constricts in response to light intensity and even to inner emotions. (When we're feeling amorous, our telltale dilated pupils and dark eyes subtly signal our interest.) Each iris is so distinctive that an iris-scanning machine can confirm your identity.

Behind the pupil is a **lens** that focuses incoming light rays into an image on the **retina,** a multilayered tissue on the eyeball's sensitive inner surface. The lens focuses the rays by changing its curvature in a process called **accommodation.**

For centuries, scientists knew that when an image of a candle passes through a small opening, it casts an inverted mirror image on a dark wall behind. If the retina receives this sort of upside-down image, as in Figure 18.3, how can we see the world right side up? The ever-curious Leonardo da Vinci had an idea: Perhaps the eye's watery fluids bend the light rays, reinverting the image to the upright position as it reaches the retina. But then in 1604, the astronomer and optics expert Johannes Kepler showed that the retina does receive upside-down images of the world (Crombie, 1964). And how could we understand such a world? "I leave it," said the befuddled Kepler, "to natural philosophers."

**Figure 18.3**

**The eye** Light rays reflected from a candle pass through the cornea, pupil, and lens. The curvature and thickness of the lens change to bring nearby or distant objects into focus on the retina. Rays from the top of the candle strike the bottom of the retina, and those from the left side of the candle strike the right side of the retina. The candle's image on the retina thus appears upside down and reversed.



Eventually, the answer became clear: The retina doesn't "see" a whole image. Rather, its millions of receptor cells convert particles of light energy into neural impulses and forward those to the brain. *There,* the impulses are reassembled into a perceived, upright-seeming image.

## The Retina

If you could follow a single light-energy particle into your eye, you would first make your way through the retina's outer layer of cells to its buried receptor cells, the **rods** and **cones** (**FIGURE 18.4**). There, you would see the light energy trigger chemical changes that would spark neural signals, activating nearby *bipolar cells.* The bipolar cells in turn would activate the neighboring *ganglion cells,* whose axons twine together like the strands of a rope to form the **optic nerve.** That nerve will carry the information to your brain, where your thalamus stands ready to distribute the information. The optic nerve can send nearly 1 million messages at once through its nearly 1 million ganglion fibers. (The auditory nerve, which enables hearing, carries much less information through its mere 30,000 fibers.) We pay a small price for this eye-to-brain highway. Where the optic nerve leaves the eye, there are no receptor cells—creating a **blind spot** (**FIGURE 18.5** on the next page). Close one eye and you won't see a black hole, however. Without seeking your approval, your brain fills in the hole.

Rods and cones differ in where they're found and in what they do (**TABLE 18.1** on the next page). *Cones* cluster in and around the **fovea,** the retina's area of central focus (see Figure 18.3). Many have their own hotline to the brain: Each one transmits to a single bipolar cell that helps relay the cone's individual message to the visual cortex, which devotes a large area to input from the fovea. These direct connections preserve the cones' precise information, making them better able to detect fine detail.

*Rods* have no such hotline; they share bipolar cells with other rods, sending combined messages. To experience this rod-cone difference in sensitivity to details, pick a word in this sentence and stare directly at it, focusing its image on the cones in your fovea. Notice that

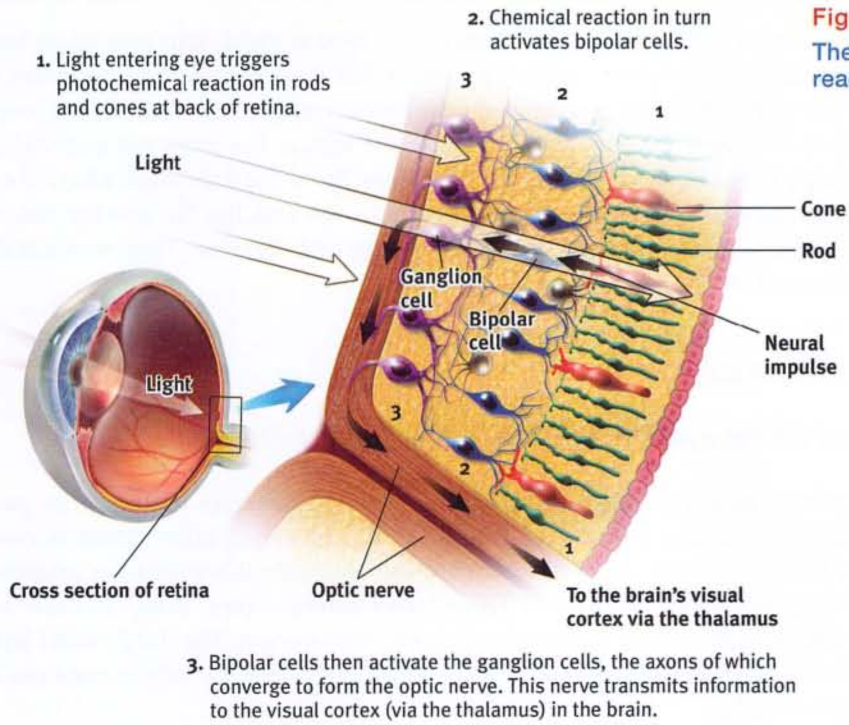



**Figure 18.4**
**The retina's reaction to light**

**AP® Exam Tip**

There's a lot of vocabulary here. Make sure you understand the name and the function of each of the parts of the eye. To learn how all the parts fit together, it may help to make rough sketches (you don't need to be an artist to try this!) and then compare your sketches with Figures 18.3 and 18.4. You'll be better off making several quick, rough sketches than one time-consuming, nicely drawn one.

**rods** retinal receptors that detect black, white, and gray; necessary for peripheral and twilight vision, when cones don't respond.

**cones** retinal receptor cells that are concentrated near the center of the retina and that function in daylight or in well-lit conditions. The cones detect fine detail and give rise to color sensations.

**optic nerve** the nerve that carries neural impulses from the eye to the brain.

**blind spot** the point at which the optic nerve leaves the eye, creating a "blind" spot because no receptor cells are located there.

**fovea** the central focal point in the retina, around which the eye's cones cluster.

**Figure 18.5**

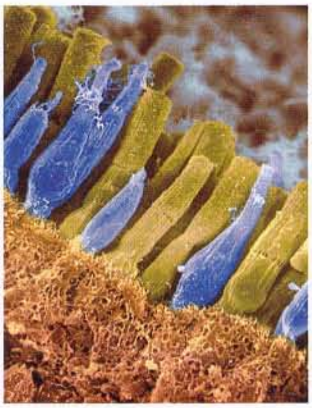
**The blind spot** There are no receptor cells where the optic nerve leaves the eye. This creates a blind spot in your vision. To demonstrate, first close your left eye, look at the spot, and move the page to a distance from your face at which one of the cars disappears (which one do you predict it will be?). Repeat with the other eye closed—and note that now the other car disappears. Can you explain why?

words a few inches off to the side appear blurred? Their image strikes the outer regions of your retina, where rods predominate. Thus, when driving or biking, you can detect a car in your peripheral vision well before perceiving its details.

Cones also enable you to perceive color. In dim light they become ineffectual, so you see no colors. Rods, which enable black-and-white vision, remain sensitive in dim light. Several rods will funnel their faint energy output onto a single bipolar cell. Thus, cones and rods each provide a special sensitivity—cones to detail and color, and rods to faint light.

**Table 18.1 Receptors in the Human Eye: Rod-Shaped Rods and Cone-Shaped Cones**

| | Cones | Rods |
|---|---|---|
| *Number* | 6 million | 120 million |
| *Location in retina* | Center | Periphery |
| *Sensitivity in dim light* | Low | High |
| *Color sensitivity* | High | Low |
| *Detail sensitivity* | High | Low |



Omikron/Science Source

When you enter a darkened theater or turn off the light at night, your eyes adapt. Your pupils dilate to allow more light to reach your retina, but it typically takes 20 minutes or more before your eyes fully adapt. You can demonstrate dark adaptation by closing or covering one eye for up to 20 minutes. Then make the light in the room not quite bright enough to read this book with your open eye. Now open the dark-adapted eye and read (easily). This period of dark adaptation matches the average natural twilight transition between the Sun's setting and darkness. How wonderfully made we are.

Andrey Armyagov /Shutterstock

## Visual Information Processing

**18-2** How do the eye and the brain process visual information?

Visual information percolates through progressively more abstract levels on its path through the thalamus and on to the visual cortex. At the entry level, information processing begins in the retina's neural layers, which are actually brain tissue that has migrated to the eye during early fetal development. These layers don't just pass along electrical impulses; they also help to encode and analyze sensory information. The third neural layer in a frog's eye, for example, contains the "bug detector" cells that fire only in response to moving fly-like stimuli.

After processing by your retina's nearly 130 million receptor rods and cones, information travels to your bipolar cells, then to your million or so ganglion cells, and through their axons making up the optic nerve to your brain. Any given retinal area relays its information to a corresponding location in the visual cortex, in the occipital lobe at the back of your brain (**FIGURE 18.6**).

The same sensitivity that enables retinal cells to fire messages can lead them to misfire, as you can demonstrate for yourself. Turn your eyes to the left, close them, and then gently rub the right side of your right eyelid with your fingertip. Note the patch of light to the left, moving as your finger moves. Why do you see light? Why at the left?

Your retinal cells are so responsive that even pressure triggers them. But your brain interprets their firing as light. Moreover, it interprets the light as coming from the left—the normal direction of light that activates the right side of the retina.

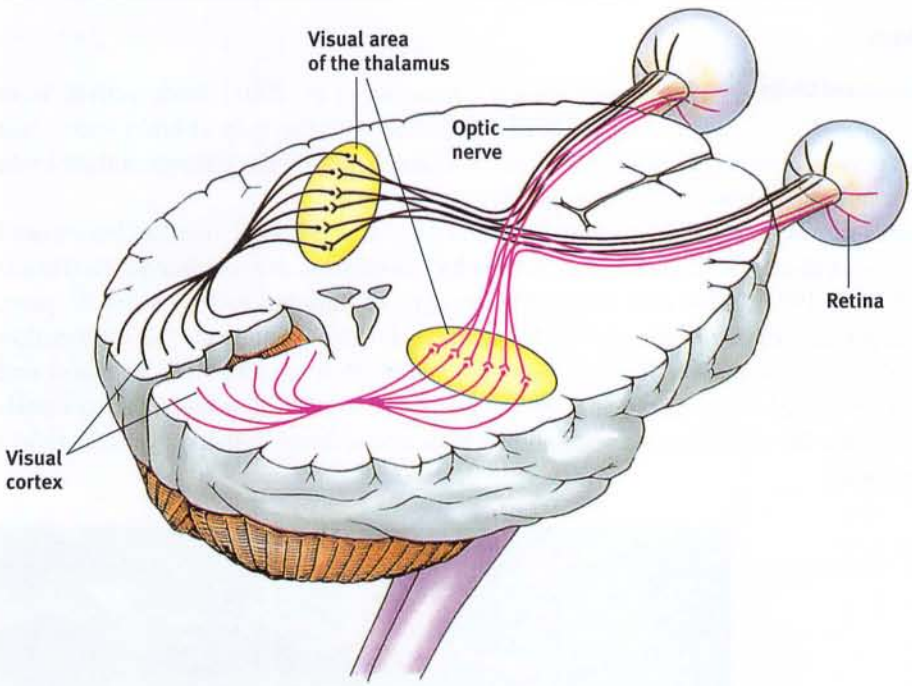



**Figure 18.6**
**Pathway from the eyes to the visual cortex** Ganglion axons forming the optic nerve run to the thalamus, where they synapse with neurons that run to the visual cortex.

## Feature Detection

David Hubel and Torsten Wiesel (1979) received a Nobel Prize for their work on **feature detectors.** These specialized neurons in the occipital lobe's visual cortex receive information from individual ganglion cells in the retina. Feature detector cells derive their name from their ability to respond to a scene's specific features—to particular edges, lines, angles, and movements. These cells pass this information to other cortical areas, where teams of cells *(supercell clusters)* respond to more complex patterns. As we noted in Module 12, one temporal lobe area by your right ear (**FIGURE 18.7** on the next page) enables you to perceive faces and, thanks to a specialized neural network, to recognize them from varied viewpoints (Connor, 2010). If this region were damaged, you might recognize other forms and objects, but, like Heather Sellers, not familiar faces. When researchers temporarily disrupt the brain's face-processing areas with magnetic pulses, people are unable to recognize faces.

They will, however, be able to recognize houses, because the brain's face-perception occurs separately from its object-perception (McKone et al., 2007; Pitcher et al., 2007). Thus, functional MRI (fMRI) scans show different brain areas activating when people

**feature detectors** nerve cells in the brain that respond to specific features of the stimulus, such as shape, angle, or movement.

**AP® Exam Tip**

Warning! Sometimes students spend so much time mastering the parts of the eye that they skim over the part you're about to read. Do not forget that you see with your brain as much as you see with your eyes.

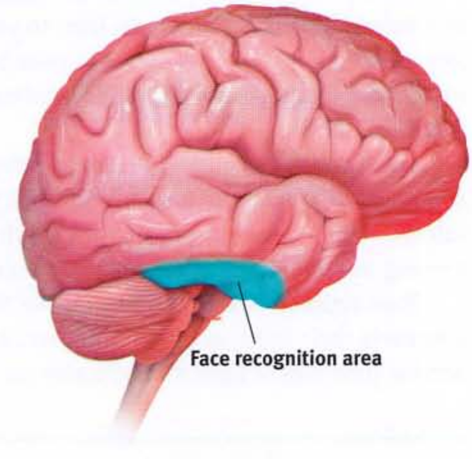



**Figure 18.7**
**Face recognition processing** In social animals such as humans, a dedicated brain system (shown here in a right-facing brain) assigns considerable neural bandwidth to the crucial task of face recognition.

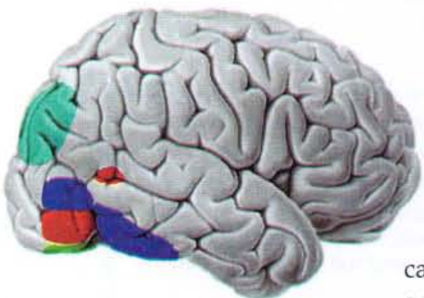



**Figure 18.8**
**The telltale brain** Looking at faces, houses, and chairs activates different brain areas in this right-facing brain.

view varied objects (Downing et al., 2001). Brain activity is so specific (**FIGURE 18.8**) that, with the help of brain scans, "we can tell if a person is looking at a shoe, a chair, or a face, based on the pattern of their brain activity," noted one researcher (Haxby, 2001).

Research shows that for biologically important objects and events, monkey brains (and surely ours as well) have a "vast visual encyclopedia" distributed as specialized cells (Perrett et al., 1988, 1992, 1994). These cells respond to one type of stimulus, such as a specific gaze, head angle, posture, or body movement. Other supercell clusters integrate this information and fire only when the cues collectively indicate the direction of someone's attention and approach. This instant analysis, which aided our ancestors' survival, also helps a soccer goalkeeper anticipate the direction of an impending kick, and a driver anticipate a pedestrian's next movement.

FIFA via Getty Images

**Well-developed supercells** In this 2011 World Cup match, USA's Abby Wambach instantly processed visual information about the positions and movements of Brazil's defenders and goalkeeper and somehow managed to get the ball around them all and into the net.

**parallel processing** the processing of many aspects of a problem simultaneously; the brain's natural mode of information processing for many functions, including vision. Contrasts with the step-by-step (serial) processing of most computers and of conscious problem solving.

## Parallel Processing

Our brain achieves these and other remarkable feats by means of **parallel processing:** doing many things at once. To analyze a visual scene, the brain divides it into subdimensions—motion, form, depth, color—and works on each aspect simultaneously (Livingstone & Hubel, 1988). We then construct our perceptions by integrating the separate but parallel work of these different visual teams (**FIGURE 18.9**).

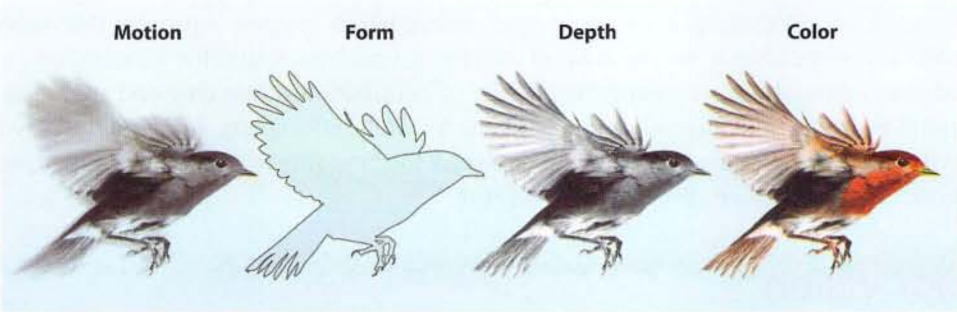



**Figure 18.9**

**Parallel processing** Studies of patients with brain damage suggest that the brain delegates the work of processing motion, form, depth, and color to different areas. After taking a scene apart, the brain integrates these subdimensions into the perceived image. How does the brain do this? The answer to this question is the Holy Grail of vision research.

To recognize a face, your brain integrates information projected by your retinas to several visual cortex areas, compares it with stored information, and enables you to recognize the face: *Grandmother!* Scientists are debating whether this stored information is contained in a single cell or distributed over a network. Some supercells—"grandmother cells"—do appear to respond very selectively to 1 or 2 faces in 100 (Bowers, 2009). The whole facial recognition process requires tremendous brain power—30 percent of the cortex (10 times the brain area devoted to hearing).

Destroy or disable a neural workstation for a visual subtask, and something peculiar results, as happened to "Mrs. M." (Hoffman, 1998). Since a stroke damaged areas near the rear of both sides of her brain, she has been unable to perceive movement. People in a room seem "suddenly here or there but I have not seen them moving." Pouring tea into a cup is a challenge because the fluid appears frozen—she cannot perceive it rising in the cup.

After stroke or surgery damage to the brain's visual cortex, others have experienced *blindsight* (a phenomenon we met in Module 13). Shown a series of sticks, they report seeing nothing. Yet when asked to guess whether the sticks are vertical or horizontal, their visual intuition typically offers the correct response. When told, "You got them all right," they are astounded. There is, it seems, a second "mind"—a parallel processing system—operating unseen. These separate visual systems for perception and action illustrate dual processing—the two-track mind.

* * *

Think about the wonders of visual processing. As you look at that tiger in the zoo, information enters your eyes, is transduced, and is sent to your brain as millions of neural impulses. As your brain buzzes with activity, various areas focus on different aspects of the tiger's image. Finally, in some as yet mysterious way, these separate teams pool their work to produce a meaningful image, which you compare with previously stored images and recognize: a crouching tiger (**FIGURE 18.10**).

"I am . . . wonderfully made."
-King David, Psalm 139:14

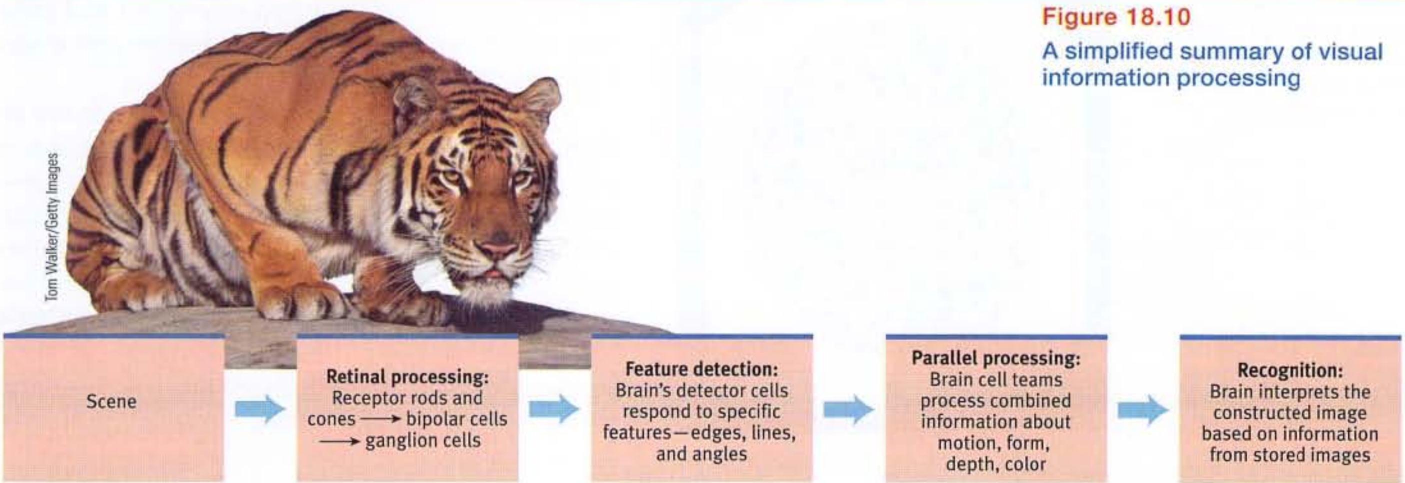



**Figure 18.10**

**A simplified summary of visual information processing**

Think, too, about what is happening as you read this page. The printed squiggles are transmitted by reflected light rays onto your retina, which triggers a process that sends formless nerve impulses to several areas of your brain, which integrates the information and decodes meaning, thus completing the transfer of information across time and space from my mind to your mind. That all of this happens instantly, effortlessly, and continuously is indeed awesome. As Roger Sperry (1985) observed, the "insights of science give added, not lessened, reasons for awe, respect, and reverence."

## Color Vision

**18-3** What theories help us understand color vision?

We talk as though objects possess color: "A tomato is red." Perhaps you have pondered the old question, "If a tree falls in the forest and no one hears it, does it make a sound?" We can ask the same of color: If no one sees the tomato, is it red?

The answer is *No.* First, the tomato is everything *but* red, because it *rejects* (reflects) the long wavelengths of red. Second, the tomato's color is our mental construction. As Isaac Newton (1704) noted, "The [light] rays are not colored." Color, like all aspects of vision, resides not in the object but in the theater of our brain, as evidenced by our dreaming in color.

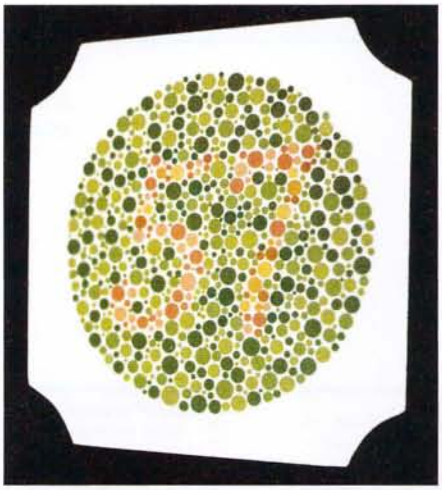
"Only mind has sight and hearing; all things else are deaf and blind." -Epicharmus, *Fragments*, 550 B.C.E.

One of vision's most basic and intriguing mysteries is how we see the world in color. How, from the light energy striking the retina, does the brain manufacture our experience of color—and of such a multitude of colors? Our difference threshold for colors is so low that we can discriminate more than 1 million different color variations (Neitz et al., 2001). At least most of us can. For about 1 person in 50, vision is color deficient—and that person is usually male, because the defect is genetically sex-linked.

Why is some people's vision deficient? To answer that question, we need to understand how normal color vision works. Modern detective work on this mystery began in the nineteenth century, when Hermann von Helmholtz built on the insights of an English physicist, Thomas Young. Knowing that any color can be created by combining the light waves of three primary colors—red, green, and blue—Young and von Helmholtz inferred that the eye must have three corresponding types of color receptors. Years later, researchers measured the response of various cones to different color stimuli and confirmed the **Young-Helmholtz trichromatic (three-color) theory,** which implies that the receptors do their color magic in teams of three. Indeed, the retina has three types of color receptors, each especially sensitive to one of three colors. And those colors are, in fact, red, green, and blue. When we stimulate combinations of these cones, we see other colors. For example, there are no receptors especially sensitive to yellow. We see yellow when mixing red and green light, which stimulates both red-sensitive and green-sensitive cones.

**Young-Helmholtz trichromatic (three-color) theory** the theory that the retina contains three different color receptors—one most sensitive to red, one to green, one to blue—which, when stimulated in combination, can produce the perception of any color.

**Figure 18.11**
**Color-deficient vision** People who suffer red-green deficiency have trouble perceiving the number within the design.



Annabella Bluesky/Science Source

Most people with color-deficient vision are not actually "colorblind." They simply lack functioning red- or green-sensitive cones, or sometimes both. Their vision—perhaps unknown to them, because their lifelong vision *seems* normal—is monochromatic (one-color) or dichromatic (two-color) instead of trichromatic, making it impossible to distinguish the red and green in **FIGURE 18.11** (Boynton, 1979). Dogs, too, lack receptors for the wavelengths of red, giving them only limited, dichromatic color vision (Neitz et al., 1989).

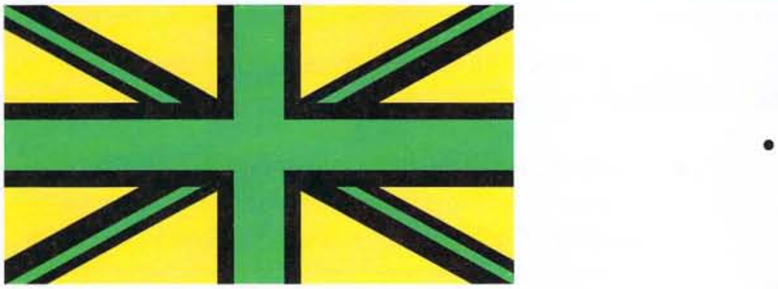


**Figure 18.12**

**Afterimage effect** Stare at the center of the flag for a minute and then shift your eyes to the dot in the white space beside it. What do you see? (After tiring your neural response to black, green, and yellow, you should see their opponent colors.) Stare at a white wall and note how the size of the flag grows with the projection distance.

But how is it that people blind to red and green can often still see yellow? And why does yellow appear to be a pure color and not a mixture of red and green, the way purple is of red and blue? As Ewald Hering soon noted, trichromatic theory leaves some parts of the color vision mystery unsolved.

Hering, a physiologist, found a clue in *afterimages.* Stare at a green square for a while and then look at a white sheet of paper, and you will see red, green's *opponent color.* Stare at a yellow square and its opponent color, blue, will appear on the white paper. (To experience this, try the flag demonstration in **FIGURE 18.12**.) Hering surmised that there must be two additional color processes, one responsible for red-versus-green perception, and one for blue-versus-yellow.

Indeed, a century later, researchers also confirmed Hering's **opponent-process theory.** Three sets of opponent retinal processes—*red-green, yellow-blue,* and *white-black*—enable color vision. In the retina and in the thalamus (where impulses from the retina are relayed en route to the visual cortex), some neurons are turned "on" by red but turned "off" by green. Others are turned on by green but off by red (DeValois & DeValois, 1975). Like red and green marbles sent down a narrow tube, "red" and "green" messages cannot both travel at once. So we do not experience a reddish green. (Red and green are thus opponents.) But red and blue travel in separate channels, so we *can* see a reddish-blue magenta.

**opponent-process theory**
the theory that opposing retinal processes (red-green, yellow-blue, white-black) enable color vision. For example, some cells are stimulated by green and inhibited by red; others are stimulated by red and inhibited by green.

So how do we explain afterimages, such as in the flag demonstration? By staring at green, we tire our green response. When we then stare at white (which contains all colors, including red), only the red part of the green-red pairing will fire normally.

The present solution to the mystery of color vision is therefore roughly this: Color processing occurs in two stages. The retina's red, green, and blue cones respond in varying degrees to different color stimuli, as the Young-Helmholtz trichromatic theory suggested. Their signals are then processed by the nervous system's opponent-process cells, as Hering's theory proposed.

## Before You Move On

### ▶ ASK YOURSELF

If you were forced to give up one sense, which would it be? Why?

### ▶ TEST YOURSELF

What is the rapid sequence of events that occurs when you see and recognize a friend?

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

# Module 18 Review

### 18-1 What is the energy that we see as visible light, and how does the eye transform light energy into neural messages?

- The *hue* we perceive in light depends on its *wavelength,* and its brightness depends on its *intensity.*
- After entering the eye and being focused by the *lens,* light energy particles (from a thin slice of the broad spectrum of electromagnetic energy) strike the eye's inner surface, the *retina.* The retina's light-sensitive *rods* and color-sensitive *cones* convert the light energy into neural impulses.

### 18-2 How do the eye and the brain process visual information?

- After processing by bipolar and ganglion cells in the eyes' retina, neural impulses travel through the *optic nerve,* to the thalamus, and on to the visual cortex. In the visual cortex, *feature detectors* respond to specific features of the visual stimulus. Supercell clusters in other critical brain areas respond to more complex patterns.
- Through *parallel processing,* the brain handles many aspects of vision (color, movement, form, and depth) simultaneously. Other neural teams integrate the results, comparing them with stored information and enabling perceptions.

### 18-3 What theories help us understand color vision?

- *The Young-Helmholtz trichromatic (three-color) theory* proposed that the retina contains three types of color receptors. Contemporary research has found three types of cones, each most sensitive to the wavelengths of one of the three primary colors of light (red, green, or blue).
- Hering's *opponent-process theory* proposed three additional color processes (red-versus-green, blue-versus-yellow, black-versus-white). Contemporary research has confirmed that, en route to the brain, neurons in the retina and the thalamus code the color-related information from the cones into pairs of opponent colors.
- These two theories, and the research supporting them, show that color processing occurs in two stages.

## Multiple-Choice Questions

**1.** Light's _________ is the distance from one wave peak to the next. This dimension determines the _________ we experience.

a. hue; wavelength
b. wavelength; hue
c. hue; intensity
d. wavelength; intensity
e. intensity; wavelength

**2.** What do we call the specialized neurons in the occipital lobe's visual cortex that respond to particular edges, lines, angles, and movements?

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

**3.** Which of the following explains reversed-color afterimages?

a. Young-Helmholtz trichromatic theory
b. The blind spot
c. Hering's opponent-process theory
d. Feature detectors
e. Parallel processing

**4.** Your best friend decides to paint her room an extremely bright electric blue. Which of the following best fits the physical properties of the color's light waves?

a. No wavelength; large amplitude
b. Short wavelength; large amplitude
c. Short wavelength; small amplitude
d. Long wavelength; large amplitude
e. No wavelength; small amplitude

**5.** What do we call the transparent, protective layer that light passes through as it enters the eye?

a. Pupil
b. Iris
c. Cornea
d. Lens
e. Fovea

## Practice FRQs

**1.** As light reflected off an object reaches your eye, it passes through several structures before it reaches the retina. Describe three of these structures, including the function of each.

### Answer

*1 point:* The cornea is at the front of the eye. It bends and focuses the light waves.

*1 point:* The pupil is the opening through which light enters the eyeball. It is surrounded by the iris, which can expand or contract to allow more or less light to pass through the pupil.

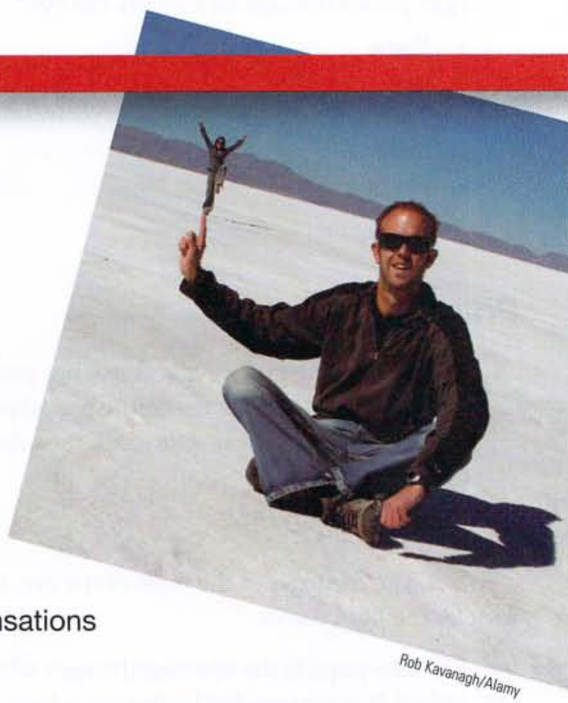
*1 point:* The lens is the transparent structure behind the pupil that changes shape to help focus images on the retina.

**2.** Explain two theories of color vision in humans. How does one of them explain color deficiency?

*(3 points)*

# Module 19

## Visual Organization and Interpretation


Rob Kavanagh/Alamy

### Module Learning Objectives

**19-1** Describe Gestalt psychologists' understanding of perceptual organization, and explain how figure-ground and grouping principles contribute to our perceptions.

**19-2** Explain how we use binocular and monocular cues to perceive the world in three dimensions and perceive motion.

**19-3** Explain how perceptual constancies help us organize our sensations into meaningful perceptions.

**19-4** Describe what research on restored vision, sensory restriction, and perceptual adaptation reveals about the effects of experience on perception.

## Visual Organization

**19-1** How did the Gestalt psychologists understand perceptual organization, and how do figure-ground and grouping principles contribute to our perceptions?

It's one thing to understand how we see shapes and colors. But how do we organize and interpret those sights (or sounds or tastes or smells) so that they become meaningful perceptions—a rose in bloom, a familiar face, a sunset?

Early in the twentieth century, a group of German psychologists noticed that when given a cluster of sensations, people tend to organize them into a **gestalt,** a German word meaning a "form" or a "whole." For example, look at **FIGURE 19.1**. Note that the individual elements of this figure, called a *Necker cube,* are really nothing but eight blue circles, each containing three converging white lines. When we view these elements all together, however, we see a cube that sometimes reverses direction. This phenomenon nicely illustrates a favorite saying of Gestalt psychologists: In perception, the whole may exceed the sum of its parts. If we combine sodium (a corrosive metal) with chlorine (a poisonous gas), something very different emerges—table salt. Likewise, a unique perceived form emerges from a stimulus' components (Rock & Palmer, 1990).

Over the years, the Gestalt psychologists demonstrated many principles we use to organize our sensations into perceptions. Underlying all of them is a fundamental truth: *Our brain does more than register information about the world.* Perception is not just opening a shutter and letting a picture print itself on the brain. We filter incoming information and construct perceptions. Mind matters.

**gestalt** an organized whole. Gestalt psychologists emphasized our tendency to integrate pieces of information into meaningful wholes.

**AP® Exam Tip**

The Necker cube is an excellent vehicle for understanding the distinction between sensation and perception. The only visual stimuli are the blue wedges. The circles, lines, and cube are all the products of perception—they are in your mind and not on the page.

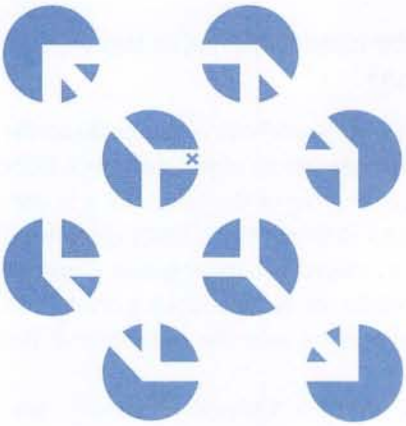



**Figure 19.1**

**A Necker cube** What do you see: circles with white lines, or a cube? If you stare at the cube, you may notice that it reverses location, moving the tiny X in the center from the front edge to the back. At times, the cube may seem to float in front of the page, with circles behind it. At other times, the circles may become holes in the page through which the cube appears, as though it were floating behind the page. There is far more to perception than meets the eye. (From Bradley et al., 1976.)

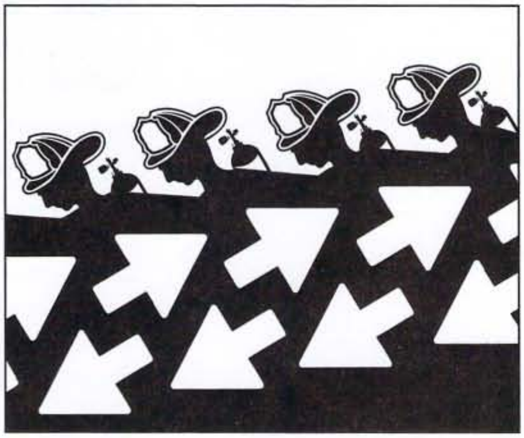


**Figure 19.2**
**Reversible figure and ground**

## Form Perception

Imagine designing a video-computer system that, like your eye-brain system, can recognize faces at a glance. What abilities would it need?

### FIGURE AND GROUND

To start with, the video-computer system would need to separate faces from their backgrounds. Likewise, in our eye-brain system, our first perceptual task is to perceive any object (the *figure*) as distinct from its surroundings (the *ground*). Among the voices you hear at a party, the one you attend to becomes the figure; all others are part of the ground. As you read, the words are the figure; the white paper is the ground. Sometimes the same stimulus can trigger more than one perception. In **FIGURE 19.2,** the **figure-ground** relationship continually reverses—but always we organize the stimulus into a figure seen against a ground.

**figure-ground** the organization of the visual field into objects (the *figures*) that stand out from their surroundings (the *ground*).

**grouping** the perceptual tendency to organize stimuli into coherent groups.

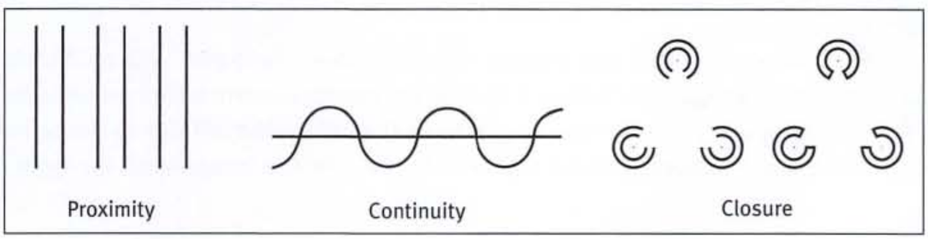
### GROUPING

Having discriminated figure from ground, we (and our video-computer system) must also organize the figure into a *meaningful* form. Some basic features of a scene—such as color, movement, and light-dark contrast—we process instantly and automatically (Treisman, 1987). Our minds bring order and form to stimuli by following certain rules for **grouping**. These rules, identified by the Gestalt psychologists and applied even by infants, illustrate how the perceived whole differs from the sum of its parts (Quinn et al., 2002; Rock & Palmer, 1990). Three examples:

**PROXIMITY** We group nearby figures together. We see not six separate lines, but three sets of two lines.

**CONTINUITY** We perceive smooth, continuous patterns rather than discontinuous ones. This pattern could be a series of alternating semicircles, but we perceive it as two continuous lines—one wavy, one straight.

**CLOSURE** We fill in gaps to create a complete, whole object. Thus we assume that the circles on the right are complete but partially blocked by the (illusory) triangle. Add nothing more than little line segments to close off the circles and your brain stops constructing a triangle. Such principles usually help us construct reality.



## Depth Perception

**19-2** How do we use binocular and monocular cues to perceive the world in three dimensions and perceive motion?

From the two-dimensional images falling on our retinas, we somehow organize three-dimensional perceptions. **Depth perception** enables us to estimate an object's distance from us. At a glance, we can estimate the distance of an oncoming car or the height of a house. Depth perception is partly innate, as Eleanor Gibson and Richard Walk (1960) discovered using a model of a cliff with a drop-off area (which was covered by sturdy glass). Gibson's inspiration for these **visual cliff** experiments occurred while she was picnicking on the rim of the Grand Canyon. She wondered: Would a toddler peering over the rim perceive the dangerous drop-off and draw back?

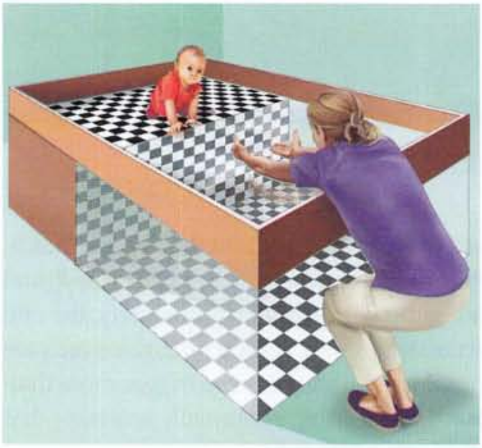


**Figure 19.3**

**Visual cliff** Eleanor Gibson and Richard Walk devised a miniature cliff with a glass-covered drop-off to determine whether crawling infants can perceive depth. Even when coaxed, infants are reluctant to venture onto the glass over the cliff (Gibson & Walk, 1960).

Back in their Cornell University laboratory, Gibson and Walk placed 6- to 14-month-old infants on the edge of a safe canyon and had the infants' mothers coax them to crawl out onto the glass (**FIGURE 19.3**). Most infants refused to do so, indicating that they could perceive depth.

Had they *learned* to perceive depth? Learning seems to be part of the answer because crawling, no matter when it begins, seems to increase infants' wariness of heights (Campos et al., 1992). Yet, the researchers observed, mobile newborn animals come prepared to perceive depth. Even those with virtually no visual experience—including young kittens, a day-old goat, and newly hatched chicks—will not venture across the visual cliff. Thus, it seems that biology predisposes us to be wary of heights and experience amplifies that fear.

How do we perceive depth? *How* do we transform two differing two-dimensional (2-D) retinal images into a single three-dimensional (3-D) perception? Our brain constructs these perceptions using information supplied by one or both eyes.

### BINOCULAR CUES

Try this: With both eyes open, hold two pens or pencils in front of you and touch their tips together. Now do so with one eye closed. With one eye, the task becomes noticeably more difficult, demonstrating the importance of **binocular cues** in judging the distance of nearby objects. Two eyes are better than one.

Because your eyes are about 2½ inches apart, your retinas receive slightly different images of the world. By comparing these two images, your brain can judge how close an object is to you. The greater the **retinal disparity,** or difference between the two images, the closer the object. Try it. Hold your two index fingers, with the tips about half an inch apart, directly in front of your nose, and your retinas will receive quite different views. If you close one eye and then the other, you can see the difference. (You may also create a finger sausage, as in **FIGURE 19.4.**) At a greater distance—say, when you hold your fingers at arm's length—the disparity is smaller.

We could easily build this feature into our video-computer system. Moviemakers can simulate or exaggerate retinal disparity by filming a scene with two cameras placed a few inches apart. Viewers then wear glasses that allow the left eye to see only the image from the left camera, and the right eye to see only the image from the right camera.

**depth perception** the ability to see objects in three dimensions although the images that strike the retina are two-dimensional; allows us to judge distance.

**visual cliff** a laboratory device for testing depth perception in infants and young animals.

**binocular cues** depth cues, such as retinal disparity, that depend on the use of two eyes.

**retinal disparity** a binocular cue for perceiving depth: By comparing images from the retinas in the two eyes, the brain computes distance—the greater the disparity (difference) between the two images, the closer the object.

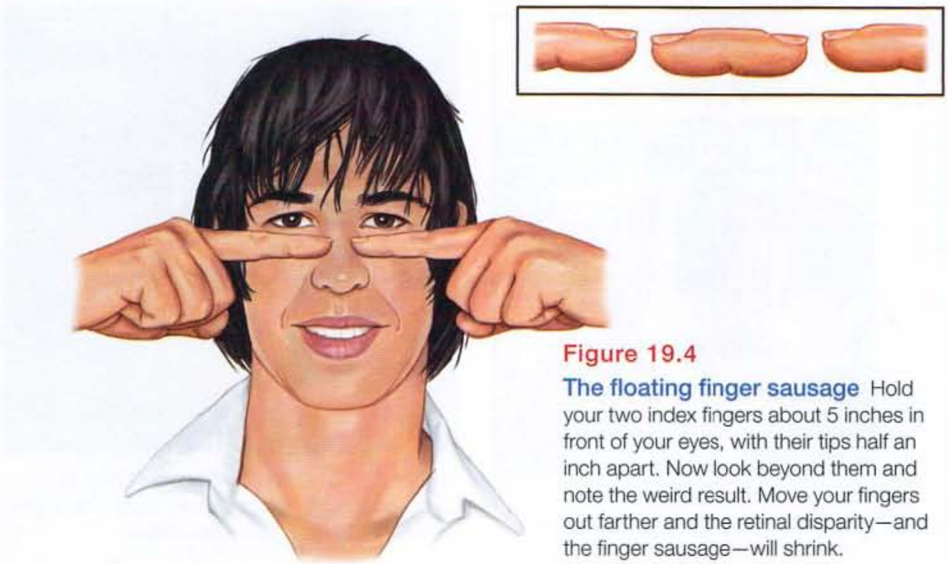


**Figure 19.4**

**The floating finger sausage** Hold your two index fingers about 5 inches in front of your eyes, with their tips half an inch apart. Now look beyond them and note the weird result. Move your fingers out farther and the retinal disparity—and the finger sausage—will shrink.

**FYI**

Carnivorous animals, including humans, have eyes that enable forward focus on a prey and offer binocular vision-enhanced depth perception. Grazing herbivores, such as horses and sheep, typically have eyes on the sides of their skull. Although lacking binocular depth perception, they have sweeping peripheral vision.

The resulting 3-D effect, as 3-D movie fans know, mimics or exaggerates normal retinal disparity. Similarly, twin cameras in airplanes can take photos of terrain for integration into 3-D maps.

### MONOCULAR CUES

How do we judge whether a person is 10 or 100 meters away? Retinal disparity won't help us here, because there won't be much difference between the images cast on our right and left retinas. At such distances, we depend on **monocular cues** (depth cues available to each eye separately). See **FIGURE 19.5** on the next page for some examples.

**monocular cues** depth cues, such as interposition and linear perspective, available to either eye alone.

**phi phenomenon** an illusion of movement created when two or more adjacent lights blink on and off in quick succession.

## Motion Perception

Imagine that you could perceive the world as having color, form, and depth but that you could not see motion. Not only would you be unable to bike or drive, you would have trouble writing, eating, and walking.

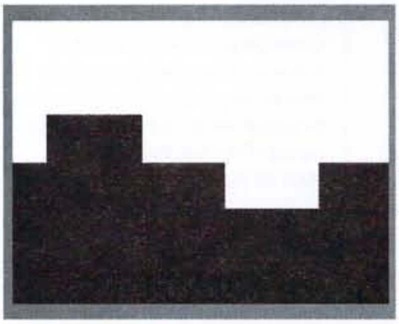
Normally your brain computes motion based partly on its assumption that shrinking objects are retreating (not getting smaller) and enlarging objects are approaching. But you are imperfect at motion perception. Large objects, such as trains, appear to move more slowly than smaller objects, such as cars, moving at the same speed. (Perhaps at an airport you've noticed that jumbo jets seem to land more slowly than little jets.)

To catch a fly ball, softball or cricket players (unlike drivers) want to achieve a collision—with the ball that's flying their way. To accomplish that, they follow an unconscious rule—one they can't explain but know intuitively: Run to keep the ball at a constantly increasing angle of gaze (McBeath et al., 1995). A dog catching a Frisbee does the same (Shaffer et al., 2004).

"Sometimes I wonder: Why is that Frisbee getting bigger? And then it hits me." -Anonymous

The brain also perceives continuous movement in a rapid series of slightly varying images (a phenomenon called *stroboscopic movement*). As film animation artists know well, you can create this illusion by flashing 24 still pictures a second. The motion we then see in popular action adventures is not in the film, which merely presents a superfast slide show. We construct that motion in our heads, just as we construct movement in blinking marquees and holiday lights. When two adjacent stationary lights blink on and off in quick succession, we perceive a single light moving back and forth between them. Lighted signs exploit this **phi phenomenon** with a succession of lights that creates the impression of, say, a moving arrow.

"From there to here, from here to there, funny things are everywhere." -Dr. Seuss, *One Fish, Two Fish, Red Fish, Blue Fish*, 1960





**Relative height** We perceive objects higher in our field of vision as farther away. Because we assume the lower part of a figure-ground illustration is closer, we perceive it as figure (Vecera et al., 2002). Invert this illustration and the black will become ground, like a night sky.


**Relative size** If we assume two objects are similar in size, *most* people perceive the one that casts the smaller retinal image as farther away.

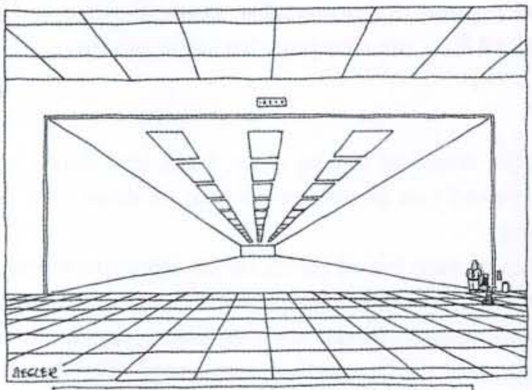


**Interposition** *Interpose* means "to come between." If one object partially blocks our view of another, we perceive it as closer.

**Relative motion** As we move, objects that are actually stable may appear to move. If while riding on a bus you fix your gaze on some point—say, a house—the objects beyond the fixation point will appear to move with you. Objects in front of the point will appear to move backward. The farther an object is from the fixation point, the faster it will seem to move.


Direction of passenger's motion →

**Linear perspective** Parallel lines appear to meet in the distance. The sharper the angle of convergence, the greater the perceived distance.






**Light and shadow** Shading produces a sense of depth consistent with our assumption that light comes from above. If you invert this illustration, the hollow will become a hill.



**Figure 19.5**
**Monocular depth cues**

**AP® Exam Tip**

The illustrations in Figure 19.5 provide you with excellent opportunities to practice identifying monocular depth cues. To really demonstrate your understanding, look for these cues in other drawings and photographs. There are almost always cues to identify.

## Perceptual Constancy

**19-3** How do perceptual constancies help us organize our sensations into meaningful perceptions?

So far, we have noted that our video-computer system must perceive objects as we do—as having a distinct form, location, and perhaps motion. Its next task is to recognize objects without being deceived by changes in their color, brightness, shape, or size—a top-down process called **perceptual constancy.** Regardless of the viewing angle, distance, and illumination, we can identify people and things in less time than it takes to draw a breath, a feat that would be a monumental challenge for even advanced computers and that has intrigued researchers for decades.

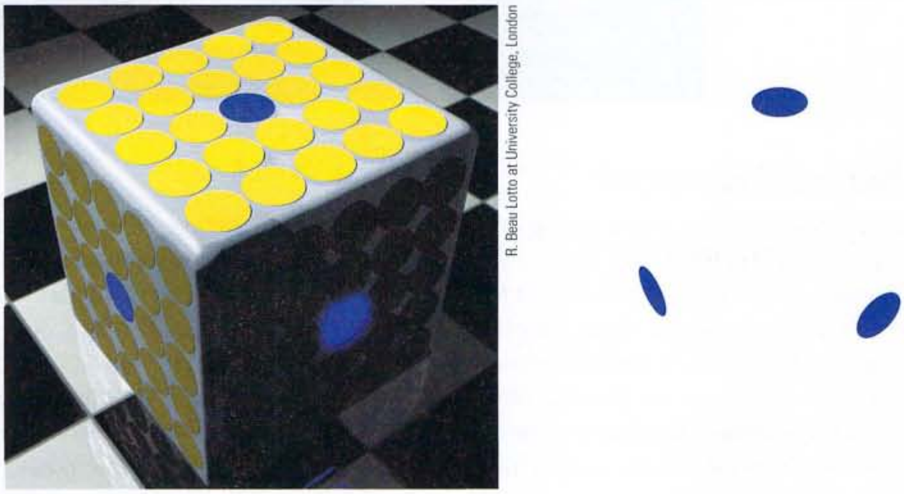
## COLOR AND BRIGHTNESS CONSTANCIES

Color does not reside in an object. Our experience of color depends on the object's *context*. If you view an isolated tomato through a paper tube, its color would seem to change as the light—and thus the wavelengths reflected from its surface—changed. But if you viewed that tomato as one item in a bowl of fresh fruit and vegetables, its color would remain roughly constant as the lighting shifts. This perception of consistent color is known as **color constancy.**

**perceptual constancy** perceiving objects as unchanging (having consistent shapes, size, brightness, and color) even as illumination and retinal images change.

**color constancy** perceiving familiar objects as having consistent color, even if changing illumination alters the wavelengths reflected by the object.

Though we take color constancy for granted, this ability is truly remarkable. A blue poker chip under indoor lighting reflects wavelengths that match those reflected by a sunlit gold chip (Jameson, 1985). Yet bring a bluebird indoors and it won't look like a goldfinch. The color is not in the bird's feathers. You and I see color thanks to our brain's computations of the light reflected by an object *relative to the objects surrounding it.* (But only if we grew up with normal light, it seems. Monkeys raised under a restricted range of wavelengths later have great difficulty recognizing the same color when illumination varies [Sugita, 2004].) **FIGURE 19.6** dramatically illustrates the ability of a blue object to appear very different in three different contexts. Yet we have no trouble seeing these disks as blue.



R. Beau Lotto at University College, London

(a) (b)

**Figure 19.6**

**Color depends on context**

(a) Believe it or not, these three blue disks are identical in color.
(b) Remove the surrounding context and see what results.

Similarly, *brightness constancy* (also called *lightness constancy*) depends on context. We perceive an object as having a constant brightness even while its illumination varies. This perception of constancy depends on *relative luminance*—the amount of light an object reflects *relative to its surroundings* (**FIGURE 19.7** on the next page). White paper reflects 90 percent of the light falling on it; black paper, only 10 percent. Although a black paper viewed in sunlight may reflect 100 times more light than does a white paper viewed indoors, it will still look black (McBurney & Collings, 1984). But if you view sunlit black paper through a narrow tube so nothing else is visible, it may look gray, because in bright sunshine it reflects a fair amount of light. View it without the tube and it is again black, because it reflects much less light than the objects around it.

This principle—that we perceive objects not in isolation but in their environmental context—matters to artists, interior decorators, and clothing designers. Our perception of the color and brightness of a wall or of a streak of paint on a canvas is determined not just by the paint in the can but by the surrounding colors. The take-home lesson: *Comparisons govern our perceptions.*

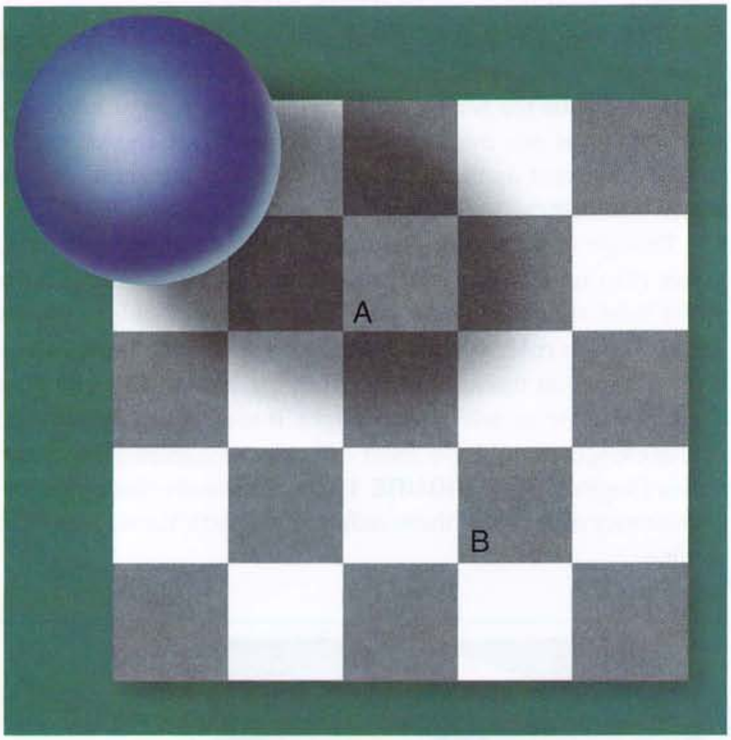



**Figure 19.7**

**Relative luminance** Squares A and B are identical in color, believe it or not. (If you don't believe me, photocopy the illustration, cut out the squares, and compare.) But we perceive A as lighter, thanks to its surrounding context.

## SHAPE AND SIZE CONSTANCIES

Sometimes an object whose actual shape cannot change *seems* to change shape with the angle of our view (**FIGURE 19.8**). More often, thanks to *shape constancy,* we perceive the form of familiar objects, such as the door in **FIGURE 19.9**, as constant even while our retinas receive changing images of them. Our brain manages this feat thanks to visual cortex neurons that rapidly learn to associate different views of an object (Li & DiCarlo, 2008).

Thanks to *size constancy,* we perceive objects as having a constant size, even while our distance from them varies. We assume a car is large enough to carry people, even when we see its tiny image from two blocks away. This assumption also illustrates the close connection between perceived *distance* and perceived *size*. Perceiving an object's distance gives us cues to its size. Likewise, knowing its general size—that the object is a car—provides us with cues to its distance.

**Figure 19.8**

**Perceiving shape** Do the tops of these tables have different dimensions? They appear to. But—believe it or not—they are identical. (Measure and see.) With both tables, we adjust our perceptions relative to our viewing angle.

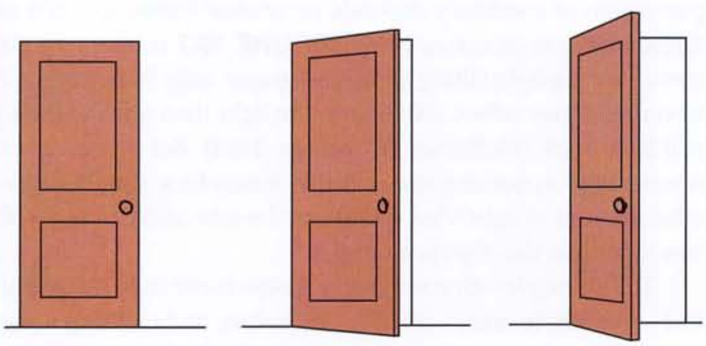


**Figure 19.9**

**Shape constancy** A door casts an increasingly trapezoidal image on our retinas as it opens, yet we still perceive it as rectangular.

Even in size-distance judgments, however, we consider an object's context. The dogs in Module 17's Figure 17.3 cast identical images on our retinas. Using linear perspective as a cue (see Figure 19.5), our brain assumes that the pursuing dog is farther away. We therefore perceive it as larger. It isn't.

This interplay between perceived size and perceived distance helps explain several well-known illusions, including the *Moon illusion:* The Moon looks up to 50 percent larger when near the horizon than when high in the sky. Can you imagine why? For at least 22 centuries, scholars have debated this question (Hershenson, 1989). One reason is that cues to objects' distances make the horizon Moon—like the distant dog in Figure 17.3—appear farther away. If it's farther away, our brain assumes, it must be larger than the Moon high in the night sky (Kaufman & Kaufman, 2000). Take away the distance cue, by looking at the horizon Moon (or each dog) through a paper tube, and the object will immediately shrink.

Size-distance relationships also explain why in **FIGURE 19.10** the two same-age girls seem so different in size. As the diagram reveals, the girls are actually about the same size, but the room is distorted. Viewed with one eye through a peephole, the room's trapezoidal walls produce the same images you would see in a normal rectangular room viewed with both eyes. Presented with the camera's one-eyed view, your brain makes the reasonable assumption that the room *is* normal and each girl is therefore the same distance from you. Given the different sizes of the girls' images on your retinas, your brain ends up calculating that the girls must be very different in size.

Perceptual illusions reinforce a fundamental lesson: Perception is not merely a projection of the world onto our brain. Rather, our sensations are disassembled into information bits that our brain, using both bottom-up and top-down processing, then reassembles into its own functional model of the external world. During this reassembly process, our assumptions—such as the usual relationship between distance and size—can lead us astray. *Our brain constructs our perceptions.*

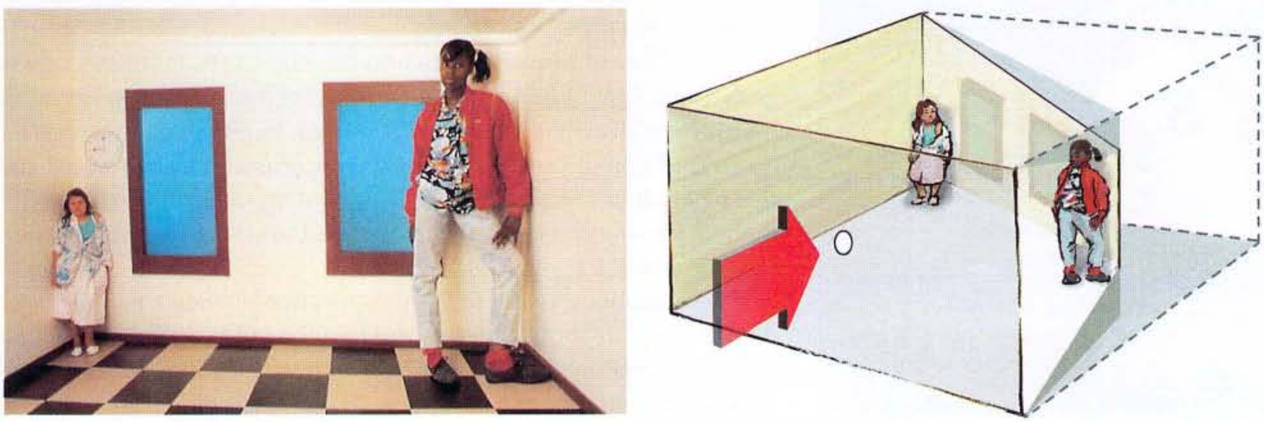
* * *

Form perception, depth perception, motion perception, and perceptual constancies illuminate how we organize our visual experiences. Perceptual organization applies to our other senses, too. It explains why we perceive a clock's steady tick not as a *tick-tick-tick-tick* but as grouped sounds, say, *TICK-tick, TICK-tick.* Listening to an unfamiliar language, we have trouble hearing where one word stops and the next one begins. Listening to our own language, we automatically hear distinct words. This, too, reflects perceptual organization. But it is more, for we even organize a string of letters—THEDOGATEMEAT—into words that make an intelligible phrase, more likely "The dog ate meat" than "The do gate me at" (McBurney & Collings, 1984). This process involves not only the organization we've been discussing, but also interpretation—discerning meaning in what we perceive.

**Figure 19.10**

**The illusion of the shrinking and growing girls** This distorted room, designed by Adelbert Ames, appears to have a normal rectangular shape when viewed through a peephole with one eye. The girl in the right corner appears disproportionately large because we judge her size based on the false assumption that she is the same distance away as the girl in the left corner.

S. Schwartzenberg/The Exploratorium



# Visual Interpretation

"Let us then suppose the mind to be, as we say, white paper void of all characters, without any ideas: How comes it to be furnished? . . . To this I answer, in one word, from EXPERIENCE." -JOHN LOCKE, *AN ESSAY CONCERNING HUMAN UNDERSTANDING*, 1690

Philosophers have debated whether our perceptual abilities should be credited to our nature or our nurture. To what extent do we *learn* to perceive? German philosopher Immanuel Kant (1724–1804) maintained that knowledge comes from our *inborn* ways of organizing sensory experiences. Indeed, we come equipped to process sensory information. But British philosopher John Locke (1632–1704) argued that through our experiences we also *learn* to perceive the world. Indeed, we learn to link an object's distance with its size. So, just how important is experience? How radically does it shape our perceptual interpretations?

## Experience and Visual Perception

**19-4** What does research on restored vision, sensory restriction, and perceptual adaptation reveal about the effects of experience on perception?

### RESTORED VISION AND SENSORY RESTRICTION

Writing to John Locke, William Molyneux wondered whether "a man *born* blind, and now adult, taught by his *touch* to distinguish between a cube and a sphere" could, if made to see, visually distinguish the two. Locke's answer was *No,* because the man would never have *learned* to see the difference.

Molyneux's hypothetical case has since been put to the test with a few dozen adults who, though blind from birth, have gained sight (Gregory, 1978; von Senden, 1932). Most had been born with cataracts—clouded lenses that allowed them to see only diffused light, rather as someone might see a foggy image through a Ping-Pong ball sliced in half. After cataract surgery, the patients could distinguish figure from ground and could sense colors—suggesting that these aspects of perception are innate. But much as Locke supposed, they often could not visually recognize objects that were familiar by touch.

Seeking to gain more control than is provided by clinical cases, researchers have outfitted infant kittens and monkeys with goggles through which they could see only diffuse, unpatterned light (Wiesel, 1982). After infancy, when the goggles were removed, these animals exhibited perceptual limitations much like those of humans born with cataracts. They could distinguish color and brightness, but not the form of a circle from that of a square. Their eyes had not degenerated; their retinas still relayed signals to their visual cortex. But lacking stimulation, the cortical cells had not developed normal connections. Thus, the animals remained functionally blind to shape. Experience guides, sustains, and maintains the brain's neural organization as it forms the pathways that affect our perceptions.

**Learning to see:** At age 3, Mike May lost his vision in an explosion. Decades later, after a new cornea restored vision to his right eye, he got his first look at his wife and children. Alas, although signals were now reaching his visual cortex, it lacked the experience to interpret them. May could not recognize expressions, or faces, apart from features such as hair. Yet he can see an object in motion and has learned to navigate his world and to marvel at such things as dust floating in sunlight (Abrams, 2002).


AP Photo/Marcio Jose Sanchez

In both humans and animals, similar sensory restrictions later in life do no permanent harm. When researchers cover the eye of an adult animal for several months, its vision will be unaffected after the eye patch is removed. When surgeons remove cataracts that develop during late adulthood, most people are thrilled at the return to normal vision.

The effect of sensory restriction on infant cats, monkeys, and humans suggests there is a *critical period* for normal sensory and perceptual development. Nurture sculpts what nature has endowed. In less dramatic ways, it continues to do so throughout our lives. Despite concerns about their social costs (more on this in Module 78), action video games sharpen spatial skills such as visual attention, eye-hand coordination and speed, and tracking multiple objects (Spence & Feng, 2010).

Experiments on early sensory deprivation provide a partial answer to the enduring question about experience: Does the effect of early experience last a lifetime? For some aspects of perception, the answer is clearly *Yes:* "Use it *soon* or lose it." We retain the imprint of some early sensory experiences far into the future.

### PERCEPTUAL ADAPTATION

Given a new pair of glasses, we may feel slightly disoriented, even dizzy. Within a day or two, we adjust. Our **perceptual adaptation** to changed visual input makes the world seem normal again. But imagine a far more dramatic new pair of glasses—one that shifts the apparent location of objects 40 degrees to the left. When you first put them on and toss a ball to a friend, it sails off to the left. Walking forward to shake hands with the person, you veer to the left.

**perceptual adaptation** in vision, the ability to adjust to an artificially displaced or even inverted visual field.

Could you adapt to this distorted world? Baby chicks cannot. When fitted with such lenses, they continue to peck where food grains *seem* to be (Hess, 1956; Rossi, 1968). But we humans adapt to distorting lenses quickly. Within a few minutes your throws would again be accurate, your stride on target. Remove the lenses and you would experience an aftereffect: At first your throws would err in the *opposite* direction, sailing off to the right; but again, within minutes you would readapt.

Indeed, given an even more radical pair of glasses—one that literally turns the world upside down—you could still adapt. Psychologist George Stratton (1896) experienced this when he invented, and for eight days wore, optical headgear that flipped left to right *and* up to down, making him the first person to experience a right-side-up retinal image while standing upright. The ground was up, the sky was down.

At first, when Stratton wanted to walk, he found himself searching for his feet, which were now "up." Eating was nearly impossible. He became nauseated and depressed. But he persisted, and by the eighth day he could comfortably reach for an object in the right direction and walk without bumping into things. When Stratton finally removed the headgear, he readapted quickly.

In later experiments, people wearing the optical gear have even been able to ride a motorcycle, ski the Alps, and fly an airplane (Dolezal, 1982; Kohler, 1962). The world around them still seemed above their heads or on the wrong side. But by actively moving about in these topsy-turvy worlds, they adapted to the context and learned to coordinate their movements.

Courtesy of Hubert Dolezal

**Perceptual adaptation** "Oops, missed," thought researcher Hubert Dolezal as he viewed the world through inverting goggles. Yet, believe it or not, kittens, monkeys, and humans can adapt to an inverted world.

## Before You Move On

**▶ ASK YOURSELF**

Try drawing a realistic depiction of the scene from your window. Which monocular cues will you use in your drawing?

**▶ TEST YOURSELF**

What do we mean when we say that, in perception, "the whole is greater than the sum of its parts"?

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

# Module 19 Review

## 19-1 How did the Gestalt psychologists understand perceptual organization, and how do figure-ground and grouping principles contribute to our perceptions?

- Gestalt psychologists searched for rules by which the brain organizes fragments of sensory data into *gestalts* (from the German word for "whole"), or meaningful forms. In pointing out that the whole may exceed the sum of its parts, they noted that we filter sensory information and construct our perceptions.
- To recognize an object, we must first perceive it (see it as a *figure*) as distinct from its surroundings (the *ground*). We bring order and form to stimuli by organizing them into meaningful *groups*, following such rules as proximity, continuity, and closure.

## 19-2 How do we use binocular and monocular cues to perceive the world in three dimensions and perceive motion?

- *Depth perception* is our ability to see objects in three dimensions and judge distance. The *visual cliff* and other research demonstrate that many species perceive the world in three dimensions at, or very soon after, birth.
- *Binocular cues,* such as *retinal disparity,* are depth cues that rely on information from both eyes.
- *Monocular cues* (such as relative size, interposition, relative height, relative motion, linear perspective, and light and shadow) let us judge depth using information transmitted by only one eye.
- As objects move, we assume that shrinking objects are retreating and enlarging objects are approaching.
- A quick succession of images on the retina can create an illusion of movement, as in stroboscopic movement or the *phi phenomenon.*

## 19-3 How do perceptual constancies help us organize our sensations into meaningful perceptions?

- *Perceptual constancy* enables us to perceive objects as stable despite the changing image they cast on our retinas.
  - *Color constancy* is our ability to perceive consistent color in objects, even though the lighting and wavelengths shift.
  - Brightness (or lightness) constancy is our ability to perceive an object as having a constant lightness even when its illumination—the light cast upon it—changes.
  - Our brain constructs our experience of an object's color or brightness through comparisons with other surrounding objects.
  - Shape constancy is our ability to perceive familiar objects (such as an opening door) as unchanging in shape.
  - Size constancy is perceiving objects as unchanging in size despite their changing retinal images.
- Knowing an object's size gives us clues to its distance; knowing its distance gives clues about its size, but we sometimes misread monocular distance cues and reach the wrong conclusions, as in the Moon illusion.

## 19-4 What does research on restored vision, sensory restriction, and perceptual adaptation reveal about the effects of experience on perception?

- Experience guides our perceptual interpretations. People blind from birth who gained sight after surgery lack the experience to visually recognize shapes, forms, and complete faces.
- Sensory restriction research indicates that there is a critical period for some aspects of sensory and perceptual development. Without early stimulation, the brain's neural organization does not develop normally.
- People given glasses that shift the world slightly to the left or right, or even upside down, experience *perceptual adaptation.* They are initially disoriented, but they manage to adapt to their new context.

## Multiple-Choice Questions

**1.** A teacher used distortion goggles, which shifted the wearer's gaze 20 degrees, to demonstrate an altered perception. A student wearing the goggles initially bumped into numerous desks and chairs while walking around, but chose to wear the goggles for a half hour. After 30 minutes, the student was able to smoothly avoid obstacles, illustrating the concept of

a. perceptual adaptation.
b. visual interpretation.
c. sensory restriction.
d. perceptual constancy.
e. binocular cues.

**2.** What do we call the illusion of movement that results from two or more stationary, adjacent lights blinking on and off in quick succession?

a. Phi phenomenon
b. Perceptual constancy
c. Binocular cues
d. Retinal disparity
e. Depth perception

**3.** Bryanna and Charles are in a dancing competition. It is easy for spectators to see them against the dance floor because of

a. the visual cliff.
b. the phi phenomenon.
c. color constancy.
d. sensory restriction.
e. figure-ground relationships.

**4.** The view from Narmeen's left eye is slightly different from the view from her right eye. This is due to which depth cue?

a. Retinal disparity
b. Relative size
c. Linear perspective
d. Relative motion
e. Convergence

**5.** Bringing order and form to stimuli, which illustrates how the whole differs from the sum of its parts, is called

a. grouping.
b. monocular cue.
c. binocular cue.
d. disparity.
e. motion.

## Practice FRQs

**1.** Look at the **relative size** cartoon in Figure 19.5. Describe how the artist who drew this cartoon incorporated relative size, linear perspective, and interposition to create depth.

### Answer

*Specific explanations may utilize different aspects of the cartoon.*

***1 point:*** Relative size: We know the woman is closer to us than the police officer, because she is drawn larger.

***1 point:*** Linear perspective: We can tell that the sidewalk is receding into the distance, because its sides pinch closer together in the distance.

***1 point:*** Interposition: We know the woman is closer to us than the police officer, because our view of her partially blocks our view of him.

**2.** Explain the meaning of the word *gestalt* as it applies to perception. Then, apply any two gestalt principles to the perception of food on a plate.

***(3 points)***

# 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 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

## The Stimulus Input: Sound Waves

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.

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.

**AP® Exam Tip**

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

## 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.

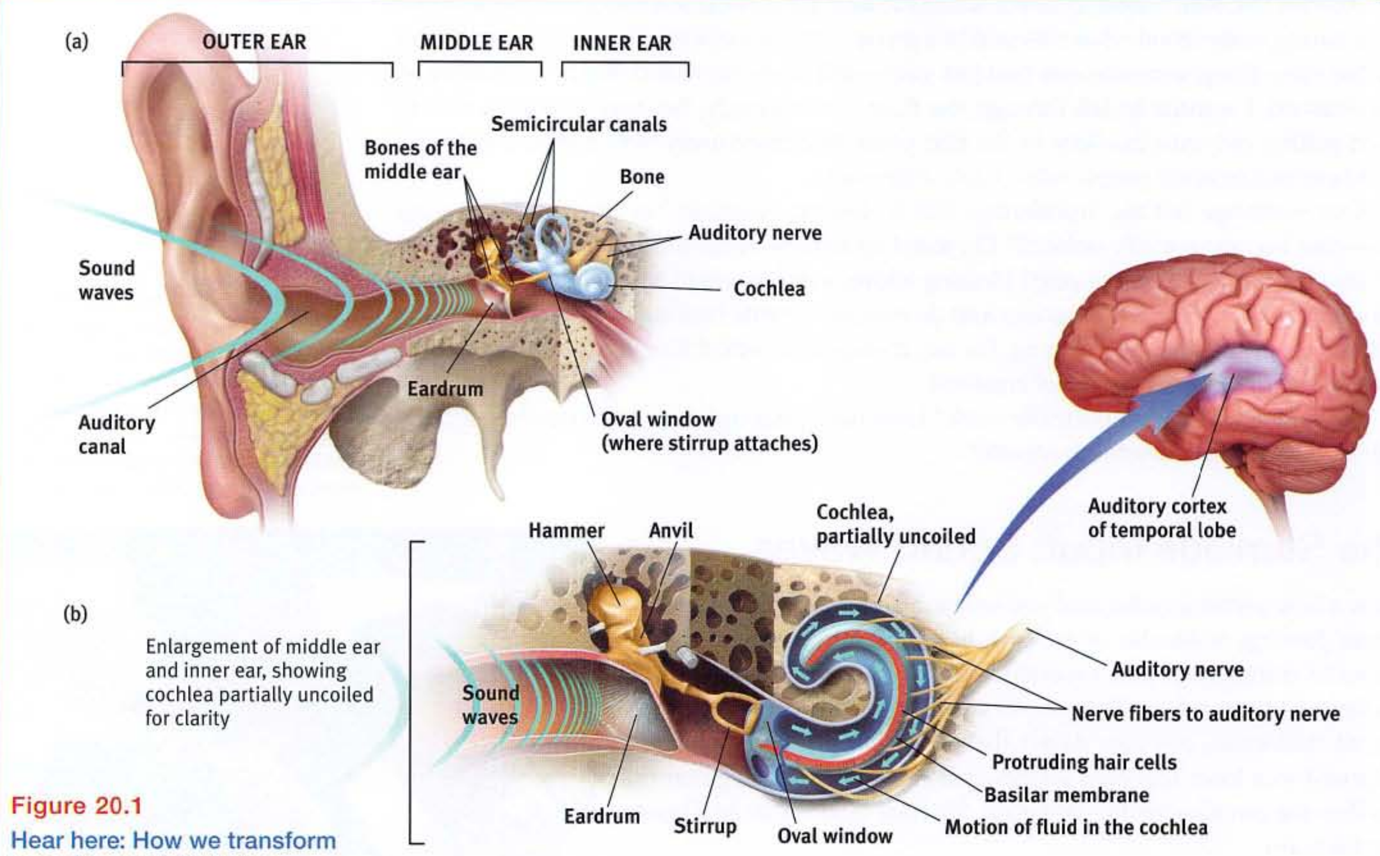



**Figure 20.1**

**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.

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.

**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.

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.

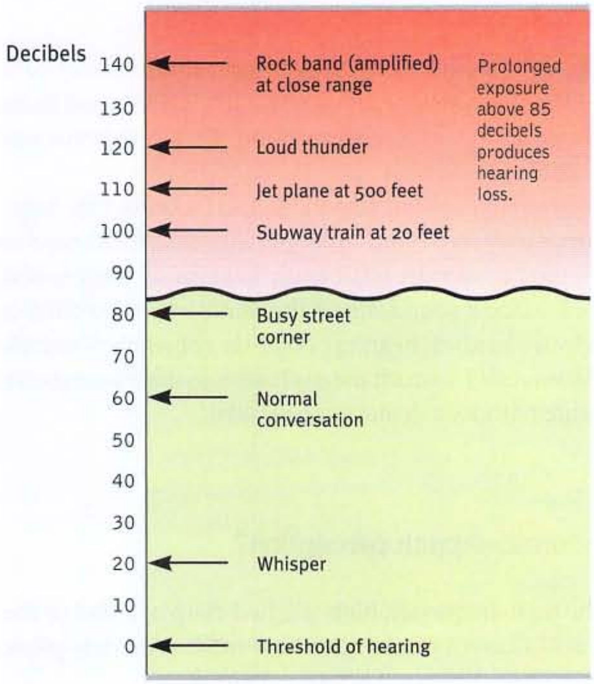
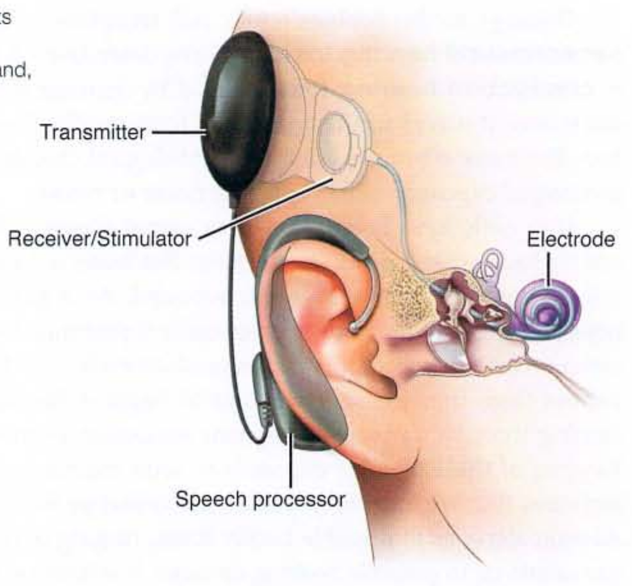



**Figure 20.2**
**The intensity of some common sounds**

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.

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).

**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).

## 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).

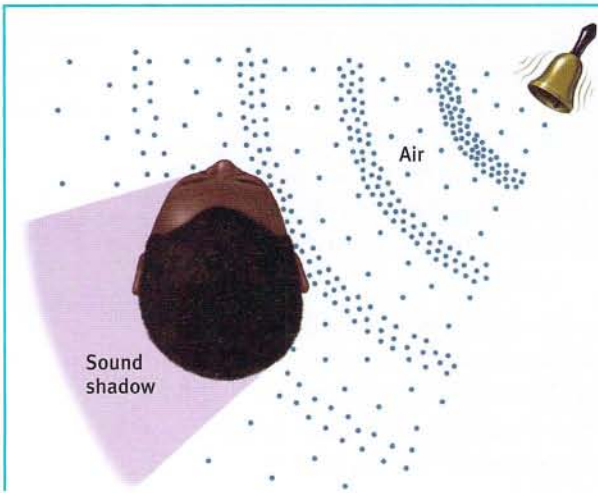



**Figure 20.3** **How we locate sounds** Sound waves strike one ear sooner and more intensely than the other. From this information, our nimble brain computes the sound's location. As you might therefore expect, people who lose all hearing in one ear often have difficulty locating sounds.

## 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

## 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?

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).

"Touch is both the alpha and omega of affection." -WILLIAM JAMES (1890)

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.

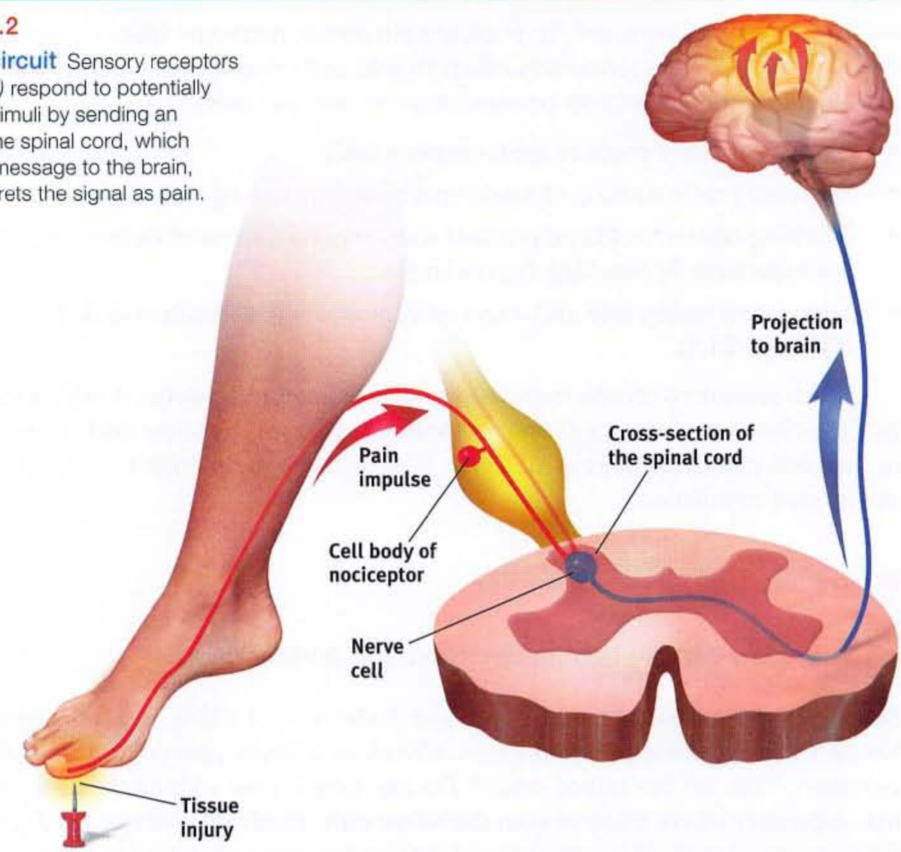



**Figure 21.2**
**The pain circuit** Sensory receptors *(nociceptors)* respond to potentially damaging stimuli by sending an impulse to the spinal cord, which passes the message to the brain, which interprets the signal as pain.

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.

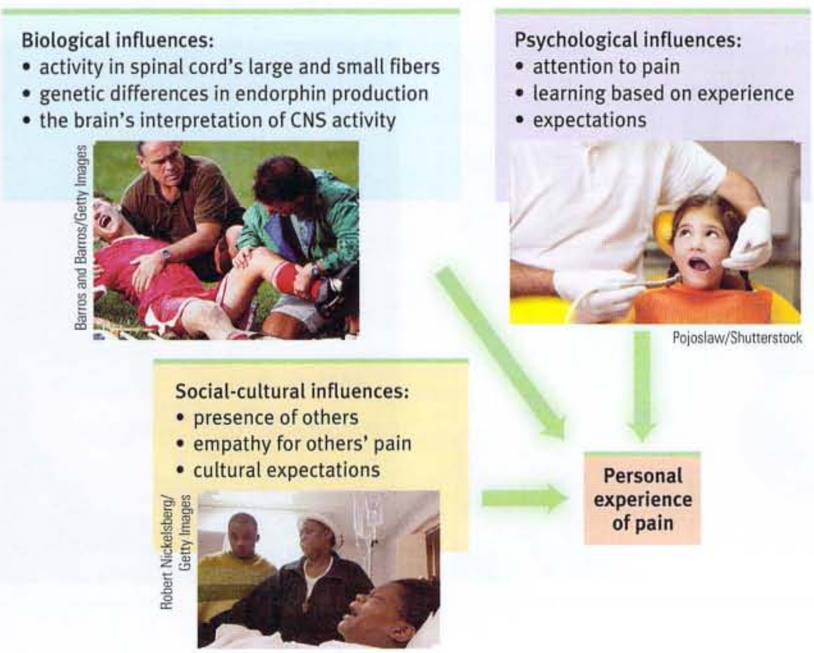



**Figure 21.3**

**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.*

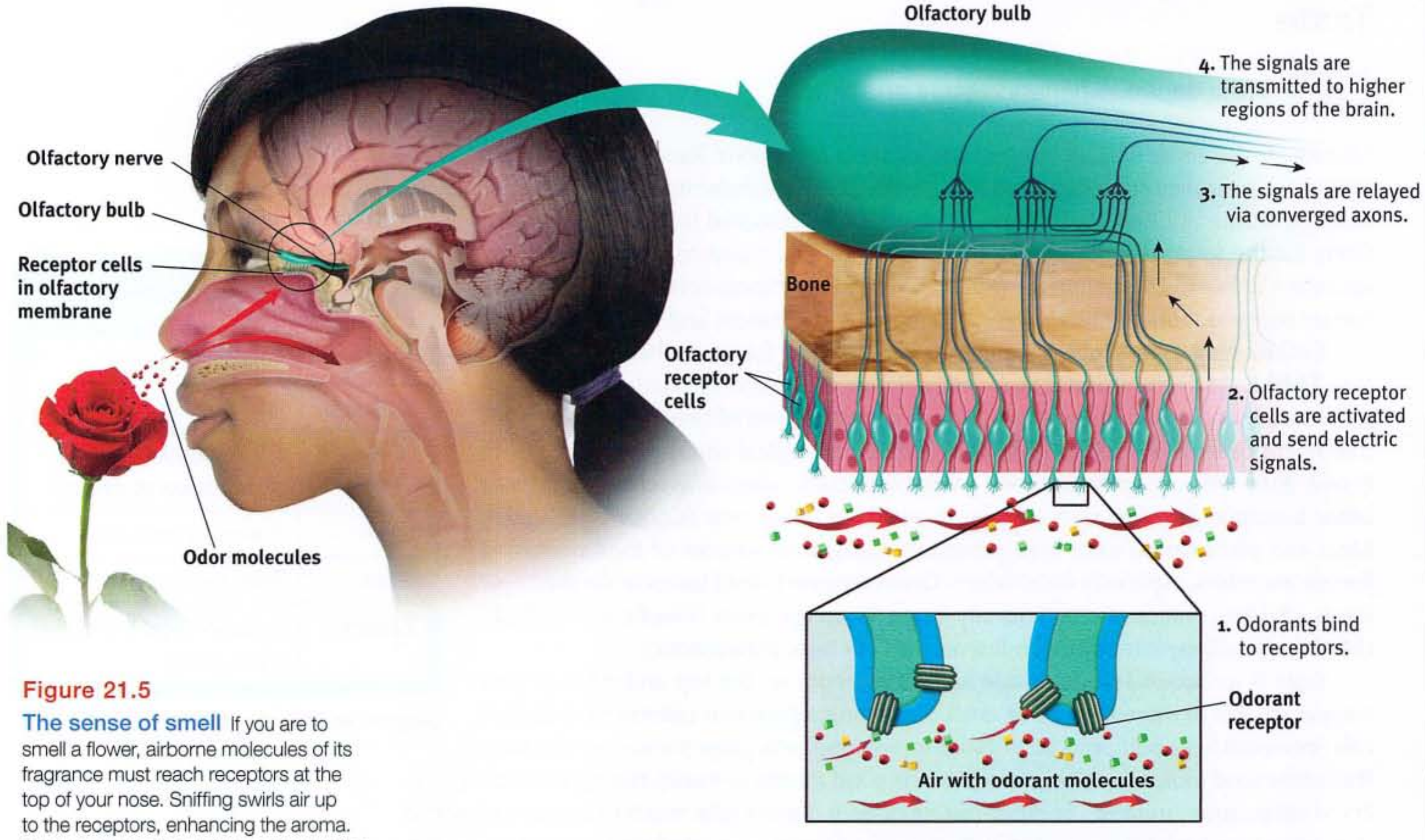



**Figure 21.5**
**The sense of smell** If you are to smell a flower, airborne molecules of its fragrance must reach receptors at the top of your nose. Sniffing swirls air up to the receptors, enhancing the aroma. The receptor cells send messages to the brain's olfactory bulb, and then onward to the temporal 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).

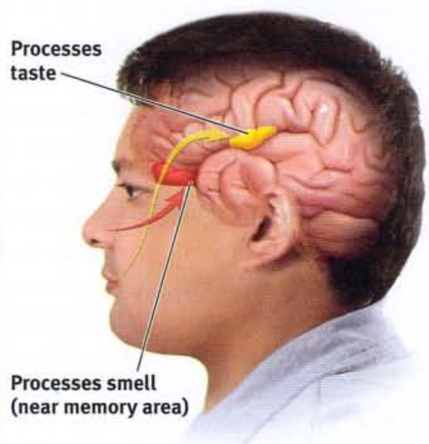



**Figure 21.6**

**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.

© Robert Kanavel

**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).

**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.

Courtesy of Action Hearing Loss

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 *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.

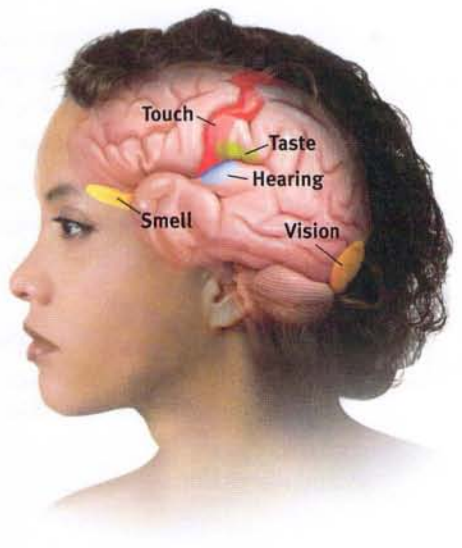
So, the senses interact: As we attempt to decipher our world, our brain blends inputs from multiple channels. For many people, an odor, perhaps of mint or chocolate, can evoke a sensation of taste (Stevenson & Tomiczek, 2007). But in a few select individuals, the senses become joined in a phenomenon 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
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Young-Helmholtz trichromatic (three-color) theory, p. 178
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color constancy, p. 187
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audition, p. 194
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pitch, p. 195
middle ear, p. 195
cochlea [KOHK-lee-uh], p. 195
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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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