Key Question Chapter Outline

How Does Stimulation Become Sensation?

Transduction: Changing Stimulation to Sensation
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How Are the Senses Alike? And How Are They Different?

Vision: How the Nervous System Processes Light
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Sensation and Perception: The State of the Art

CORE CONCEPTS

The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.

The senses all operate in much the same way, but each extracts different information and sends it to its own specialized processing region in the brain.

Perception brings *meaning* to sensation, so perception produces an interpretation of the world, not a perfect representation of it.

Psychology in Your Life

A Critical Look at Subliminal Persuasion

Subliminal perception occurs, but individual differences in perceptual thresholds make widespread use of subliminal persuasion unworkable.

The Experience of Pain

Pain is more than just a stimulus; it is an experience that varies from person to person. Pain control methods include drugs, hypnosis, and—for some—placebos.

Seeing and Believing

Magicians and politicians rely on the fact that we don't merely sense the world, we perceive it.

USING PSYCHOLOGY TO LEARN PSYCHOLOGY:
Studying for the Gestalt

Chapter

4

Sensation and Perception

CAN YOU IMAGINE WHAT your world would be like if you could no longer see colors—but merely black, white, and gray? Such a bizarre sensory loss actually befell Jonathan I., a 65-year-old New Yorker, following an automobile accident (Sacks, 1995). Apparently the trauma of the crash caused damage to a region in his brain that processes color information. At first, Jonathan also had some amnesia for reading letters of the alphabet, which all seemed like nonsensical markings to him. But, after five days, his inability to read disappeared. His loss of color vision, however, persisted as a permanent condition known as *cerebral achromatopsia* (pronounced *ay-kroma-TOP-see-a*).

As you might expect, Jonathan became depressed by this turn of events in his life. The problem was aggravated by the fact that he was a painter whose profession was based on representing his visual images of the world in vivid colors. Now this world of colors was all gone, all drab, all "molded in lead." When he looked at his own paintings, which had seemed bursting with special meaning and emotional associations, all he now saw were unfamiliar and meaningless objects on canvas.

Curiously, Jonathan also lost his memory of color and eventually the names for colors. He could no longer even imagine, for instance, what "red" once looked like. What Jonathan's experience dramatically demonstrated to the researchers and clinicians who studied him and tried to help him was the nonobvious neurological truth that colors do not really exist "out there." Rather, the world of color is constructed by the sensory and perceptual processes in the brain.

Jonathan's story has a more or less happy ending, one that reveals much about the resilience of the human spirit. First, Jonathan became a "night person," traveling and working at night and socializing with other night people. (As we will see in this chapter, good color vision depends on bright illumination such as daylight; most people's color vision is not as acute in the dark of night.) He also became aware that what remained of his vision was remarkably good, enabling him to read license plates from four blocks away at night. Jonathan began to reinterpret his "loss" as a gift in the sense that he was no longer distracted by color and could now focus his work more intently on shape, form, and content. Finally, he switched to painting only in black and white, and critics acclaimed his "new phase" as a success. He has also become good at sculpting, which he had never attempted before his accident. So, as Jonathan's world of color died, a new world of "pure forms" was born in his perception of the people, objects, and events in his environment.

To hunt small flying objects at night, bats rely on the sensory system of echolocation, a kind of sonar. Bats emit high-frequency sounds that bounce off insects, revealing their locations so the bats can find and eat them.

What are the lessons we can learn from Jonathan's experience? His unusual sensory loss tells us that our picture of the world around us depends on an elaborate sensory system that processes incoming information. In other words, we don't experience the world directly, but instead through a series of "filters" that we call our *senses.* By examining such cases of sensory loss, psychologists have learned much about how the sensory processing system works. And, on a more personal level, case studies like Jonathan allow us momentarily to slip outside our own experience to see more clearly how resilient humans can be in the face of catastrophic loss.

Although the very private processes that connect us with the outside world extend deep into the brain, we will begin our chapter at the surface—at the sense organs. This is the territory of *sensory psychology.* We will define **sensation** simply as the process by which a stimulated receptor (such as the eyes or ears) creates a pattern of neural messages that represent the stimulus in the brain, giving rise to our initial experience of the stimulus. An important idea to remember is that sensation involves changing stimulation (such as a pinprick, a sound, or a flash of light) into a form the brain can understand (neural signals)—much as a cell phone converts an electronic signal into sound waves you can hear.

In this chapter you will see how all our sense organs, in some fundamental ways, are much alike. They all transform physical stimulation (such as light waves) into the neural impulses that give us sensations (such as light and dark). Along the way, you will learn about the psychological basis for color, odor, sound, texture, and taste. When you have finished the chapter, you will know why tomatoes and limes seem to have different hues, why a pinprick feels different from a caress, and why seeing doesn't always give us an accurate basis for believing.

Happily, under most conditions our sensory experience is highly reliable. So, when you catch sight of a friend, the sensation usually registers clearly, immediately, and accurately. Yet we humans do have our sensory limitations—just as other creatures do. In fact, we lack the acute senses so remarkable in many other species: the vision of hawks, the hearing of bats, the sense of smell of rodents, and the sensitivity to magnetic fields found in migratory birds. So, is there a human specialty? In a way, there is: Our species has evolved the sensory equipment that enables us to process a wider range and variety of sensory input than any other creature.

Sensation The process by which stimulation of a sensory receptor produces neural impulses that the brain interprets as a sound, a visual image, an odor, a taste, a pain, or other sensory image. Sensation represents the first series of steps in processing of incoming information.

Beyond that fact, our ultimate destination in this chapter lies, far beyond mere sensation, in the amazing realm of *perception.* There we will uncover the psychological processes that attach meaning and personal significance to the sensory messages entering our brains. *Perceptual psychology* will help you understand how we assemble a series of tones into a familiar melody or a barrage of shapes and shadings into a familiar face. More generally, we will define **perception** as a mental process that elaborates and assigns meaning to the incoming sensory patterns. Thus, *perception creates an interpretation of sensation.* Perception answers questions such as: Is the tomato ripe? Is the sound a church bell or a doorbell? Does the face belong to someone you know?

In this chapter, you will also learn that many complex acts of sensing and perceiving occur behind the scenes, so effortlessly, continuously, and flawlessly that we pay them little conscious mind. Even more fundamentally, you will learn the sobering fact that our minds lack direct access to the outside world. No matter what we do, the information we get about external events must always be filtered through our sense organs and then combined with our unique mix of memories, emotions, motives, and expectations. Indeed, the inner world of sensation and perception is the only world we can ever know.

As you can see, the boundary of sensation blurs into that of perception. Perception is essentially an interpretation and elaboration of sensation. Seen in these terms, sensation refers just to the initial steps in the processing of a stimulus. It is to these first sensory steps that we now turn our attention.

HOW DOES STIMULATION BECOME SENSATION?

KEY QUESTION

A thunderstorm is approaching, and you feel the electric charge in the air make the hair stand up on your neck. Lightning flashes, and a split second later you hear the thunderclap. It was close by, and you smell the ozone left in the wake of the bolt, as it sizzled through the air. Your senses are warning you of danger.

Our senses have other adaptive functions, too. They aid our survival by directing us toward certain stimuli, such as tasty foods, which provide nourishment. Our senses also help us locate mates, seek shelter, and recognize our friends. Incidentally, our senses also give us the opportunity to find pleasure in music, art, athletics, food, and sex.

How do our senses accomplish all this? The complete answer is complex, but it involves one elegantly simple idea that applies across the sensory landscape: Our sensory impressions of the world involve *neural representations* of stimuli—not the actual stimuli themselves. The Core Concept puts it this way:

CORE CONCEPT

The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.

As we have noted, the brain never receives stimulation directly from the outside world. Its experience of a tomato is not the same as the tomato itself—although we usually assume that the two are identical. Neither can the brain receive light from a sunset, reach out and touch velvet, or inhale the fragrance of a rose. It must always rely on secondhand information from the go-between sensory system, which delivers only a coded neural message, out of which the brain must create its own experience. (See Figure 4.1.) Just as you cannot receive phone messages without a telephone receiver to convert the electronic energy into sound you can hear, your brain needs its sensory system

■ **Perception** A process that makes sensory patterns meaningful. It is perception that makes these words meaningful, rather than just a string of visual patterns. To make this happen, perception draws heavily on memory, motivation, emotion, and other psychological processes.

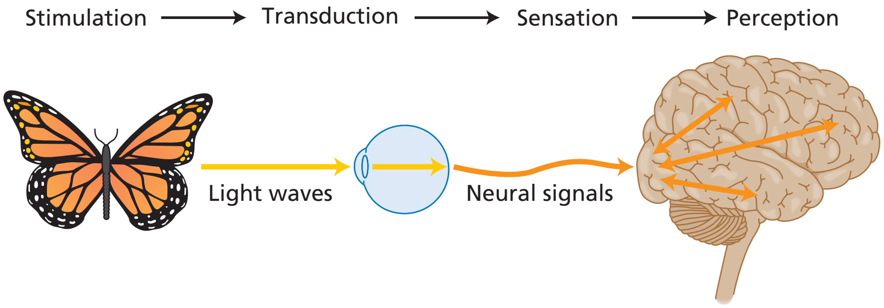


FIGURE 4.1 Stimulation Becomes Perception

For visual stimulation to become meaningful perception, it must undergo several transformations. First, physical stimulation (light waves from the butterfly) are transduced by the eye, where information about the wavelength and intensity of the light is coded into neural signals. Second, the neural messages travel to the sensory cortex of the brain, where they become sensations of color, brightness, form, and movement. Finally, the process of perception interprets these sensations by making connections with memories, expectations, emotions, and motives in other parts of the brain. Similar processes operate on information taken in by the other senses.

to convert the stimuli from the outside world into neural signals that it can comprehend.

To understand more deeply how the world's stimulation becomes the brain's sensation, we need to think about three attributes common to all the senses: *transduction, sensory adaptation,* and *thresholds.* They determine which stimuli will actually become sensation, what the quality and impact of that sensation will be, and whether it grabs our interest. These attributes determine, for example, whether a tomato actually registers in the sensory system strongly enough to enter our awareness, what its color and form appear to be, and how strongly it bids for our attention.

Transduction: Changing Stimulation to Sensation

The idea that basic sensations, such as the redness and flavor of our tomato, are entirely creations of the sense organs and brain may seem incredible to you. But remember that all sensory communication with the brain flows through neurons in the form of neural signals: Neurons cannot transmit light or sound waves or any other external stimulus. Accordingly, none of the light bouncing off the tomato ever actually reaches the brain. In fact, light gets only as far as the back of the eyes, where the information it contains is converted to neural messages. Likewise, the chemicals that signal taste make their way only as far as the tongue, not all the way to the brain.

In all the sense organs, it is the job of the *sensory receptors* to convert incoming stimulus information into electrochemical signals—neural activity—the only language the brain understands. As Jonathan I.'s case suggests, sensations, such as "red" or "sweet" or "cold," occur only when the neural signal reaches the cerebral cortex. The whole process seems so immediate and direct that it fools us into assuming that the sensation of redness is characteristic of a tomato or the sensation of cold is a characteristic of ice cream. But they are not! (You can demonstrate to yourself how light is not necessary for sensations of light with the demonstration in the "Do It Yourself!" box, "Phosphenes Show That Your Brain Creates Sensations.")

Psychologists use the term **transduction** for the sensory process that converts physical energy, such as light or sound waves, into the form of neural messages. Transduction begins with the detection by a sensory neuron of the physical stimulus (such as the sound wave made by a vibrating guitar string). When the appropriate stimulus reaches a sense organ, it activates specialized neurons, called *receptors,* which respond by converting their excitation into a nerve signal. This happens in much the same way that a bar-code reader (which is, after all, merely an electronic receptor) converts the series of lines on a frozen pizza box into an electronic signal that a computer can match with a price. In our own sensory system, it is the neural impulse that carries a code

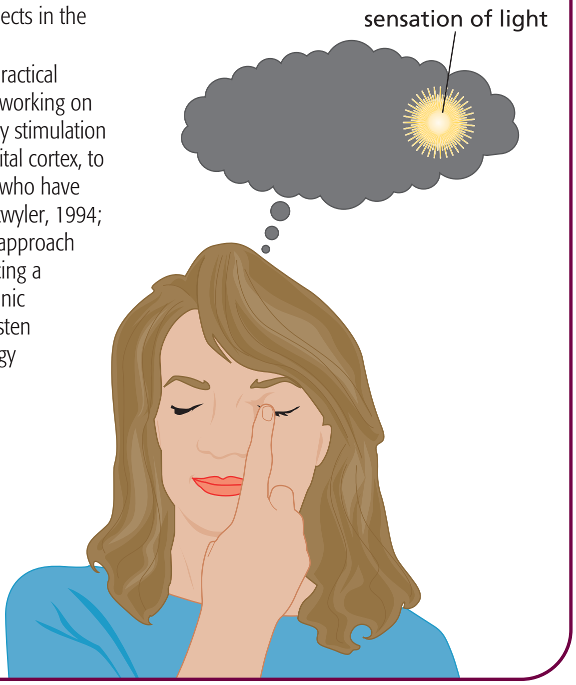
Transduction Transformation of one form of energy into another—especially the transformation of stimulus information into nerve signals by the sense organs. Without transduction, ripe tomatoes would not appear red (or pinkish-gray, in the case of tomatoes purchased in many grocery stores).

DO IT YOURSELF! Phosphenes Show That Your Brain Creates Sensations

One of the simplest concepts in perceptual psychology is among the most difficult for most people to understand: The brain and its sensory systems create the colors, sounds, tastes, odors, textures, and pains that you sense. You can demonstrate this to yourself in the following way.

Close your eyes and press gently with your finger on the inside corner of one eye. On the opposite side of your visual field you will "see" a pattern caused by the pressure of your finger—not by light. These light sensations are *phosphenes,* visual images caused by fooling your visual system with pressure, which stimulates the optic nerve in much the same way light does. Direct electrical stimulation of the occipital lobe, sometimes done during brain surgery, can have the same effect. This shows that light waves are not absolutely necessary for the sensation of light. The sensory experience of light, therefore, must be a creation of the brain, rather than a property of objects in the external world.

Phosphenes may have some practical value, too. Several laboratories are working on ways to use phosphenes, created by stimulation sent from a TV camera to the occipital cortex, to create visual sensations for people who have lost their sight (Dobelle, 1977; Leutwyler, 1994; Service, 1999). Another promising approach under development involves replacing a section of the retina with an electronic microchip (Liu et al., 2000). We hasten to add, however, that this technology is in its infancy (Cohen, 2002).



of the sensory event in a form that can be further processed by the brain. To get to its destination, this information-carrying signal travels from the receptor cells along a *sensory pathway* by way of the thalamus to specialized sensory processing areas in the brain. From neural impulses arriving from these pathways, the brain then extracts information about the basic qualities of the stimulus, such as its intensity, pitch, and direction. Please keep in mind, however, that the stimulus itself terminates in the receptor: The only thing that continues on into the nervous system is *information* carried by the neural impulse.

A swimmer must undergo sensory adaptation when jumping into cool water.

Sensory Adaptation

If you have ever jumped into a cool pool on a hot day, you know that sensation is critically influenced by *change.* In fact, a main role of our stimulus detectors is to announce changes in the external world such as a flash of light, a splash of water, a clap of thunder, the prick of a pin, or the burst of flavor from a dollop of salsa. Thus, our sense organs are change detectors. Their receptors specialize in gathering information about new and changing events.

The great quantity of incoming sensation would quickly overwhelm us, if not for the ability of our sensory systems to adapt. **Sensory adaptation** is the diminishing responsiveness of sensory systems to prolonged stimulation, as when you adapted to the feel of swimming in cool water. Unless it is quite intense or painful, stimulation that persists without changing in intensity or some other quality usually shifts into the background of our awareness. To give another example, you probably did not realize, until we called your attention to it, that your sense of touch had adapted to the press of furniture against

Sensory adaptation Loss of responsiveness in receptor cells after stimulation has remained unchanged for a while, as when a swimmer becomes adapted to the temperature of the water.

your body. On the other hand, any change in the stimulation you are receiving (if an air conditioner suddenly becomes louder or higher-pitched, for example) will draw your attention. Incidentally, sensory adaptation is why the background music often played in stores is so unmemorable: It has been deliberately selected and filtered to remove any large changes in volume or pitch that might distract attention from the merchandise. (Do you see why it's not a good idea to listen to interesting music while you are studying?)

Thresholds

What is the weakest stimulus that an organism can detect? How dim can a light be and still be visible? How soft can music be and still be heard? These questions refer to the **absolute threshold** for different types of stimulation, which is the minimum amount of physical energy needed to produce a sensory experience. In the laboratory, a psychologist would define this operationally as the intensity at which the stimulus is detected accurately 50% of the time over many trials. Obviously, this threshold will vary from one person to another. So, if you point out a faint star to a friend who says he cannot see it, the star's light is above your absolute threshold (you can see it) but below that of your friend (who cannot).

CONNECTION: CHAPTER 1

An *operational definition* describes a concept in terms of the operations required to produce, observe, or measure it.

A faint stimulus does not abruptly become detectable as its intensity increases. Because of the fuzzy boundary between detection and nondetection, a person's absolute threshold is not absolute! In fact, it varies continually with our mental alertness and physical condition. Experiments designed to determine thresholds for various types of stimulation were among the earliest studies done by psychologists—who called this line of inquiry *psychophysics.* Table 4.1 shows some typical absolute threshold levels for several familiar natural stimuli.

We can illustrate another kind of threshold with the following imaginary experiment. Suppose you are relaxing by watching television on the one night you don't need to study, while your sister busily prepares for an early morning exam. Your sibling asks you to "turn it down a little" to eliminate the distraction. You feel that you should make some effort to comply but really wish to leave the volume as it is. What is the least amount you can lower the volume to prove your good intentions to your sibling while still keeping the volume clearly audible? Your ability to make judgments like this one depends on your **difference threshold,** the smallest physical difference between two stimuli that can still be recognized as a difference.

■ **Absolute threshold** The amount of stimulation necessary for a stimulus to be detected. In practice, this means that the presence or absence of a stimulus is detected correctly half the time over many trials.

■ **Difference threshold** The smallest amount by which a stimulus can be changed and the difference be detected half the time.

TABLE 4.1 Approximate Perceptual Thresholds of Five Senses

Sense Modality	Detection Threshold
Light	A candle flame at 30 miles on a dark, clear night
Sound	The tick of a mechanical watch under quiet conditions at 20 feet
Taste	One teaspoon of sugar in two gallons of water
Smell	One drop of perfume diffused into the entire volume of a three-bedroom apartment
Touch	The wing of a bee falling on your cheek from a distance of one centimeter

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DO IT YOURSELF! An Enlightening Demonstration of Sensory Relationships

In this simple demonstration, you will see how detection of change depends on the intensity of the background stimulation. Find a three-way lamp equipped with a bulb having equal wattage increments, such as a 50–100–150 watt bulb. (Wattage is closely related to brightness.) Then, in a dark room, switch the light on to 50 watts. This will unmistakably increase brightness. Changing from 50 to 100 watts will also seem like a large increase. But why does the last 50-watt increase (from 100 to 150 watts) appear only slightly brighter? Your sensory system does not give you a sensation of the exact brightness. Rather, it compares the stimulus change to the background stimulation, translating the jump from 100 to 150 watts as a mere 50% increase (50 watts added to 100) compared to the earlier 100% increase (50 watts added to 50). This illustrates how your brain computes sensory relationships, rather than absolutes.

If you turn the volume knob as little as possible, your sister might complain, "I don't hear any difference" or "You haven't turned it down enough." By "enough," your sister probably means her difference threshold. Even if you have adjusted the volume downward slightly, the difference might not be large enough to detect. If you hear the difference, it exceeds your own difference threshold; if your sister can hear the difference, it exceeds hers. Suppose you start adjusting the volume and ask your sister to "say when"—to stop you when the adjustment is sufficient to be detected. This minimal amount of change in the signal that is still recognizable is the **just noticeable difference (JND).** The terms *difference threshold, just noticeable difference,* and *JND* are used interchangeably by psychologists.

Investigation of the JND for different senses has yielded some interesting insights into how human stimulus detection works. It turns out that *the JND is always large when the stimulus intensity is high, and small when the stimulus intensity is low.* Psychologists refer to this idea—that the size of the JND is proportional to the intensity of the stimulus—as **Weber's law.** Weber's law is represented by the formula $\Delta I/I = k$, where I is the intensity of the stimulus and k is a constant (there is a different constant for each sense).

And what does Weber's law tell us about adjusting the TV volume? If you have the volume turned up very high, you will have to turn the volume down a lot to make the difference noticeable. On the other hand, if you already have the volume set to a very low level, so that you can barely hear it if you listen carefully, a small adjustment will probably be noticeable enough for your sibling. The same principle operates across all our senses. Knowing this, you might guess that a weight lifter would notice the difference when small amounts were added to light weights, but it would take a much larger addition to be noticeable with heavy weights.

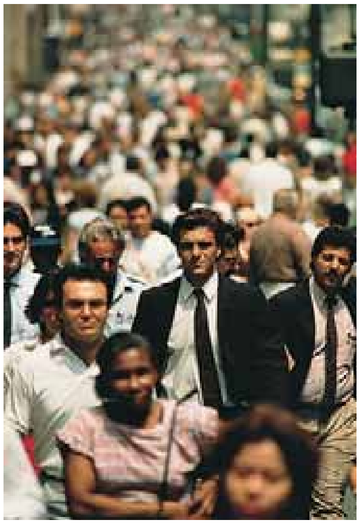
In addition to Weber's law, two other principles affect stimulus detection. **Fechner's law** expresses the relationship between the actual magnitude of the stimulus and its perceived magnitude. An increase in the physical magnitude of a stimulus progressively produces smaller increases in perceived magnitude. The formula for this is $S = k \log R$ (S = sensation, R = stimulus, and k = a constant that differs for each sensory modality). The third principle of stimulus detection is known as **Steven's power law.** This "law" addresses some issues with Fechner's law and why it cannot account for some changes in stimulus detection, and works for a variety of additional stimuli, namely pain and temperature. Steven's power law is written as $S = kI^a$, where S = sensation, k = a constant, I = stimulus intensity, and a = a power exponent that depends on the sense we are measuring. It is through Weber's law, Fechner's law, and Steven's power law that we know and can distinguish among different intensities of stimuli.

■ **Just noticeable difference (JND)** Same as the difference threshold.

■ **Weber's law** This concept says that the size of a JND is proportional to the intensity of the stimulus; the JND is large when the stimulus intensity is high and is small when the stimulus intensity is low. (This concept has *no* connection with Ann Weber, one of your authors.)

■ **Fechner's law** The magnitude of a stimulus can be estimated by the formula $S = k \log R$, where S = sensation, R = stimulus, and k = a constant that differs for each sensory modality (sight, touch, temperature, etc.).

■ **Steven's power law** A law of magnitude estimation that is more accurate than Fechner's law and covers a wider variety of stimuli. It is represented by the formula $S = kI^a$, where S = sensation, k = a constant, I = stimulus intensity, and a = a power exponent that depends on the sense being measured.



Signal detection theory says that the background stimulation would make it less likely for you to hear someone calling your name on a busy downtown street than in a quiet park.

What does all this mean for our understanding of human sensation? The general principle is this: We are built to detect *changes* in stimulation and *relationships* among stimuli. You can see how this works in the box, "Do It Yourself! An Enlightening Demonstration of Sensory Relationships."

Signal Detection Theory

A deeper understanding of absolute and difference thresholds comes from *signal detection theory* (Green & Swets, 1966). Originally developed for engineering electronic sensors, signal detection theory uses the same concepts to explain both the electronic sensing of stimuli by devices, such as your TV set, and by the human senses, such as vision and hearing.

According to **signal detection theory,** sensation depends on the characteristics of the stimulus, the background stimulation, and the detector. You may have noticed, for example, that you get more out of an 8 o'clock class if your nervous system has been aroused by a strong cup of coffee. Similarly, a person's interests and biases can affect the "signals" he or she gets from the evening news.

Signal detection theory also helps us understand why thresholds are variable—why, for example, you might notice a certain sound one time and not the next. The classical theory of thresholds ignored the effects of the perceiver's physical condition, judgments, or biases. Thus, in classical psychophysics (the study of stimulation, thresholds, and sensory experience), if a signal were intense enough to exceed one's absolute threshold, it would be sensed; if below threshold, it would be missed. In the view of modern signal detection theory, sensation is not a simple present/absent, yes/no experience.

So, what does signal detection theory offer psychology that was missing in classical psychophysics? One factor is the variability in human judgment. Signal detection theory recognizes that the observer, whose physical and mental status is always in flux, must compare a sensory experience with ever-changing expectations and biological conditions. For example, when something "goes bump in the night" after you have gone to bed, you must decide whether it is the cat, an intruder, or just your imagination. What you decide depends on the keenness of your hearing and what you expect to hear, as well as other noises in the background. By taking into account the variable conditions that affect detection of a stimulus, signal detection theory provides a more accurate portrayal of sensation than did classical psychophysics.

PSYCHOLOGY IN YOUR LIFE: A CRITICAL LOOK AT SUBLIMINAL PERSUASION

Can extremely weak stimulation—stimulation that you don't even notice—affect your mind or behavior? The alluring promise that signals can be processed in your sensory system without awareness lies at the basis of the industry that sells "subliminal" tapes and CDs touted as remedies for obesity, shoplifting, smoking, and low self-esteem. But before you put your money in the mail, let's look at a bit of history and some fundamentals of sensory psychology.

Signal detection theory Explains how we detect "signals," consisting of stimulation affecting our eyes, ears, nose, skin, and other sense organs. Signal detection theory says that sensation is a judgment the sensory system makes about incoming stimulation. Often, it occurs outside of consciousness. In contrast to older theories from psychophysics, signal detection theory takes observer characteristics into account.

Some years ago, advertising executive James Vicary dramatically announced to the press that he had discovered an irresistible sales technique now known as "subliminal advertising." Vicary said that his method consisted of projecting very brief messages on the screen of a movie theater, urging the audience to "Drink Coke" and "Buy popcorn." He claimed that the ads presented ideas so fleetingly that the conscious mind could not perceive them—yet, he said, the messages would still lodge in the unconscious mind, where they would work on the viewer's desires unnoticed. Vicary also boasted that sales of Coca Cola and popcorn had soared at a New Jersey theater where he tested the technique.

The public was both fascinated and outraged. Subliminal advertising became the subject of intense debate. People worried that they were being manipulated by powerful psychological forces without their consent. As a result, laws were proposed to quash the practice. But aside from the hysteria, was there any real cause for concern? For answers to that question we must return to the concept of *threshold,* the minimum amount of stimulation necessary to trigger a response. The word *subliminal* means "below the threshold" (*limen* = threshold). In the language of perceptual psychology, *subliminal* more specifically refers to stimuli lying near the absolute threshold. Such stimuli may, in fact, be strong enough to affect the sense organs and to enter the sensory system, without causing conscious awareness of the stimulus. But the real question is this: Can subliminal stimuli in this range influence our thoughts and behavior?

Several studies have found that subliminal words flashed briefly on a screen (for less than 1/100 second) can "prime" a person's later responses (Merikle & Reingold, 1990). For example, can you fill in the following blanks to make a word?

S N _ _ _ E L

If you had been subliminally primed by a brief presentation of the appropriate word, it would be more likely that you would have found the right answer, even though you were not aware of the priming stimulus.

Apparently people do respond to stimuli below the absolute threshold, under some circumstances (Greenwald et al., 1996; Reber, 1993). But here is the problem for would-be subliminal advertisers who would attempt to influence us in the uncontrolled world outside the laboratory: Different people have thresholds at different levels. So, what might be *sub*liminal for me could well be *supra*liminal (above the threshold) for you. Consequently, the subliminal advertiser runs the risk that some in the audience will notice—and be angry about—a stimulus aimed slightly below the average person's threshold. In fact, *no controlled research has ever shown that subliminal messages delivered to a mass audience can influence people's buying habits.*

But what about those subliminal recordings that some stores play to prevent shoplifting? Again, no reputable study has ever demonstrated their effectiveness. A more likely explanation for any decrease in shoplifting "associated with" these tapes lies in increased vigilance from employees who know that management is worried about shoplifting. The same goes for the tapes that claim to help you quit smoking, lose weight, become wildly creative, or achieve other dozens of elusive dreams. In a comprehensive study of subliminal self-help techniques, the U.S. Army found all to be without foundation (Druckman & Bjork, 1991). The simplest explanation for reports of success lies in the purchasers' expectations and in the need to prove that they did not spend their money foolishly. And finally, to take the rest of the worry out of subliminal persuasion, you should know that James Vicary eventually admitted that his claims for subliminal advertising were a hoax (Druckman & Bjork, 1991).

The answer to the fill-in-the-blanks problem, by the way, is "snorkel."

CHECK YOUR UNDERSTANDING

1. **RECALL:** The sensory pathways carry information
   - a. from the brain to the muscles.
   - b. from the brain to the sense organs.
   - c. from the central nervous system to the autonomic nervous system.
   - d. from the muscles to the brain.
   - e. from the sense organs to the brain.

2. **RECALL:** Which one refers to the least amount of stimulation that your perceptual system can detect about half the time?
   - a. Fechner's law
   - b. the absolute threshold
   - c. the action threshold
   - d. the difference threshold
   - e. the stimulus threshold

3. **APPLICATION:** Which one would involve sensory adaptation?
   - a. You no longer pay attention to the feel of the clothes on your body.
   - b. The flavor of a spicy salsa on your taco seems hot by comparison with the blandness of the sour cream.
   - c. The water in a swimming pool seems warmer after you have been in it for a while than it did when you first jumped in.
   - d. You are unaware of a priming stimulus flashed on the screen at 1/100 of a second.
   - e. You prefer the feel of silk to the feel of velvet.

4. **RECALL:** Which of the following is a process that adds meaning to incoming information obtained by the sensory systems?
   - a. detection
   - b. perception
   - c. sensation
   - d. sensory adaptation
   - e. stimulation

5. **UNDERSTANDING THE CORE CONCEPT:** When you hear the sound of a tree falling in the forest, the brain has received nothing but
   - a. sound waves from the air.
   - b. the vibration of the eardrums.
   - c. the sense of the air rushing by you.
   - d. sound waves traveling through the sensory pathways.
   - e. neural activity in the sensory pathways.

ANSWERS: 1. e 2. b 3. c 4. b 5. e

KEY QUESTION

HOW ARE THE SENSES ALIKE? AND HOW ARE THEY DIFFERENT?

Vision, hearing, smell, taste, touch, pain, body position: In certain ways, all these senses are the same. They all transduce stimulus energy into neural impulses. They are all more sensitive to change than to constant stimulation. And they all provide us information about the world—information that has survival value. But how are they different? With the exception of pain, each sense taps a different form of stimulus energy, and each sends the information it extracts to a different part of the brain. These contrasting ideas lead us to the Core Concept of this section:

CORE CONCEPT

The senses all operate in much the same way, but each extracts different information and sends it to its own specialized processing region in the brain.

Each sense organ has a different design, and each sends neural messages to its own specialized region in the brain. So, in the end, *different sensations occur because different areas of the brain become activated.* Whether you hear a bell or see a bell depends ultimately on which part of the brain receives stimulation. We will explore how this all works by looking at each of the senses in turn. First, we will explore the visual system—the best understood of the senses—to discover how it transduces light waves into visual sensations of color and brightness.

Vision: How the Nervous System Processes Light

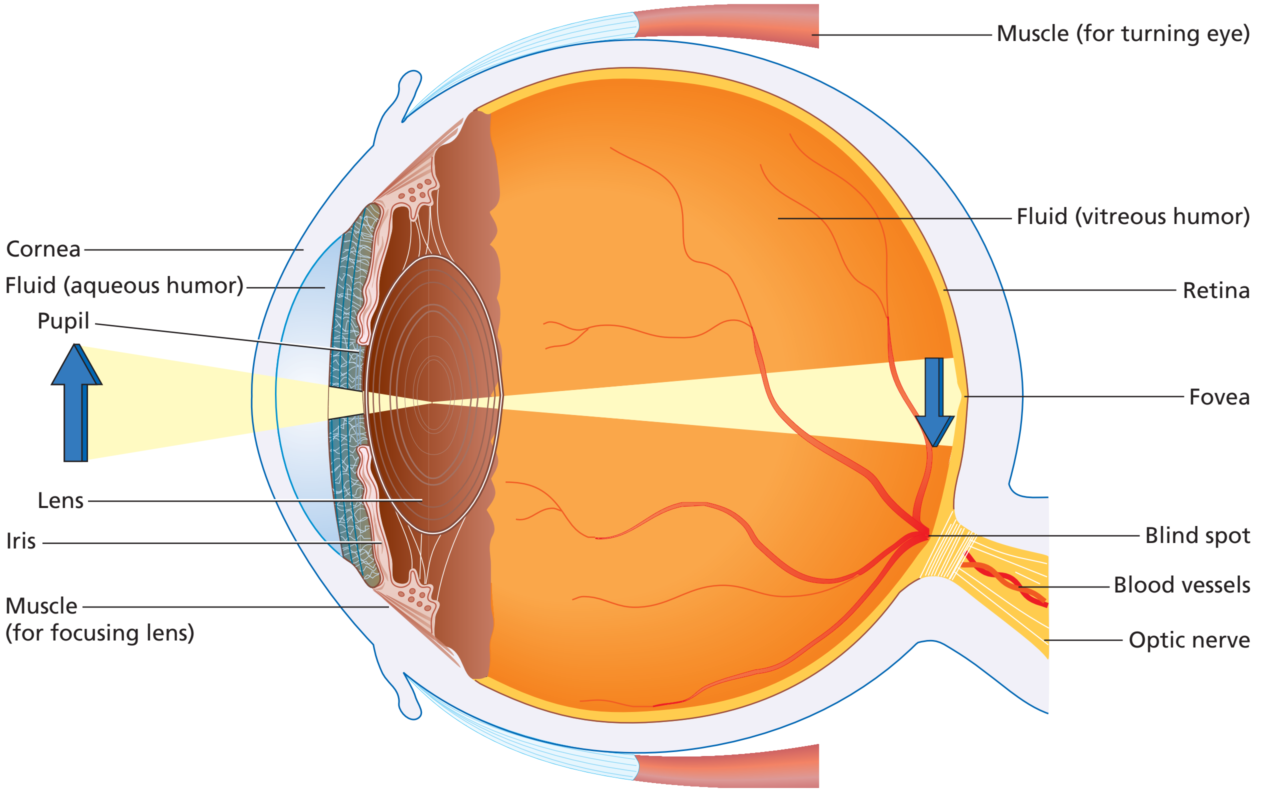
Animals with good vision have an enormous biological advantage. This fact has exerted evolutionary pressure to make vision the most complex, best developed, and important sense for humans and most other highly mobile creatures. Good vision helps us detect desired targets, threats, and changes in our physical environment and to adapt our behavior accordingly. So, how does the visual system accomplish this?

The Anatomy of Visual Sensation You might think of the eye as a camera the brain uses to make motion pictures of the world (see Figure 4.2). Like a camera, the eye gathers light, focuses it, converts it to neural signals, and sends these signals on their way for subsequent processing into a visual image. The unique characteristic of the eye—what makes the eye different from other sense organs—lies in its ability to extract the information from light waves, which are simply a form of electromagnetic energy. (Visible light is not fundamentally different from radio waves or X rays, as we shall find.) The eye, then, *transduces* the characteristics of light into neural signals that the brain can process. This transduction happens in the **retina,** the light-sensitive layer of cells at the back of the eye that acts much like the light-sensitive chip in a digital camera.

The real work in the retina is performed by light-sensitive cells known as **photoreceptors,** which operate much like the tiny pixel receptors in a digital camera. These photoreceptors consist of two different types of specialized neurons—the rods and cones that absorb light energy and respond by creating neural impulses (see Figure 4.3). But why two types of photoreceptors?

■ **Retina** The thin, light-sensitive layer at the back of the eyeball. The retina contains millions of photoreceptors and other nerve cells.

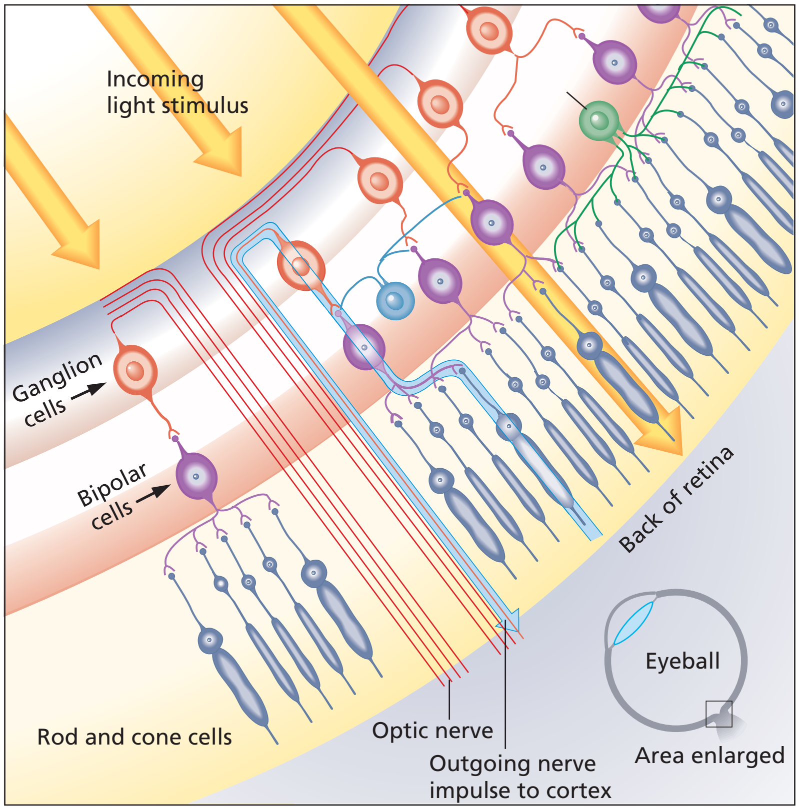
■ **Photoreceptors** Light-sensitive cells (neurons) in the retina that convert light energy to neural impulses. The photoreceptors are as far as light gets into the visual system.



● **FIGURE 4.2** Structures of the Human Eye

● **FIGURE 4.3** Transduction of Light in the Retina

This simplified diagram shows the pathways that connect three layers of nerve cells in the retina. Incoming light passes through the ganglion cells and bipolar cells first before striking the photoreceptors at the back of the eyeball. Once stimulated, the rods and cones transmit information to the bipolar cells (note that one bipolar cell combines information from several receptor cells). The bipolar cells then transmit neural impulses to the ganglion cells. Impulses travel from the ganglia to the brain via axons that make up the optic nerve.



Because we sometimes function in near-darkness and sometimes in bright light, we have evolved two ways of processing, using two distinct receptor cell types named for their shapes. The 125 million tiny **rods** "see in the dark"—that is, they detect low intensities of light at night, though they cannot make the fine distinctions that give rise to our sensations of color. Rod cells enable you to find a seat in a darkened movie theatre.

Making the fine distinctions necessary for color vision is the job of the seven million **cones** that come into play in bright light. Each cone is specialized to detect the light waves we sense either as blue, red, or green. In good light, then, we can use these cones to distinguish ripe tomatoes (sensed as red) from unripe ones (sensed as green). The cones concentrate in the very center of the retina, in a small region called the **fovea,** which gives us our sharpest vision. With movements of our eyeballs, we use the fovea to scan whatever interests us visually—the features of a face or, perhaps, a flower. (You can learn more about the way cones work by trying the "Do It Yourself!" demonstration on the next page.)

There are still other types of cells in the retina, but while they are vital to vision, they do not respond directly to light. In particular, the *bipolar cells* have the job of collecting impulses from many photoreceptors (rods and cones) and shuttling them on to the *ganglion cells,* much as an airline "hub" collects passengers from many regional airports and shuttles them on to other destinations. Bundled together, the axons of the ganglion cells make up the **optic nerve,** which transports visual information from the eye to the brain. (See Figures 4.2 and 4.3.) Again, it is important to understand that your visual system carries no light at all beyond the retina—only patterns of nerve impulses conveying *information* derived from the incoming light.

■ **Rods** Photoreceptors in the retina that are especially sensitive to dim light but not to colors. Strange as it may seem, they are rod-shaped.

■ **Cones** Photoreceptors in the retina that are especially sensitive to colors but not to dim light. You may have guessed that the cones are cone-shaped.

■ **Fovea** The tiny area of sharpest vision in the retina.

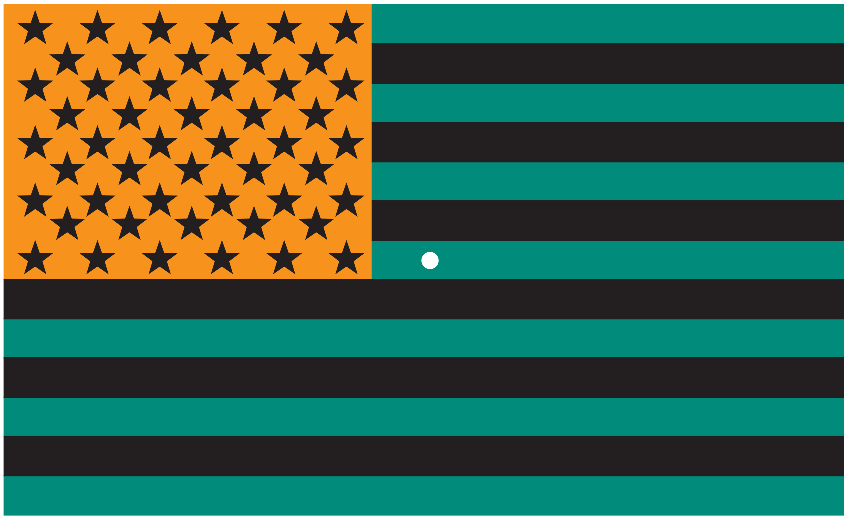
■ **Optic nerve** The bundle of neurons that carries visual information from the retina to the brain.

DO IT YOURSELF! The Amazing Afterimage

After you stare at a colored object for a while, cells in your retina will become fatigued, causing an interesting visual effect. When you shift your gaze to a blank surface, you can "see" the object in complementary colors—as a visual afterimage. The "phantom flag" demonstration will show you how this works.

Stare at the dot in the center of the green, black, and orange flag for at least 30 seconds. Take care to hold your eyes steady and not to let them scan over the image during this time. Then quickly shift your gaze to the center of a sheet of white paper or to a light-colored blank wall. What do you see? Have your friends try this, too. Do they see the same afterimage? (The effect may not work for people who are color-blind.)

Afterimages may be negative or positive. Positive afterimages are caused by a continuation of the receptor and neural processes following stimulation. They are brief. An example of positive afterimages occurs when you see the trail of a sparkler twirled by a Fourth of July reveler. Negative afterimages are the opposite or the reverse of the original experience, as in the flag example. They last longer. Negative afterimages operate according to the *opponent-process theory* of color vision, which involves ganglion cells in the retina and the optic nerve. Apparently, in a negative afterimage, the fatigue in these cells produces sensations of a complementary color when they are exposed to white light.



Just as strangely, there is a small area of the retina in each eye where everyone is blind, because that part of the retina has no photoreceptors. This **blind spot** is located at the point where the optic nerve exits each eye, and the result is a gap in the visual field. If your vision is normal, you do not experience blindness there because what one eye misses is registered by the other eye, and the brain "fills in" the spot with information that matches the background. You can find your own blind spot by following the instructions in the "Do It Yourself!" box on the next page.

Processing Visual Sensation in the Brain We *look* with our eyes but we *see* with the brain. To do so, we use a special processing area in the brain to create visual images from the information imported through the optic nerve (see Figure 4.4). In the *visual cortex*, the brain begins working its magic by transforming the incoming neural impulses into visual sensations of color, form, boundary, and movement. Amazingly, the visual cortex also manages to take the two-dimensional patterns from each eye and assemble them into a three-dimensional world of depth (Barinaga, 1998a; Dobbins et al., 1998). With further processing, the cortex ultimately combines these visual sensations with memories, motives, emotions, and sensations of body position and touch to create a representation of the visual world that fits our current concerns and interests (Barinaga, 1999; Batista et al., 1999; de Gelder, 2000; Maunsell, 1995). Now you know why you can be strongly attracted by the visual appeal of appetizing foods if you go grocery shopping when you are hungry.

How the Visual System Creates Brightness Sensations of **brightness** come from the intensity or *amplitude* of light, determined by how much light reaches the

CONNECTION: CHAPTER 3
The *visual cortex* lies in the brain's occipital lobe.

■ **Blind spot** The point where the optic nerve exits the eye and where there are no photoreceptors. Any stimulus that falls on this area cannot be seen.

■ **Brightness** A psychological sensation caused by the intensity of light waves.

DO IT YOURSELF! Find Your Blind Spot

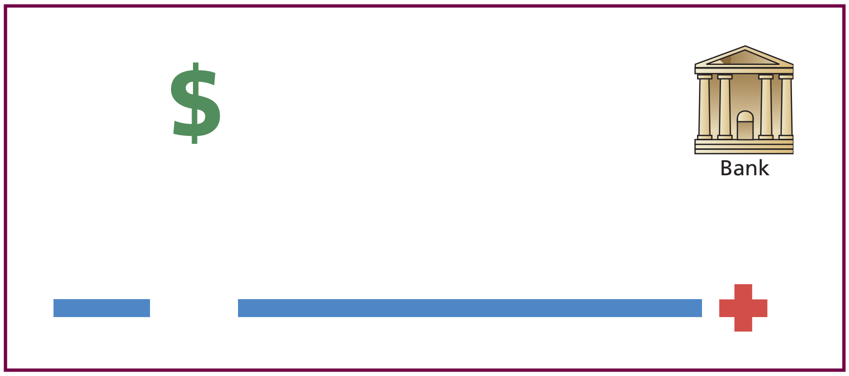
The "blind spot" occurs at the place on the retina where the neurons from the retina bunch together to exit the eyeball and form the optic nerve. There are no light-sensitive cells at this point on the retina. Consequently, you are "blind" in this small region of your visual field. The following demonstrations will help you determine where this blind spot occurs in your visual field.

DEMONSTRATION 1

Hold the book at arm's length, close your right eye, and fix your left eye on the "bank" figure. Keep your right eye closed and bring the book slowly closer. When it is about 10 to 12 inches away and the dollar sign is in your blind spot, the dollar sign will disappear—but you will not see a "hole" in your visual field. Instead, your visual system "fills in" the missing area with information from the white background. You have "lost" your money!

DEMONSTRATION 2

To convince yourself that the brain fills in the missing part of the visual field with appropriate background, close your right eye again and focus on the cross in the lower part of the figure. Once again, keeping the right eye closed, bring the book closer to you as you focus your left eye on the cross. This time, the gap in the line will disappear and will be filled in with a continuation of the line on either side. This shows that what you see in your blind spot may not really exist!



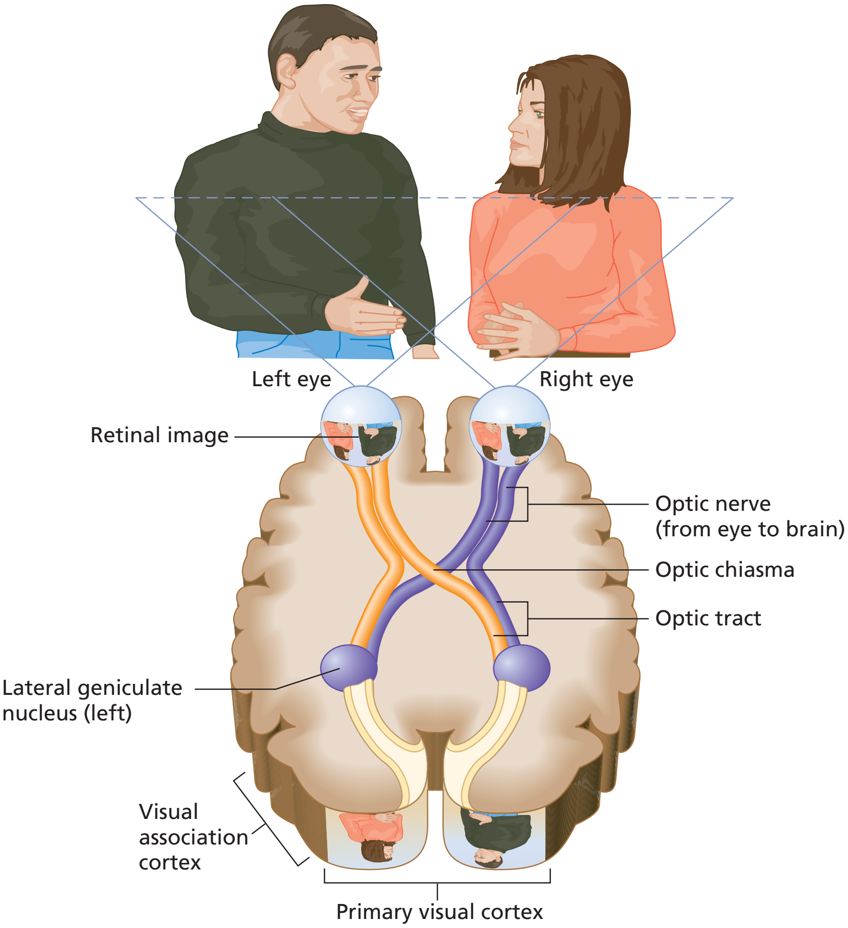


FIGURE 4.4 How Visual Stimulation Goes from the Eyes to the Brain

Light from objects in the visual field projects images on the retinas of the eyes. Please note two important things. First, the lens of the eye reverses the image on the retina—so the image of the man falls on the right side of the retina and the image of the woman falls on the left. Second, the visual system splits the retinal image coming from each eye, so that part of the image coming from each eye crosses over to the opposite side of the brain. (Note how branches of the optic pathway cross at the *optic chiasma.*) As a result, objects appearing in the *left* part of the visual field *of both eyes* (the man, in this diagram) are sent to the *right* hemisphere's visual cortex for processing, while objects in the *right* side of the visual field *of both eyes* (the woman, in this diagram) are sent to the *left* visual cortex. In general, the right hemisphere "sees" the left visual field, while the left hemisphere "sees" the right visual field. (*Source:* From SEEING: Illusion, Brain and Mind by J. P. Frisby. Copyright © 1979. Reprinted by permission of J. P. Frisby.)

TABLE 4.2	Visual Stimulation Becomes Sensation
Physical Stimulation	**Psychological Sensation**
Wavelength →	color
Intensity (amplitude) →	brightness

Color and brightness are the psychological counterparts of the wavelength and intensity of a lightwave. Wavelength and intensity are physical characteristics of light waves, while color and brightness are psychological characteristics that exist only in the brain.

retina (see Table 4.2). Bright light, as from approaching headlights, involves a more intense light wave, which creates much neural activity in the retina, whereas relatively dim light, from your car's instrument panel, does not. Ultimately, the brain senses brightness by the level of neural activity produced in the retina and passed along through the optic pathways.

How the Visual System Creates Color You may have been surprised to learn that a flower or a ripe tomato, itself, has no **color** or *hue.* Physical objects seen in bright light seem to have the marvelous property of being awash with color; but, as we have noted, the red tomatoes, yellow flowers, green trees, blue oceans, and multihued rainbows are, in themselves, actually quite colorless. Nor does the light reflected from these objects have color. Despite the way the world appears to us, color does not exist outside the brain because color is a *sensation* that the brain creates based on the wavelength of light striking our eyes. Thus, color exists only in the mind of the viewer—a *psychological* property of our sensory experience. Color is created when the wavelength in a beam of light is recoded by the photoreceptors in the form of neural impulses and sent to specialized areas of the brain for sensory processing. To understand more fully how this happens, you must first know something of the nature of light.

The eyes detect the special form of energy that we call *visible light.* Physicists tell us that this light is pure energy—fundamentally the same as radio waves, microwaves, infrared light, ultraviolet light, X rays, and cosmic rays. All are forms of *electromagnetic energy,* consisting of waves that move at light's speed limit of nearly 670 million MPH. These waves differ in their *wavelength,* the distance they travel in making one wave cycle, as they vibrate in space, like ripples on a pond (see Figure 4.5). The light we can see occupies but a tiny segment of the vast **electromagnetic spectrum.** Our only access to this electromagnetic spectrum lies through a small visual "window" called the **visible spectrum.** Because we have no biological receptors sensitive to the other portions of the electromagnetic spectrum, we must employ special detection instruments, such as radios and TVs, to help us convert energy in the range outside our vision into signals we can use.

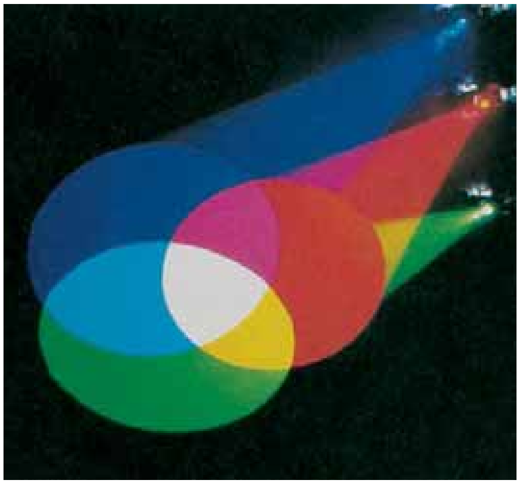
Within the visible spectrum light waves of different wavelengths give rise to different colors. Longer waves make us see a tomato as red, and medium-length waves give rise to the sensations of yellow and green we see in lemons and limes. The shorter waves from a clear sky stimulate sensations of blue. Thus, it is the wavelength of light from which the eye extracts the information used by the brain to construct colors (see Table 4.2).

Remarkably, our visual experiences of color, form, position, and depth are all based on processing the same stream of sensory information in different parts of the visual cortex. Colors

■ **Color** Also called *hue.* Color is *not* a property of things in the external world. Rather, it is a *psychological sensation* created in the brain from information obtained by the eyes from the wavelengths of visible light.

■ **Electromagnetic spectrum** The entire range of electromagnetic energy, including radio waves, X rays, microwaves, and visible light.

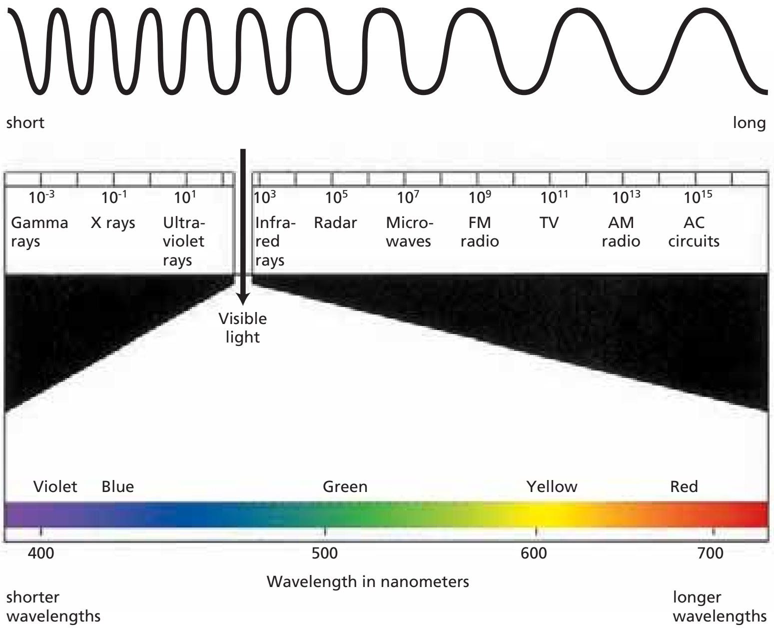
■ **Visible spectrum** The tiny part of the electromagnetic spectrum to which our eyes are sensitive. The visible spectrum of other creatures may be slightly different from our own.



● The combination of any two unique hues yields the complement of a third color. The combination of all three wavelengths produces white light, as does the combination of two complementary colors.

● **FIGURE 4.5** The Electromagnetic Spectrum

The only difference between visible light and other forms of electromagnetic energy is *wavelength*. (*Source:* Fig. 2.1, p. 27, "The Electromagnetic Spectrum," from PERCEPTION 3rd ed. by Sekuler & Blake. Copyright © 1994. Reprinted by permission of The McGraw-Hill Companies.)



themselves are realized in a specialized area, where humans are capable of discriminating among about five million different hues. Other nearby cortical areas take responsibility for processing information about boundaries, shapes, and movements.

Two Ways of Sensing Colors Even though color is realized in the cortex, color processing begins in the retina. There, three different types of cones sense different parts of the visible spectrum—light that we sense as red, green, and blue. This three-receptor explanation for color vision is known as the **trichromatic theory,** and for a time it was considered to account for color vision completely. We now know that the trichromatic theory best explains the initial stages of color vision in the cone cells.

Another explanation, called the **opponent–process theory,** better explains some cases of color blindness, as well as negative **afterimages** (see the "Do It Yourself!" box on p. 121)—both of which involve *opponent,* or complementary, colors. According to the opponent-process theory, from the bipolar cells onward the visual system processes colors in either-or complementary pairs, such as red or green or as yellow or blue. In all subsequent layers of the visual system, then, the sensation of a certain color, such as red, inhibits the sensation of its complement, green. Taken together, the two theories explain color vision: The trichromatic theory explains color processing in the cones, while the opponent-process theory explains what happens in the bipolar cells and beyond.

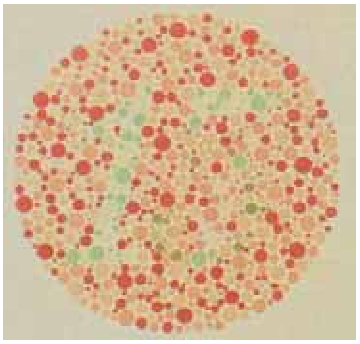
■ **Trichromatic theory** The idea that colors are sensed by three different types of cones sensitive to light in the red, blue, and green wavelengths. The trichromatic theory explains the earliest stage of color sensation.

■ **Opponent-process theory** The idea that cells in the visual system process colors in complementary pairs, such as red or green or as yellow or blue. The opponent-process theory explains color sensation from the bipolar cells onward in the visual system.

■ **Afterimages** Sensations that linger after the stimulus is removed. Most visual afterimages are *negative afterimages,* which appear in reversed colors.

■ **Color blindness** Typically a genetic disorder (although sometimes the result of trauma, as in the case of Jonathan) that prevents an individual from discriminating certain colors. The most common form is red–green color blindness.

Color Blindness Not everyone sees colors in the same way, because some people are born with a color deficiency. At the extreme, complete **color blindness** is the total inability to distinguish colors. More commonly people merely have a color weakness that causes minor problems in distinguishing colors, especially under low-light conditions. People with one form of color weakness can't distinguish pale colors, such as pink or tan. Most color weakness or blindness, however, involves a problem in distinguishing red from green, especially at weak saturations. Those who confuse yellows and blues are rare, about one or two people per thousand. Rarest of all are those who see no color at all and see only variations in brightness. In fact, only about 500 cases of this total color blindness have ever been reported—including Jonathan I., whom we met at the beginning of this chapter. To see whether you have a major color deficiency, look at Figure 4.6 and note what you see. If you see the number 15 in the dot pattern, your color vision is probably normal. If you see something else, you are probably at least partially color blind.



● **FIGURE 4.6** The Ishihani Color Blindness Test

Someone who cannot discriminate between red and green hues will not be able to identify the number hidden in the figure. What do you see? If you see the number 15 in the dot pattern, your color vision is probably normal.

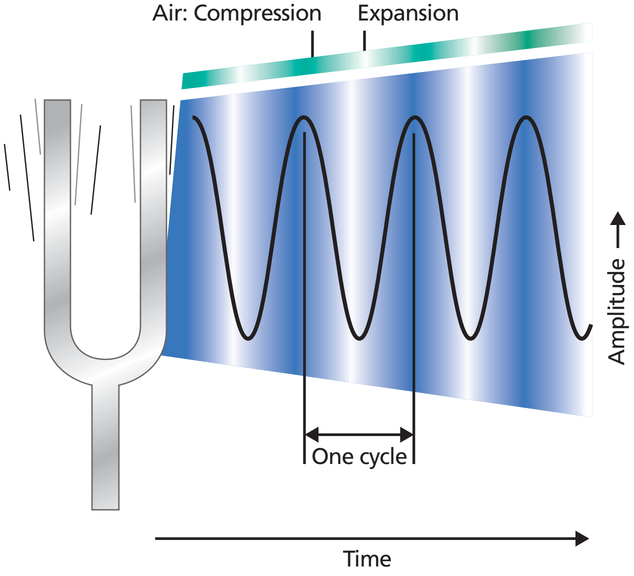
Hearing: If a Tree Falls in the Forest . . .

Imagine how your world would change if your ability to hear were suddenly diminished. You would quickly realize that hearing, like vision, provides you with the ability to locate objects in space, such as the source of a voice calling your name. In fact, hearing may be even more important than vision in orienting us toward distant events. We often hear things, such as footsteps coming up behind us, before we see the source of the sounds. Hearing may also tell us of events that we cannot see, including speech, music, or a car approaching from behind.

But there is more to hearing than its *function.* Accordingly, we will look a little deeper to learn *how* we hear. Specifically, in the next few pages we will review what sensory psychologists have discovered about how sound waves are produced, how they are sensed, and how these sensations of sound are interpreted.

The Physics of Sound: How Sound Waves Are Produced Those Hollywood explosions of spaceships or planets should be absolutely silent! On Earth, the vibrational energy of vibrating objects, such as guitar strings, bells, and vocal cords, transfers to the surrounding medium—usually air—as the vibrating objects push the molecules of the medium back and forth. The resulting changes in pressure spread outward in the form of sound waves that can travel 1100 feet per second in air. In space, however, there is no air or other medium to carry the sound wave, so if you were a witness to a planetary disaster, the experience would be eerily without sound.

Back here on Earth, the purest tones are made by a tuning fork (see Figure 4.7). When struck, a tuning fork produces an extremely simple sound wave that has only two characteristics: *frequency* and *amplitude.* These are the two physical properties of any sound wave that determine how it will be sensed



● **FIGURE 4.7** Sound Waves

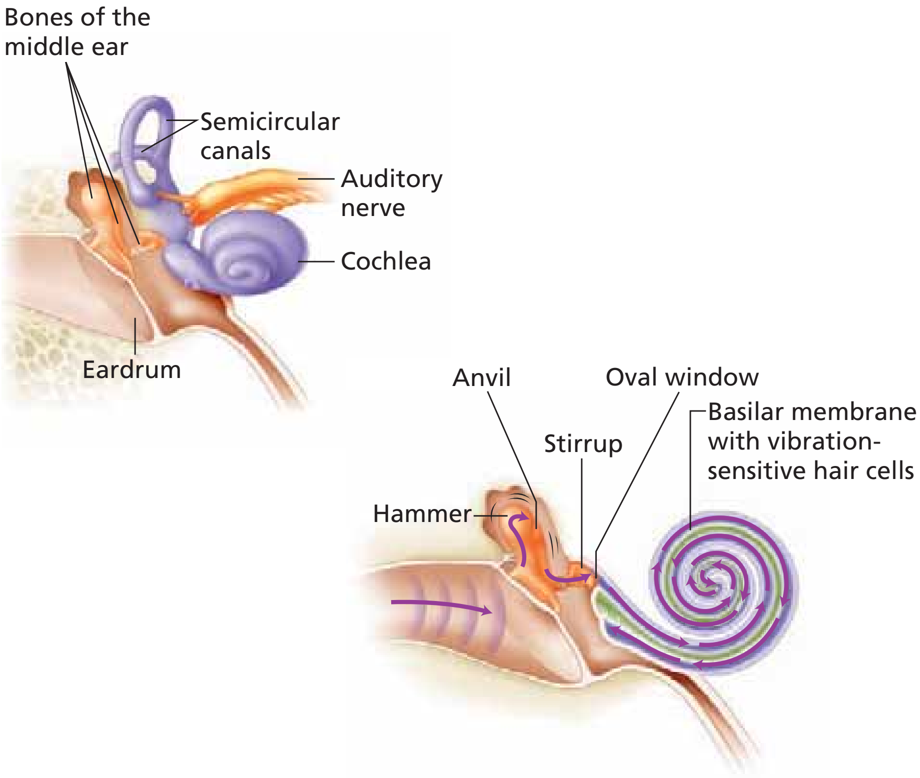
Sound waves produced by the vibration of a tuning fork create waves of compressed and expanded air. The pitch that we hear depends on the *frequency* of the wave (the number of cycles per second). High pitches are the result of high-frequency waves. The *amplitude,* or strength, of a sound wave depends on how strongly the air is affected. In this diagram, amplitude is represented by the height of the graph.

by the brain. **Frequency** refers to the number of vibrations or cycles the wave completes in a given amount of time; it is usually expressed in *cycles per second (cps)* or *hertz (Hz).* **Amplitude** is a measure of the physical strength of the sound wave (shown in its peak-to-valley height); it is defined in units of sound pressure or energy. When you turn down the volume on your stereo, you are decreasing the amplitude of the sound waves.

Sensing Sounds: How We Hear Sound Waves Much like vision, the psychological sensation of sound requires that waves be transduced into neural impulses and sent to the brain. This happens in four steps:

1. *Airborne sound waves must be relayed to the inner ear.* In this initial transformation, vibrating waves of air enter the outer ear (also called the *pinna*) and strike the *eardrum,* or **tympanic membrane** (see Figure 4.8). This tightly stretched sheet of tissue transmits the vibrations to three tiny bones: the *hammer, anvil,* and *stirrup,* named for their shapes. These bones immediately pass the vibrations on to the primary organ of hearing, the **cochlea,** located in the inner ear.
2. *The cochlea focuses the vibrations on the basilar membrane.* Here in the cochlea, the formerly airborne sound wave becomes "seaborne," because the coiled tube of the cochlea is filled with fluid. As the bony stirrup vibrates against the oval window at the base of the cochlea, the vibrations set the fluid into wave motion, working on the same principle as a submarine sending a sonar "ping" through the water. In turn, the fluid wave spreads through the cochlea, causing a sympathetic vibration in the **basilar membrane,** a thin strip of tissue running through the cochlea.
3. *The basilar membrane converts the vibrations into neural messages.* The swaying of tiny hair cells on the vibrating basilar membrane (much like the swaying of buildings during an earthquake) stimulates sensory nerve endings

■ **Frequency** The number of cycles completed by a wave in a given amount of time, usually a second.
■ **Amplitude** The physical strength of a wave. This is usually measured from peak (top) to valley (bottom) on a graph of the wave.
■ **Tympanic membrane** The eardrum.
■ **Cochlea** The primary organ of hearing; a coiled tube in the inner ear, where sound waves are transduced into nerve messages.
■ **Basilar membrane** A thin strip of tissue sensitive to vibrations in the cochlea. The basilar membrane contains hair cells connected to neurons. When a sound wave causes the hair cells to vibrate, the associated neurons become excited. As a result, the sound waves are converted (transduced) into nerve activity.



● **FIGURE 4.8** Structures of the Human Ear

Sound waves are channeled by the outer ear (*pinna*) through the external canal, causing the tympanic membrane to vibrate. The vibration activates the tiny bones in the middle ear (*hammer, anvil,* and *stirrup*). These mechanical vibrations pass from the oval window to the cochlea, where they set internal fluid in motion. The fluid movement stimulates tiny hair cells along the basilar membrane, inside the cochlea, to transmit neural impulses from the ear to the brain along the auditory nerve.

connected to the hair cells. The excited neurons, then, transform the mechanical vibrations of the basilar membrane into neural activity.

4. *Finally, the neural messages travel to the auditory cortex in the brain.* Neural signals leave the cochlea in a bundle of neurons called the *auditory nerve.* The neurons from the two ears meet in the brain stem, which passes the auditory information to both sides of the brain. Ultimately, the signals arrive in the *auditory cortex* for higher-order processing.

CONNECTION: CHAPTER 3
The auditory cortex lies in the brain's *temporal lobes.*

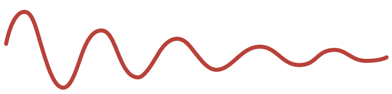
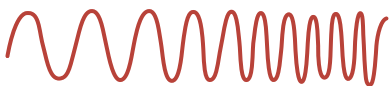
If the auditory system seems complicated, you might think of it as a sensory "relay team." Sound waves are first funneled in by the outer ear, then handed off from the tissue of the eardrum to bones in the middle ear. Mechanical vibrations of these bones are then passed to the cochlea and basilar membrane, where they finally become neural signals, which are, in turn, passed along to the brain. This series of steps transforms commonplace vibrations into experiences as exquisite and varied as music, doorbells, whispers, shouts, and psychology lectures.

Psychological Qualities of Sound: How We Distinguish One Sound from Another No matter where they come from, sounds have only three sensory qualities: *pitch, loudness,* and *timbre.* In the following discussion, we will show you how the two *physical* characteristics of a sound wave (frequency and amplitude) manage to produce these three *psychological sensations.*

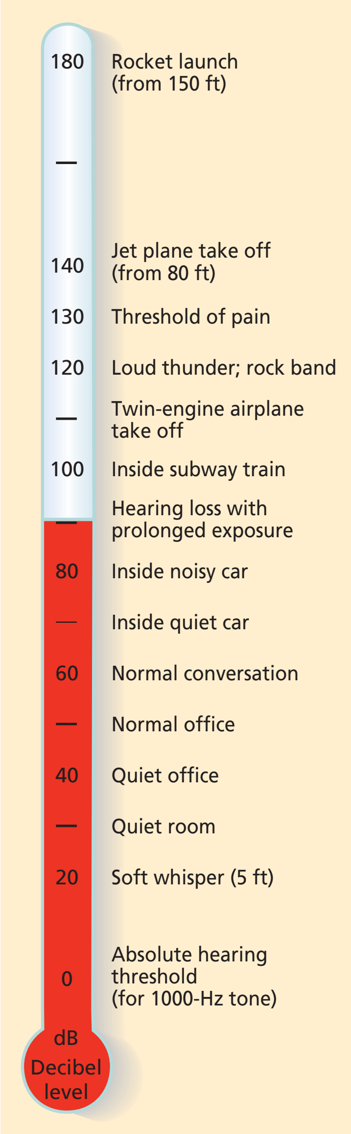
Sensations of Pitch A sound wave's *frequency* determines the highness or lowness of a sound—a quality known as **pitch.** High frequencies produce high pitch, and low frequencies produce low pitch, as you see in Table 4.3. As with light, our sensitivity to sound spans only a limited range of the sound waves that occur in nature. The range of human auditory sensitivity extends from frequencies as low as 20 cps (the lowest range of a subwoofer in a good sound system) to frequencies as high as 20,000 cps (produced by the high-frequency

■ **Pitch** A sensory characteristic of sound produced by the *frequency* of the sound wave.

TABLE 4.3 Auditory Stimulation Becomes Sensation

Physical stimulation	Waveform	Psychological sensation
Amplitude (intensity)	 Loud — Soft	Loudness
Frequency (wavelength)	 Low — High	Pitch
Complexity	 Pure — Rich	Timbre

Pitch and loudness are the psychological counterparts of the frequency and amplitude (intensity) of a sound wave. Frequency and amplitude are characteristics of the physical sound wave, while sensations of pitch and loudness exist only in the brain. In addition, sound waves can be complex combinations of simpler waves. Psychologically, we experience this complexity as *timbre.* Compare this table with Table 4.2 for vision.



● **FIGURE 4.9** Intensities of Familiar Sounds

tweeter in your sound system). Other creatures can hear sounds both higher (in dogs, for example) and lower (in elephants) than we can.

How does the auditory apparatus produce sensations of pitch? Two distinct auditory processes share the task, affording us much greater sensory precision than either could provide alone. Here's what happens:

- When sound waves pass through the inner ear, the basilar membrane vibrates (see Figure 4.8). Different frequencies activate different locations on the membrane. Thus, the pitch one hears depends, in part, on which region of the basilar membrane receives the greatest stimulation. This explanation of pitch perception, known as the *place theory,* says that different *places* on the basilar membrane send neural codes for different pitches to the auditory cortex of the brain—much as keys on different places on a piano keyboard can produce different notes. It turns out that the place theory accounts for our ability to hear high tones—above about 1000 Hz (cycles per second).
- Neurons on the basilar membrane respond with different firing rates for different sound wave frequencies, much as guitar strings vibrating at different frequencies produce different notes. And so, the rate of firing provides another code for pitch perception in the brain. This *frequency theory* explains how the basilar membrane deals with frequencies below about 5000 Hz. (Between 1000 and 5000 Hz, hearing is based on both place and frequency.)

Why is there overlap in the processes described by these two theories—specifically for sounds within the range of 1000 to 5000 Hz? Simple. This is the range of human speech, and our hearing has evolved two different ways of making sure that we are especially sensitive to sounds in this range. And, just to make sure, the auditory canal is shaped to amplify sounds within this speech range.

Sensations of Loudness The **loudness** of a sound is determined by its physical strength or *amplitude* (much as brightness is determined by the intensity of light). More intense sound waves (a shout) produce louder sounds (see Table 4.3), whereas we experience sound waves with small amplitudes (a whisper) as soft. Amplitude, then, refers to the physical sound wave, and loudness is a psychological sensation.

Because we can hear sound waves across a great range of intensity, the loudness of a sound is usually expressed as a ratio rather than an absolute amount. Specifically, sound intensity is measured in units called decibels (dB). Figure 4.9 shows the levels of some representative natural sounds in decibel units.

Sensations of Timbre The bark of a dog, a train whistle, the wail of an oboe, the clink of a spoon in a cup—all sound distinctively different, not just because they have different pitches or loudness but because they are peculiar mixtures of tones. In fact, most natural sound waves are mixtures rather than pure tones (see Figure 4.10). This complex quality of a sound wave is known as **timbre** (pronounced *TAM-b'r*). Timbre is the property that enables you to recognize a friend's voice on the phone or distinguish between the same song sung by different artists.

Now, with all this information about sound in mind, we are in a position to answer an ancient puzzle: If a tree falls in the forest and there is no ear there to hear it, is there a sound? Based on our knowledge of sensory psychology, we can emphatically say, "No." Even though a falling tree makes strong vibrations in the air, we now know that it produces no physical sound because *sound is not a physical phenomenon.* Rather, sound is a purely *psychological sensation* that requires an ear (and the rest of the auditory system) to produce it.

■ **Loudness** A sensory characteristic of sound produced by the *amplitude* (intensity) of the sound wave.

■ **Timbre** The quality of a sound wave that derives from the wave's complexity (combination of pure tones). *Timbre* comes from the Greek word for "drum," as does the term *tympanic membrane,* or eardrum.

■ **Conduction deafness** An inability to hear resulting from damage to structures of the middle or inner ear.

■ **Nerve deafness (Sensorineural Deafness)** An inability to hear, linked to a deficit in the body's ability to transmit impulses from the cochlea to the brain, usually involving the auditory nerve or higher auditory processing centers.

Deafness Deafness is usually one of two types. The first type is called conduction deafness. In **conduction deafness,** the ways in which sound waves are converted to nerve energy have been interfered with or interrupted. Specifically, it is the conduction of the vibrations that has been affected. In most cases, damage has occurred to any of the structures of the middle ear either by sound that has been too loud (see Figure 4.9) or by some sort of trauma. The second type of deafness is called nerve deafness or sensorineural deafness. In **nerve deafness,** there is a problem with how the impulses from the oval window are sent to the brain; in other words, damage has occurred to the auditory nerve or one of the higher auditory processing centers. Most people who are born deaf have this type.

How Are Auditory and Visual Sensations Alike? Earlier we discussed how visual information is carried to the brain by the optic nerve in the form of neural impulses. Now, we find that, in a similar fashion, auditory information is also conveyed to the brain as neural signals—but by a different pathway. So, why do we "see" visual information and "hear" auditory information? As our Core Concept suggested, the answer lies in the region of the cortex receiving the neural message—not on some unique quality of the message itself. In brief, different regions of the brain, when activated, produce different sensations.

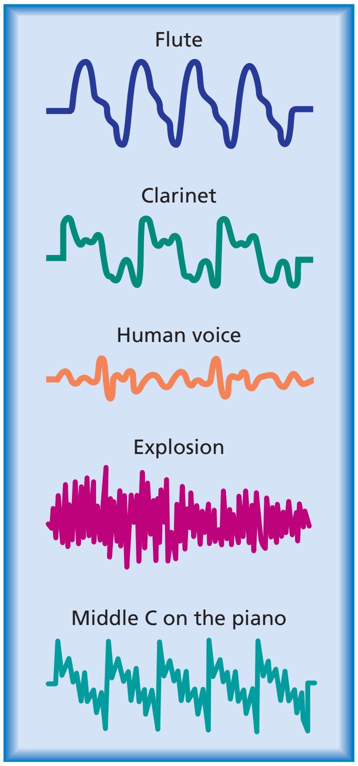


FIGURE 4.10 Waveforms of Familiar Sounds

Each sound is a distinctive combination of several pure tones. (*Source:* From THE SCIENCE OF MUSICAL SOUNDS by D. C. Miller. Reprinted by permission of Case Western Reserve University.)

How the Other Senses Are Like Vision and Hearing

Of all our senses, vision and hearing have been studied the most. However, our survival and well-being depend on other senses, too. So, to conclude this discussion of sensation, we will briefly review the processes involved in our sense of body position and movement, smell, taste, the skin senses, and pain. (See Table 4.4.) You will note that each gives us information about a different aspect of our internal or external environment. Yet each operates on similar principles. Each transduces physical stimuli into neural activity, and each is more sensitive to change than to constant stimulation. And, as was the case with vision and hearing, each of these senses is distinguished by the type of information it extracts and by the specialized regions of the brain devoted to it.

TABLE 4.4 Fundamental Features of the Human Senses

Sense	Stimulus	Sense organ	Receptor	Sensation
Vision	Light waves	Eye	Rods and cones of retina	Colors, brightness, patterns, motion, textures
Hearing	Sound waves	Ear	Hair cells of the basilar membrane	Pitch, loudness, timbre
Skin senses	External contact	Skin	Nerve endings in skin	Touch, warmth, cold
Smell	Volatile substances	Nose	Hair cells of olfactory epithelium	Odors (musky, flowery, burnt, minty, etc.)
Taste	Soluble substances	Tongue	Taste buds of tongue	Flavors (sweet, sour, salty, bitter)
Pain	Many intense or extreme stimuli: temperature, chemicals, mechanical stimuli, etc.	Net of pain fibers all over the body	Specialized pain receptors, overactive or abnormal neurons	Acute pain, chronic pain
Kinesthetic and vestibular senses	Body position, movement, and balance	Semicircular canals, skeletal muscles, joints, tendons	Hair cells in semicircular canals; neurons connected to skeletal muscles, joints, and tendons	Position of body parts in space

Finally, you will see two patterns emerging in the way the senses process information. First, as was the case with vision and hearing, the other senses also make use of only a fraction of the available stimulation. Second, you will find that the senses are built to be especially sensitive to *changes* in stimulation.

Position and Movement To act purposefully and gracefully, we need constant information about where our limbs and other body parts are in relation to each other and to objects in the environment. Without this knowledge, even our simplest actions would be hopelessly uncoordinated. (You have probably had just this experience when you tried to walk on a leg that had "gone to sleep.") The physical mechanisms that keep track of body position, movement, and balance actually consist of two different systems.

The **vestibular sense** is the body position sense that orients us with respect to gravity. It tells us how our bodies—especially our heads—are postured, whether straight, leaning, reclining, or upside down. The vestibular sense also tells us when we are moving or how our motion is changing. The receptors for this information are tiny hairs (much like those we found in the basilar membrane) in the *semicircular canals* of the inner ear (refer again to Figure 4.8). These hairs respond to our movements by detecting corresponding movements in the fluid of the semicircular canals. Disorders of this sense can cause extreme dizziness and disorientation.

The **kinesthetic sense,** the other sense of body position and movement, keeps track of body parts relative to each other. Your kinesthetic sense makes you aware of crossing your legs, for example, and tells you which hand is closer to the telephone when it rings. Kinesthesis provides constant sensory feedback about what the muscles in your body are doing during motor activities, such as whether to continue reaching for your cup of coffee or to stop before you knock it over (Turvey, 1996).

Receptors for kinesthesis reside in the joints, muscles, and tendons. These receptors, as well as those for the vestibular sense, connect to processing regions in the brain's parietal lobes—which help us make a sensory "map" of the spatial relationship among objects and events. This processing usually happens automatically and effortlessly, outside of conscious awareness, except when we are deliberately learning the movements for a new physical skill, such as swinging a golf club or playing an instrument.

Smell The sense of smell, or **olfaction,** involves a chain of biochemical events. First, odors (in the form of airborne chemical molecules) interact with receptor proteins associated with specialized hairs in the nose (Axel, 1995; Buck & Axel, 1991; Mombaerts, 1999). The stimulated nerve cells associated with these hairs (much like the sensitive hairs we found in the inner ear) convey information about the stimulus to the brain's *olfactory bulbs,* where sensations of smell are realized. These olfactory bulbs can be found on the underside of the brain just below the frontal lobes (Mori et al., 1999). (See Figure 4.11.) Unlike all the other senses, smell signals are not relayed through the thalamus, suggesting that smell evolved earlier than the other senses.

In humans, olfaction has an intimate connection with memory: Certain smells, such as a favorite perfume, can evoke emotion-laden memories (Azar, 1998a; Holloway, 1999). Originally, however, smell was probably a system in primitive organisms for detecting and locating food (Moncrieff, 1951). Even today, smell remains a major factor in survival because it helps us detect and avoid potential sources of danger, such as decaying food.

In many animals, the sense of smell is used for communication. For example, insects such as ants and termites and vertebrates such as dogs and cats communicate with each other by secreting and detecting odorous signals called **pheromones**—especially to signal sexual receptivity, danger, territorial bound-

■ **Vestibular sense** The sense of body orientation with respect to gravity. The vestibular sense is closely associated with the inner ear and, in fact, is carried to the brain on a branch of the auditory nerve.

■ **Kinesthetic sense** The sense of body position and movement of body parts relative to each other (also called *kinesthesis*).

■ **Olfaction** The sense of smell.

■ **Pheromones** Chemical signals released by organisms to communicate with other members of their species. Pheromones are often used by animals as sexual attractants. It is unclear whether or not humans employ pheromones.

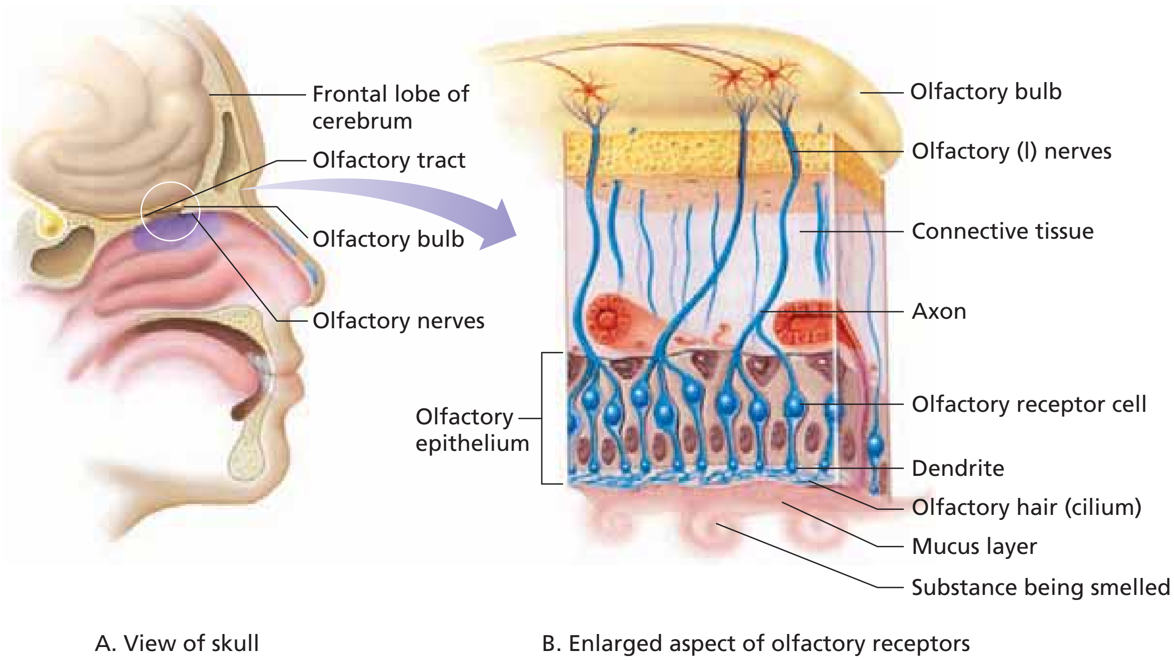


FIGURE 4.11 Receptors for Smell

(*Source:* From PSYCHOLOGY AND LIFE 15th ed. by P. G. Zimbardo and R. J. Gerrig. Copyright © 1999 by Pearson Education. Reprinted by permission of Allyn & Bacon, Boston, MA.)

aries, and food sources. We humans seem to use the sense of smell primarily in conjunction with taste to seek and sample food, but some evidence exists to suggest that people may also use sexual pheromones as well as pheromones that help us identify family members by smell (Azar, 1998b; Filsinger & Fabes, 1985; Holden, 1996b).

Taste Like smell, taste is a sense based on chemistry. But the similarity doesn't end there: The senses of taste and smell have a cooperative working relationship. Many of the subtle distinctions you may think of as flavors really come from odors. (Much of the "taste" of an onion is odor, not flavor.) You will also notice this when you have a cold, which makes food seem tasteless because your nasal passages are blocked and you can't smell the food.

Isolated in the laboratory, the sense of taste, or **gustation,** has long been known to have four main qualities: sweet, sour, bitter, and salty. Recently, however, researchers have identified a fifth taste quality called *umami* (Chaudhari et al., 2000). Umami is the flavor associated with monosodium glutamate (MSG), often used in Asian cuisine. It also occurs naturally in protein-rich foods, such as meat, seafood, and cheese.

The taste receptor cells are gathered in *taste buds,* located on the top and side of the tongue, where they can easily sample the molecules in our food and drink. These receptors cluster in small mucous-membrane projections called *papillae,* shown in Figure 4.12. Individuals vary in their sensitivity to taste sensations, a function of the density of these papillae on the tongue (Bartoshuk et al., 1994). Those with more taste buds for bitter flavors are "supertasters," who are more sensitive than regular tasters or extreme "nontasters," which accounts for supertasters' distaste for certain foods, such as broccoli or "diet" drinks. Supertasters also have a survival advantage, because most poisons are bitter (Bartoshuk, 1993).

Gustation The sense of taste—from the same word root as "gusto"—also called the *gustatory sense.*

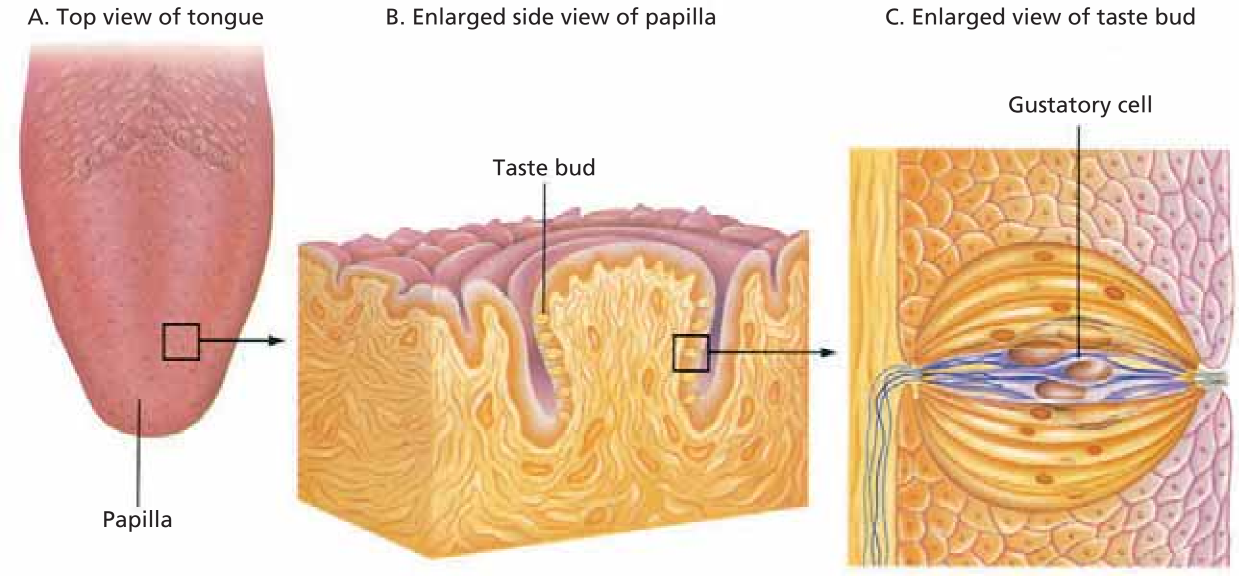


FIGURE 4.12 Receptors for Taste
(A) Distribution of the papillae on the upper side of the tongue; (B) an enlarged view with individual papillae and taste buds visible; (C) one of the taste buds enlarged.

A specialized nerve "hotline" carries nothing but taste messages to the brain. There taste is realized in a specialized region of the parietal lobe's somatosensory cortex. Conveniently for the brain, this area lies next to the patch of cortex that receives touch stimulation from the face (Gadsby, 2000).

Infants have heightened taste sensitivity, which is why you have probably never met a baby who wouldn't cringe at the bitter taste of lemon. This supersensitivity, however, decreases with age. As a result, many elderly people complain that food has lost its taste—which really means that they have lost much of their sensory ability to detect differences in the taste and smell of food. Compounding this effect, taste receptors can be easily damaged by alcohol, smoke, acids, or hot foods. Fortunately, gustatory receptors are frequently replaced (as are the smell receptors). Because of this constant renewal, the taste system is the most resistant to permanent damage of all your senses, and a total loss of taste is extremely rare (Bartoshuk, 1990).

The Skin Senses Consider the skin's remarkable versatility: It protects us against surface injury, holds in body fluids, and helps regulate body temperature. The skin also contains nerve endings that, when stimulated by contact with external objects, produce sensations of touch, warmth, and cold. Like several other senses, these **skin senses** are connected to the somatosensory cortex located in the brain's parietal lobes.

The skin's sensitivity to stimulation varies tremendously over the body, depending in part on the number of receptors in each area. For example, we are ten times more accurate in sensing stimulation on our fingertips than stimulation on our backs. In general, our sensitivity is greatest where we need it most—on our faces, tongues, and hands. Precise sensory feedback from these parts of the body permits effective eating, speaking, and grasping.

One aspect of skin sensitivity—touch—plays a central role in human relationships. Through touch we communicate our desire to give or receive comfort, support, love, and passion (Fisher, 1992; Harlow, 1965; Masters & Johnson, 1966). Touch also serves as a primary stimulus for sexual arousal in humans. And it is essential for healthy mental and physical development; the

Skin senses Sensory systems for processing touch, warmth, cold, texture, and pain.

lack of touch stimulation can stunt mental and motor development (Anand & Scalzo, 2000; Field & Schanberg, 1990; Spitz, 1946).

PSYCHOLOGY IN YOUR LIFE: THE EXPERIENCE OF PAIN

If you are in severe pain, nothing else matters. A wound or a toothache can dominate all other sensations. And if you are among the one-third of Americans who suffer from persistent or recurring pain, the experience can be debilitating and can sometimes even lead to suicide (Wallis, 1984). Yet pain is also part of your body's adaptive mechanism that makes you respond to conditions that threaten damage to your body.

Unlike other sensations, pain can arise from intense stimulation of various kinds, such as a very loud sound, heavy pressure, a pinprick, or an extremely bright light. But pain is not merely the result of stimulation. Many people who were born without a limb or have had a limb amputated feel painful sensations that seem to come from the missing part, often called a *phantom limb* (Ramachandran & Blakeslee, 1998). Neurological studies show that the painful phantom sensations do not originate in damaged nerves in the sensory pathways. Rather, the sensations arise in the brain itself. To understand pain, then, we must understand not only painful sensations but mechanisms in the brain that both process and inhibit pain.

The Gate-Control Theory No one has yet developed a theory that explains everything about pain, but Melzack and Wall's **gate-control theory** (1965, 1983) explains a lot. In particular it explains why pain can sometimes be blocked by analgesic drugs, competing stimuli, as in acupuncture, and even by the mere expectation of treatment effects. Their proposal asserts that pain depends on the relative amount of traffic in two different sensory pathways which carry information from the sense organs to the brain.

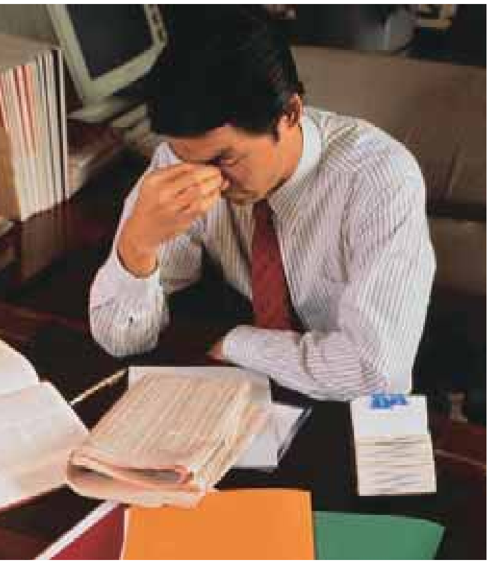
One route, consisting of neurons with a fatty myelin covering on their axons, handles messages quickly; these *fast fibers* deliver most sensory information to the brain. The smaller *slow fibers,* without the fatty sheaths on their axons, send messages more slowly. Very intense stimuli, such as that caused by tissue injury, send strong signals on the slow fibers.

Melzack and Wall hypothesize that competing messages from the fast fibers can block pain messages in the slow fibers. That is, the fast fibers can close a sort of "spinal gate," preventing the slow fibers' messages from reaching the brain. Consequently, the level of pain you experience from a wound results from the combination of information coming through these two pathways. When you hit your finger with a hammer, you automatically try to close the "gate" by vigorously shaking your hand to generate fast-fiber signals that block the pain.

The "gate," itself, probably operates in a brain stem region called the *periaqueductal gray (PAG).* The exact mechanism is unclear, but we do know that pain-blocking opiates and endorphins act on the PAG. There they cause inhibitory neurons to nullify pain messages ascending in the spinal cord (Basbaum et al., 1976; Basbaum & Fields, 1984; Pinel, 2003). Ultimately, pain signals that pass through the gate are routed to the *anterior cingulate cortex,* located along the fissure separating the frontal lobes, where we believe pain to be sensed (Craig & Reiman, 1996; Vogel, 1996).

The spinal gate can be operated top-down by psychological factors, as well. As noted above, we have long known that people's interpretations of events affect whether or not stimuli are perceived as painful (Turk, 1994). For example, soldiers and athletes often suffer severe injuries that cause little pain

■ **Gate-control theory** An explanation for pain control that proposes we have a neural "gate" that can, under some circumstances, block incoming pain signals.



Pain is affected by experience and circumstance. A person who is unhappy may find the pain of a headache unbearable, while another individual, in a more satisfactory job, considers a headache merely annoying.

until the excitement of the battle or contest is over. As we will see in a moment, this mind–body effect on pain is also evident in the action of *placebos* or other sham treatments.

Dealing with Pain Wouldn't it be nice to banish the experience of pain altogether? In reality, such a condition can be deadly. People with congenital insensitivity to pain do not feel what is hurting them, and their bodies often become scarred and their limbs deformed from injuries they could have avoided if their brains were able to warn them of danger. Because of their failure to notice and respond to tissue-damaging stimuli, these people tend to die young (Manfredi et al., 1981). In general, pain serves as an essential defense signal: It warns us of potential harm, and it helps us to survive in hostile environments and to get treatment for sickness and injury.

What can you do if you are in pain? Analgesic drugs, ranging from over-the-counter remedies, such as aspirin and ibuprofen, to prescription narcotics, such as morphine, are widely used and effective. These act in a variety of ways. We have seen that morphine, for example, mimics your body's own pain control substances, the endorphins.

All such drugs—especially the narcotics—can have unwanted side effects. These include addiction or damage to the digestive tract. But, to dispel an old concern, studies have shown that if you must use narcotics to control severe pain, the possibility of your becoming addicted is far less than it would be if you were using narcotics recreationally (Melzack, 1990).

Many people can learn to control pain by psychological techniques, such as hypnosis, deep relaxation, and thought-distraction procedures (Brown, 1998). You may be among those for whom pain can also be modified by *placebos,* mock drugs made to appear as real drugs. For example, a placebo may be an injection of mild saline solution (salt water) or a pill made of sugar. Such fake drugs are routinely given to a control group in tests of new pain drugs. Their effectiveness, of course, involves the people's *belief* that they are getting real medicine. It is important to note, however, that the brain's response to a placebo seems to be essentially the same as that of pain-relieving drugs. Because this **placebo effect** is common, any drug deemed effective must prove itself stronger than a placebo.

But how do placebos produce their effects? Apparently the expectation of pain relief is enough to cause the brain to release painkilling endorphins. We believe this is so because brain scans show essentially the same pain-suppression areas "light up" when patients take placebos or analgesic drugs (Petrovic et al., 2002). Further, we find that individuals who respond to placebos report that their pain increases when they take the endorphin-blocking drug *naltrexone* (Fields, 1978; Fields & Levine, 1984). It is likely that endorphins are responsible for the pain-relieving effects of acupuncture (Price et al., 1984; Watkins & Mayer, 1982).

Pain Tolerance The threshold of pain varies enormously from person to person. One study, for example, found that electric shocks had to be eight times more powerful to produce painful sensations in their least-sensitive subjects as compared with their most-sensitive subjects (Rollman & Harris, 1987). Another experiment found that brain scans of people who are highly sensitive to pain show greater activation of the thalamus and the anterior cingulate cortex than scans of those with greater pain tolerance (Coghill et al., 2003). These findings may explain why some people always demand Novocain at the dentist, while others may prefer dental work without the added hassle of an injection.

Placebo effect A response to a placebo (a fake drug), caused by subjects' belief that they are taking real drugs.

CHECK YOUR UNDERSTANDING

1. **RECALL:** The eyes have two distinct types of photoreceptors: the *rods,* which detect _______, and the *cones,* which detect _______.
   - a. color/brightness
   - b. low-intensity light/wavelengths corresponding to colors
   - c. stimuli in consciousness/stimuli outside of consciousness
   - d. bright light/dim light
   - e. motion/shape

2. **RECALL:** The *wavelength* of light causes sensations of _______, while the *intensity* of light causes sensations of _______.
   - a. depth/color
   - b. primary colors/secondary colors
   - c. color/brightness
   - d. bright light/dim light
   - e. motion/shape

3. **RECALL:** The *frequency theory* best explains _______ sounds, while the place theory best explains _______ sounds.
   - a. tonal/atonal
   - b. simple/complex
   - c. low-pitched/high-pitched
   - d. loud/soft
   - e. pitch/timbre

4. **RECALL:** Which sense makes use of electromagnetic energy?
   - a. hearing
   - b. olfaction
   - c. pain
   - d. taste
   - e. vision

5. **SYNTHESIS:** What do all of these forms of sensation have in common: vision, hearing, taste, smell, hearing, pain, equilibrium, and body position?
   - a. They all involve waves having frequency and amplitude.
   - b. They all arise from stimulation that comes only from outside the body.
   - c. They all involve higher-order perception.
   - d. They all are conveyed to the brain in the form of nerve signals.
   - e. They all involve location of stimulation in three-dimensional space.

6. **UNDERSTANDING THE CORE CONCEPT:** Different senses give us different sensations mainly because
   - a. they activate different sensory regions of the brain.
   - b. they have different intensities.
   - c. they travel on different neural pathways.
   - d. they involve different stimuli.
   - e. we have different memories associated with them.

ANSWERS: 1. b 2. c 3. c 4. e 5. d 6. a

KEY QUESTION

WHAT IS THE RELATIONSHIP BETWEEN SENSATION AND PERCEPTION?

So, we have described how sensory signals have been transduced and transmitted to specific regions of your brain for further processing as visual images, pain, odors, and other sensations. What happens then? To understand what that sensory information means, you must enlist your brain's perceptual machinery. Does a bitter taste mean poison? Does a red flag mean danger? Does a smile signify a friendly overture? The Core Concept of this section emphasizes this perceptual elaboration of sensory information:

CORE CONCEPT

> Perception brings *meaning* to sensation, so perception produces an interpretation of the world, not a perfect representation of it.

In brief, we might say that the task of perception is to extract sensory input from the environment and organize it into stable, meaningful *percepts*. A **percept,** then, is what we perceive: It is not just a sensation but the associated meaning, as well. Not a simple task, perception must identify features of the world that are invariant (fixed and unchanging) by sorting through a continual flood of information. For example, as you move about the room, the sights in the environment create a rapidly changing, blurred sequence of images—yet you remain sure that it is you who are moving, while the objects around you remain stationary. As we study this complex process, we will first discuss how our perceptual apparatus usually manages to give us an accurate image

■ **Percept** The meaningful product of perception—often an image that has been associated with concepts, memories of events, emotions, and motives.

of the world. Then we will look at some illusions and other instances in which perception apparently fails. Finally, we will examine some theories that attempt to identify the most fundamental principles at work behind the scenes in our perceptual processes.

FIGURE 4.13 Who Is This?
Perceptual processes help us recognize Tom Cruise by matching the stimulus to images in memory.

Perceptual Processing: Finding Meaning in Sensation

How does the sensory image of a person (such as the individual pictured in Figure 4.13) become the meaningful percept of someone you recognize? That is, how does mere sensation become an elaborate perception? In the following paragraphs, we will explore some of the physical and mental processes involved in forming perceptions. Let's begin with *feature detectors*—brain cells that operate on the front lines of perceptual processing.

Feature Detectors To help us make perceptual judgments, our brains have specialized groups of cells dedicated to the detection of specific stimulus features, such as length, slant, color, and boundary (Heeger, 1994; Hubel & Wiesel, 1979; Kandel & Squire, 2000; Lettvin et al., 1959; Maunsell, 1995; Zeki, 1992). There is even a part of the occipital lobe containing cells that are especially sensitive to features of the human face (Carpenter, 1999). Perceptual psychologists call such cells **feature detectors.**

Despite our extensive knowledge of feature detectors, we still don't know exactly how the brain manages to combine (or "bind") the multiple features it detects into a single percept of, say, a face. Psychologists call this puzzle the **binding problem,** and it may be the deepest mystery of perceptual psychology (Kandel & Squire, 2000). Yet, a few pieces of this perceptual puzzle may already be in hand: In order to assemble (bind) these pieces into a meaningful percept, the brain apparently synchronizes the firing patterns in different groups of neurons that have each detected different features of an object—much as an orchestra conductor determines the tempo at which all members of the ensemble will play a musical piece (Barinaga, 1998b; Bower, 1998a; Schechter, 1996).

Bottom-Up and Top-Down Processing Perception always involves taking sensory data into the system through receptors and sending it "upward" to the cortex, where a basic analysis, involving the feature detectors, is first performed to determine the characteristics of the stimulus: Is it moving? What color is it? Is it loud, sweet, painful, pleasant smelling, wet, hot . . . ? Often it is these characteristics that determine how we finally perceive an object or event, as when deciding which salsa we want at a Mexican restaurant. Psychologists refer to this as **bottom-up processing.** It is also known as *stimulus-driven processing* because the resulting percept is determined, or "driven," by stimulus features. Other examples include following the motion of a ball, identifying the colors of a flag, and recognizing the sound of a bell. But bottom-up processing is not the only process at work.

A complementary process occurs simultaneously at the "top"—at the highest levels of the cerebral cortex. **Top-down processing** invokes a perceiver's goals, past experience, knowledge, expectations, memory, motivations, or cultural background in the interpretation of an object or event (see Nelson, 1993). You are doing top-down processing when you form a percept based on questions such as these: Will it satisfy my hunger? Is she liberal or conservative? Will that help me get my degree? Because this sort of thinking relies heavily on concepts in the perceiver's own mind, it is also known as *conceptually driven processing.* One more example may clarify what we mean: If you go grocery shopping when you are hungry, top-down processing will probably make you notice ready-to-eat snack foods much more than you would if you had just eaten.

■ **Feature detectors** Cells in the cortex that specialize in extracting certain features of a stimulus.

■ **Binding problem** Refers to the process used by the brain to combine (or "bind") the results of many sensory operations into a single percept. This occurs, for example, when sensations of color, shape, boundary, and texture are combined to produce the percept of a person's face. No one knows exactly how the brain does this. Thus the binding problem is one of the major unsolved mysteries in psychology.

■ **Bottom-up processing** Perceptual analysis that emphasizes characteristics of the stimulus, rather than our concepts and expectations. "Bottom" refers to the stimulus, which occurs at step one of perceptual processing.

■ **Top-down processing** Perceptual analysis that emphasizes the perceiver's expectations, concept memories, and other cognitive factors, rather than being driven by the characteristics of the stimulus. "Top" refers to a mental set in the brain—which stands at the "top" of the perceptual processing system.

(A) (B)

FIGURE 4.14 A Door by Any Other Shape Is Still a Door

(A) A door seen from an angle presents the eye with a distorted rectangle image. (B) The brain perceives the door as rectangular.

Perceptual Constancies We can illustrate another aspect of perception with yet another example of top-down processing. Suppose that you are looking at a door, such as the one pictured in Figure 4.14A. You "know" that the door is rectangular, even though your sensory image of it is distorted when you are not looking at it straight-on. Your brain automatically corrects the sensory distortion, so that you perceive the door as being rectangular, as in Figure 4.14B.

This ability to see an object as being the same shape from different angles or distances is just one example of a **perceptual constancy.** In fact, there are many kinds of perceptual constancies. These include *color constancy*, which enables us to see a flower as being the same color in the reddish light of sunset as in the white glare of midday. *Size constancy* allows us to perceive a person as the same size at different distances and also serves as a strong cue for depth perception. *Shape constancy* is responsible for our ability to see the door in Figure 4.14 as remaining rectangular from different angles. Together these constancies help us identify and track objects in a changing world.

Perceptual Ambiguity and Distortion

A primary goal of perception is to get an accurate "fix" on the world—to recognize friends, foes, opportunities, and dangers. Survival sometimes depends on accurately perceiving the environment, but the environment is not always easy to "read." We can illustrate this difficulty with the photo of black and white splotches in Figure 4.15. What is it? When you eventually extract the stimulus figure from the background, you will see it as a Dalmatian dog walking to the left with its head down. The dog is hard to find because it blends so easily with the background. The same problem occurs when you try to single out a voice against the background of a noisy party.

But it is not just the inability to find an image that causes perceptual problems. Sometimes our perceptions can be wildly inaccurate because we misinterpret an image. This is a common response to stimulus patterns known as *illusions.*

Perceptual constancy The ability to recognize the same object as remaining "constant" under different conditions, such as changes in illumination, distance, or location.

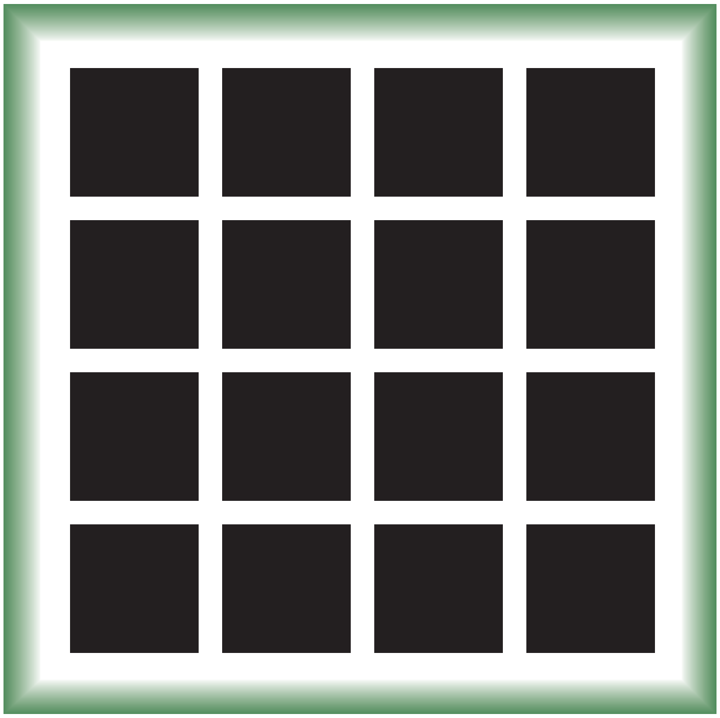
● **FIGURE 4.15** An Ambiguous Picture
What is depicted here? The difficulty in seeing the figure lies in its similarity to the background.

What Illusions Tell Us about Sensation and Perception When your mind deceives you by interpreting a stimulus pattern in a manner that is demonstrably incorrect, you are experiencing an **illusion.** Typically, illusions become more likely when the stimulus is unclear, when information is missing, when elements are combined in unusual ways, or when familiar patterns are not apparent. Such illusions can help us understand some fundamental properties of sensation and perception—particularly the discrepancy between our percepts and external reality (Coren & Girgus, 1978).

■ **Illusion** You have experienced an illusion when you have a demonstrably incorrect perception of a stimulus pattern, especially one that also fools others who are observing the same stimulus. (If no one else sees it the way you do, you could be having a *delusion* or a *hallucination.* We'll take those terms up in a later chapter on mental disorder.)

Let's first examine a remarkable illusion that works at the level of sensation: the black-and-white Hermann grid (Figure 4.16). As you stare at the center of the grid, note how dark, fuzzy spots appear at the intersections of the white bars. But when you focus on an intersection, the spot vanishes. Why? The answer lies in the way receptor cells in your visual pathways interact with

● **FIGURE 4.16** The Hermann Grid
Why do faint gray dots appear at the intersections of the grid? The illusion, which operates at the sensory level, is explained in the text. (*Source:* "The Hermann Grid" from FUNDAMENTALS OF SENSATION & PERCEPTION by M. W. Levine & J. Shefner. Reprinted by permission of Michael W. Levine.)



each other. The firing of certain cells that are sensitive to light–dark boundaries inhibits the activity of adjacent cells that would otherwise detect the white grid lines. This inhibiting process makes you sense darker regions—the grayish areas—at the white intersections just outside your focus. Even though you know the squares in the Hermann grid are black and the lines are white, this knowledge cannot overcome the illusion, which operates at a more basic, sensory level.

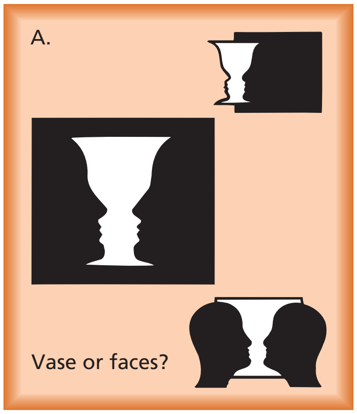
To study illusions at the level of perception, psychologists may employ **ambiguous figures**—stimulus patterns that can be interpreted (top-down) in two or more distinct ways, as in Figures 4.17A and B. Both the vase/faces figure and the Necker cube are designed to confound your interpretations, not just your sensations. Each suggests two conflicting meanings: Once you have seen both, your perception will cycle back and forth between them as you look at the figure. Studies suggest that these alternating interpretations involve the shifting of perceptual control between the left and right hemispheres of the brain (Gibbs, 2001).

Figure 4.18 shows several other illusions thought to operate primarily at the level of perception. All are compelling, and all are controversial—particularly the Müller–Lyer illusion, which has intrigued psychologists for more than 100 years. Disregarding the arrowheads, which of the two horizontal lines in this figure appears longer? If you measure them, you will see that the horizontal lines are exactly the same length. What is the explanation? Answers to that question have been offered in well over a thousand published studies, and psychologists still don't know for sure.

One popular theory, combining both top-down and bottom-up factors, has gathered some support. It suggests that we unconsciously interpret the Müller–Lyer figures as three-dimensional objects. So, instead of arrow heads, we see the ends as angles that project toward or away from us like the inside and outside corners of a building or a room, as in Figure 4.19. The inside corner seems to recede in the distance, while the outside corner appears to extend toward us. Therefore, we judge the outside corner to be closer—and shorter. Why? When two objects make the same size image on the retina and we judge one to be farther away than the other, then we assume that the more distant one is larger.

But what if you had grown up in a culture with no square-cornered buildings? Would you still see one line as longer than the other? In other words, do you have to *learn* to see the Müller–Lyer illusion, or is it "hard-wired" into your brain? The only way to answer such questions is through cross-cultural research. With this in mind, Richard Gregory (1977) went to South Africa to study a group of Zulus who live in what he called a "circular culture." Aesthetically, these people prefer curves to lines and square corners: Their round huts have round doors and windows; they till their fields along curved lines, using curved plows; the children's toys lack straight lines. And, when confronted with the Müller–Lyer, the Zulus saw the lines as nearly the same length. This suggests that the Müller–Lyer illusion is learned. A number of other studies support the conclusion that people who live in "carpentered" environments—where buildings are built with straight sides and 90-degree angles—are more susceptible to the illusion than those who (like the Zulus) live in "noncarpentered" worlds (Segall et al., 1966; Segall et al., 1990; Stewart, 1973).

Applying the Lessons of Illusions Several prominent modern artists, fascinated with the visual experiences created by ambiguity, have used perceptual illusion as a central artistic feature of their work. Consider the two examples of art shown here. *Gestalt Bleue* by Victor Vasarely (see Figure 4.20) produces



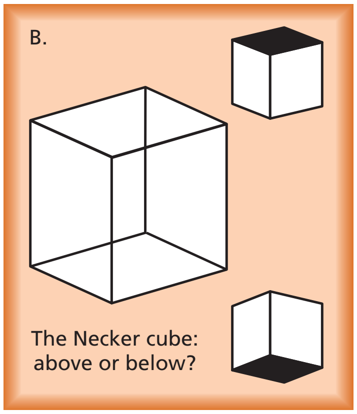


FIGURE 4.17 Perceptual Illusions
These *ambiguous figures* are illusions of perceptual interpretation.

Ambiguous figures Images that are capable of more than one interpretation. There is no "right" way to see an ambiguous figure.

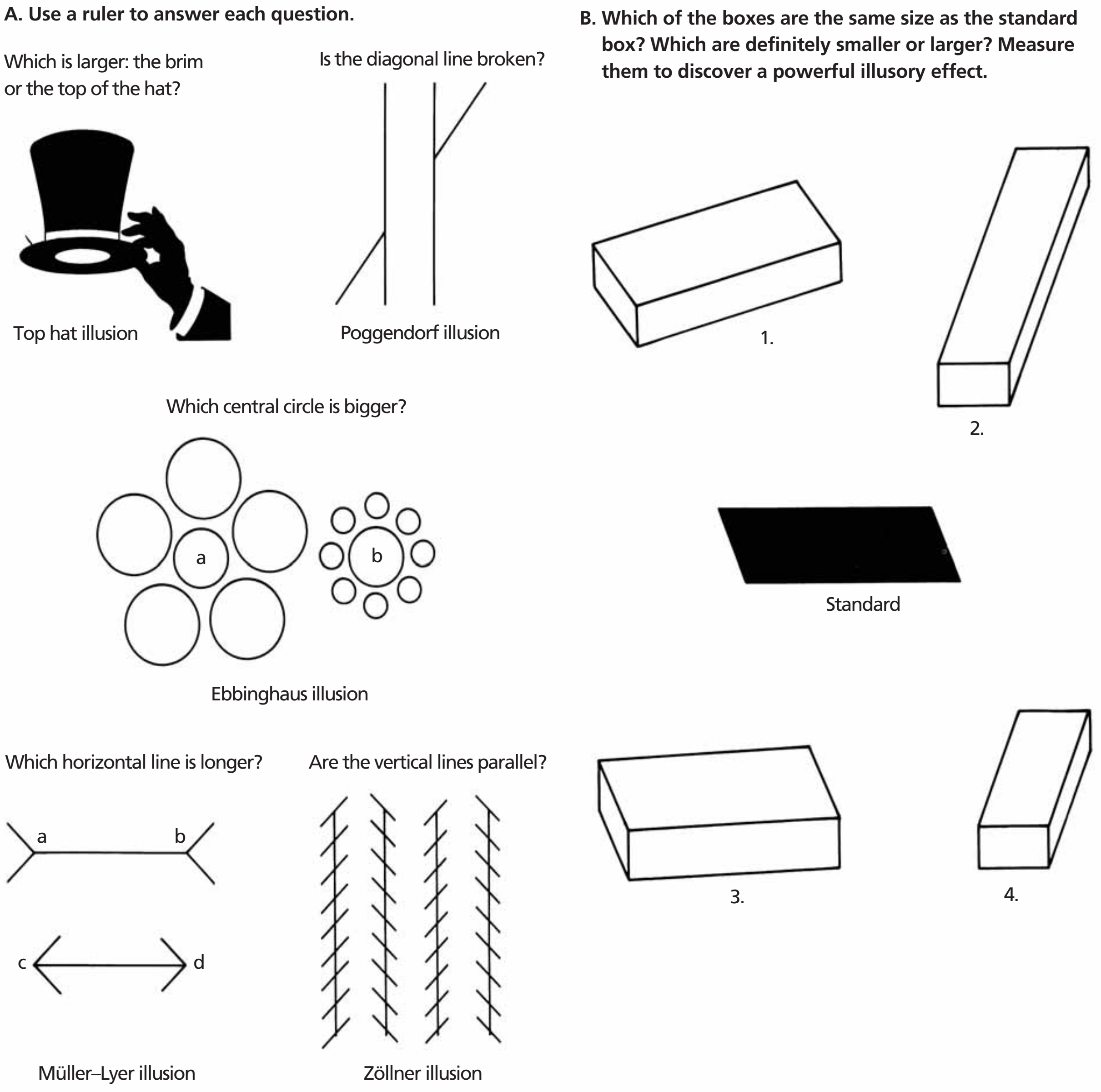
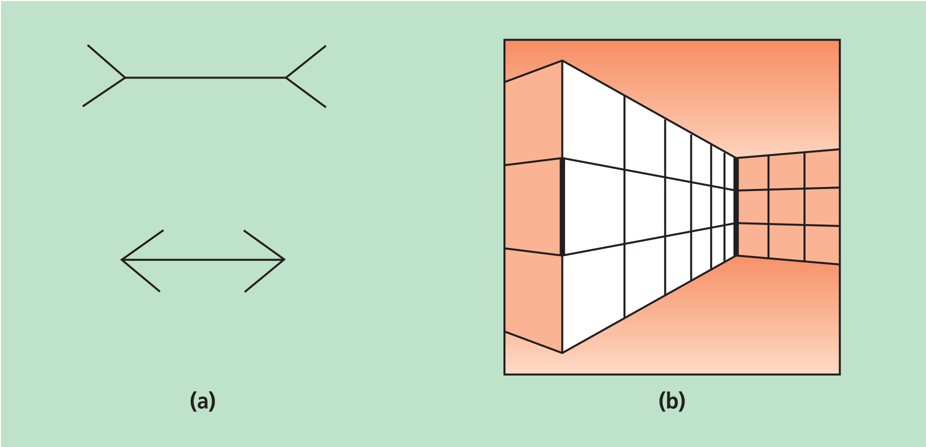


FIGURE 4.18 Five Illusions to Tease Your Brain

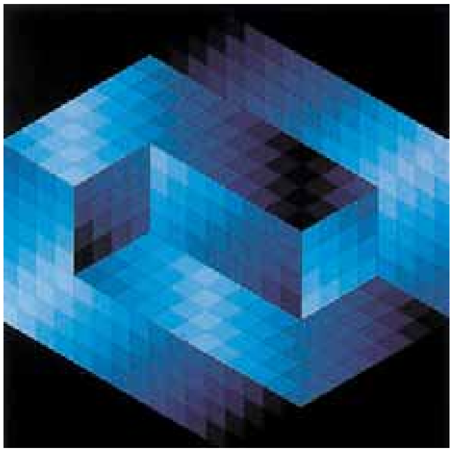
Each of these illusions involves a bad "bet" made by your brain. What explanations can you give for the distortion of reality that each of these illusions produces? Are they caused by nature or nurture?

depth reversals like those in the Necker cube, with corners that alternately project and recede. In *Sky and Water* by M. C. Escher (see Figure 4.21), you can see birds and fishes only through the process of figure–ground reversal, much like the vase/faces illusion we encountered earlier (in Figure 4.17). The effect of these paintings on us underscores the function of human perception to make sense of the world and to fix on the best interpretation we can make.

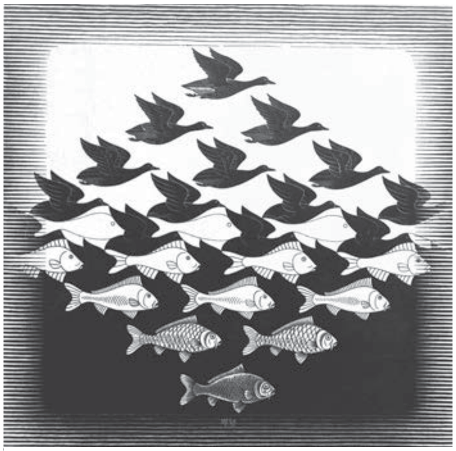
To make sense of such illusions, we draw on our personal experiences, learning, and motivation. Knowing this, those who understand the principles of perception often can control illusions to achieve desired effects far beyond the world of painting. Architects and interior designers, for example, create illusions that make spaces seem larger or smaller than they really are. They



● **FIGURE 4.19** The Müller–Lyer Illusion
One explanation for the Müller–Lyer illusion says that your brain thinks it is seeing the inside and outside corners of a building in perspective.



● **FIGURE 4.20** Victor Vasarely's *Gestalt Bleue*



● **FIGURE 4.21** M. C. Escher's *Sky and Water*

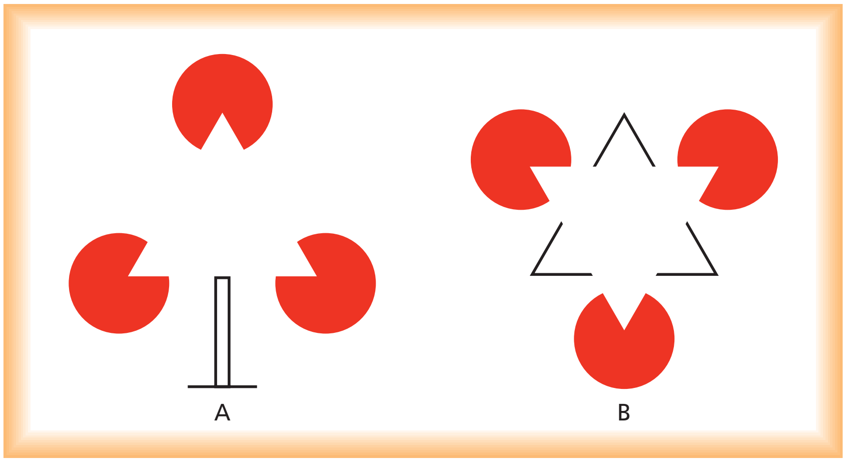
may, for example, make a small apartment appear more spacious when it is painted in light colors and sparsely furnished. Similarly, set and lighting designers in movies and theatrical productions purposely create visual illusions on film and on stage. So, too, do many of us make everyday use of illusion in our choices of cosmetics and clothing (Dackman, 1986). For example, light-colored clothing and horizontal stripes can make our bodies seem larger, while dark-colored clothing and vertical stripes can make our bodies seem slimmer. In these ways, we use illusions to distort "reality" and make our lives more pleasant.

Theoretical Explanations for Perception

The fact that perception is an interpretation and the fact that most people perceive illusions in essentially the same ways suggest that some fundamental psychological principles must be involved. Psychologists looking for these fundamental principles have formulated theories that explain how perception works. Below we will examine two of the classic explanations: the *Gestalt theory* of perception and *learning-based inference*. Although these two approaches may seem contradictory at first, they really emphasize complementary influences on perception. The Gestalt theory emphasizes how we organize incoming stimulation into meaningful perceptual patterns—because of the way our

DO IT YOURSELF! Figure Obscures Ground

The tendency to perceive a figure as being in front of a ground is strong. It is so strong, in fact, that you can even get this effect when the perceived figure doesn't actually exist! You can demonstrate this with an examination of the accompanying figure. You probably perceive a fir-tree shape against a ground of red circles on a white surface. But, of course, there is no fir-tree figure printed on the page; the figure consists only of three solid red shapes and a black-line base. You perceive the illusory white triangle in front because the wedge-shaped cuts in the red circles seem to be the corners of a solid white triangle. To see an illusory six-pointed star, look at part B. Here, the nonexistent "top" triangle appears to blot out parts of red circles and a black-lined triangle, when in fact none of these is depicted as such complete figures. Again, this demonstrates that we prefer to see the figure as an object that obscures the ground behind it. (That's why we often call the ground a "*back*ground.")



Subjective Contours
(A) A subjective fir tree; (B) a subjective 6-pointed star.

brains are innately structured. On the other hand, learning-based inference emphasizes learned influences on perception, including the power of expectations, context, and culture. In other words, Gestalt theory emphasizes nature, and learning-based inference emphasizes nurture. As you will see, we need both perspectives to understand the complexities of perception. Let's begin with Gestalt theory's view of the *nature* of perception.

CONNECTION: CHAPTER 9
The *nature–nurture* issue centers on the relative importance of heredity and environment.

Perceptual Organization: The Gestalt Theory You may have noticed that a series of blinking lights, perhaps on a theater marquee, can create the illusion of motion, where there really is no motion. Similarly, there appears to be a white triangle in the "Do It Yourself!" box below—but there *is* no white triangle. And, as we have seen, the Necker cube seems to flip back and forth between two alternative perspectives—but, of course, the flipping is all in your mind.

About 100 years ago, such perceptual tricks captured the interest of a group of German psychologists, who argued that the brain is innately wired to perceive not just stimuli by *patterns* in stimulation (Sharps & Wertheimer, 2000). They called such a pattern a *Gestalt,* the German word for "perceptual pattern" or "configuration." Thus, from the raw material of stimulation, the brain forms a perceptual whole that is more than the mere sum of its sensory parts (Prinzmetal, 1995; Rock & Palmer, 1990). This perspective became known as **Gestalt psychology.**

CONNECTION: CHAPTER 1
Gestalt psychology was one of the historical schools that competed with behaviorism and structuralism.

The Gestaltists pointed out that we perceive a square as a single figure, rather than merely four individual lines. Similarly, when you hear a familiar song, you do not focus on the individual notes. Rather, your brain extracts the melody, which is your perception of the overall *pattern* of notes. Such examples, the Gestalt psychologists argued, show that we always organize sensory information into meaningful patterns, the most basic of which are already present in our brains at birth. Because this approach has been so influential, we will examine some of the Gestalt discoveries in more detail.

■ **Gestalt psychology** From a German word (pronounced *gush-TAWLT*) that means "whole" or "form" or "configuration." (A Gestalt is also a *percept.*) The Gestalt psychologists believed that much of perception is shaped by innate factors built into the brain.

Figure and Ground One of the most basic of perceptual processes identified by Gestalt psychology divides our perceptual experience into *figure* and *ground.* A **figure** is simply a pattern, or Gestalt, that grabs our attention. Everything else becomes **ground,** the backdrop against which we perceive the figure. A melody becomes a figure heard against a background of complex harmonies, and a spicy pepperoni slice becomes a figure against the ground of cheese, sauce, and bread that make up a pizza. Visually, a figure could be a bright flashing sign or a word on the background of a page. And in the ambiguous faces/vase seen in Figure 4.17A, figure and ground reverse when the faces and vase alternately "pop out" as figure.

In *Weeping Woman,* Picasso challenges our perceptual assumptions by portraying a figure simultaneously from multiple perspectives.

Closure: Filling in the Blanks Our minds seem built to abhor a gap, as you saw in the "Do It Yourself!" box on page 142. Note especially the illusory white triangle—superimposed on red circles and black lines. Moreover, you will note that you have mentally divided the white area into two regions: the triangle and the background. Where this division occurs you perceive *subjective contours:* boundaries that exist not in the stimulus but only in the subjective experience of your mind.

Your perception of these illusory triangles demonstrates a second powerful organizing process identified by the Gestalt psychologists. **Closure** makes you see incomplete figures as wholes by supplying the missing segments, filling in gaps, and making inferences about potentially hidden objects. So, when you see a face peeking around a corner, your mind automatically fills in the hidden parts of the face and body. In general, humans have a natural tendency to perceive stimuli as complete and balanced even when pieces are missing. (Does this ring a ______ with you?) Closure is also responsible for filling in your "blind spot," as you saw on page 122 (Ramachandran, 1992).

In the foregoing demonstrations we have seen how the perception of subjective contours and closure derives from the brain's ability to create percepts out of incomplete stimulation. Now let us turn to the Gestalt laws that explain how we group the stimulus elements that are actually present into Gestalts.

The Gestalt Laws of Perceptual Grouping It's easy to see a school of fish as a single unit—as a Gestalt. But how do we mentally combine hundreds of notes together and perceive them as a single melody? How do we combine the elements of color, shadow, form, texture, and boundary into the percept of a friend's face? And why have thousands of people reported seeing "flying saucers" or the face of Jesus in the scorch marks on a tortilla? That is, how do we pull together in our minds the separate stimulus elements that seem to "belong" together? This is one of the most fundamental problems that the Gestalt psychologists addressed. As we will see, the Gestaltists made great strides in this area, but the basic processes by which perceptual organization works are still debated today (Palmer, 2002). (This problem is closely related to the *binding problem* that we discussed earlier.)

In the heyday of Gestalt psychology, of course, neuroscience was in its infancy, and there were no MRIs or PET scans. Hence, Gestalt psychologists, like Max Wertheimer (1923), had to focus on the problem of perceptual organization in a different way—with arrays of simple figures, such as you see in Figure 4.22. By varying a single factor and observing how it affected the way people perceived the structure of the array, he was able to formulate a set of **laws of perceptual grouping,** which he inferred were built into the neural fabric of the brain.

■ **Figure** The part of a pattern that commands attention. The figure stands out against the ground.

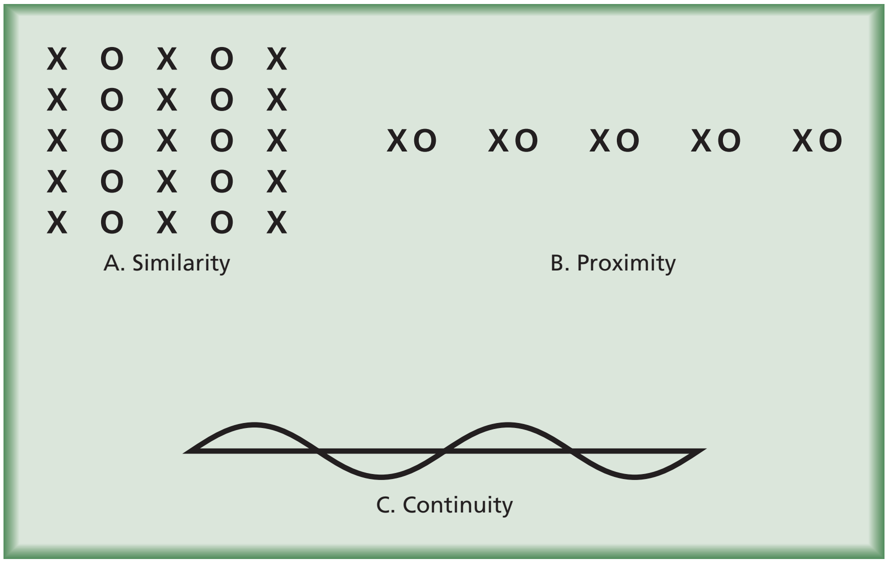
■ **Ground** The part of a pattern that does not command attention; the background.

■ **Closure** The Gestalt principle that identifies the tendency to fill in gaps in figures and to see incomplete figures as complete.

■ **Laws of perceptual grouping** The Gestalt principles of similarity, proximity, continuity, and common fate. These "laws" suggest how our brains prefer to group stimulus elements together to form a percept (Gestalt).

FIGURE 4.22 Gestalt Laws of Perceptual Grouping

(A) Similarity, (B) proximity (nearness), and (C) continuity. In (A) you most easily see the Xs grouped together, while Os form a separate Gestalt. So columns group together more easily than rows. The rows, made up of dissimilar elements, do not form patterns so easily. In (B) dissimilar elements easily group together when they are near each other. In (C), even though the lines cut each other into many discontinuous segments, it is easier to see just two lines—each of which appears to be continuous as a single line cutting through the figure.



According to the **law of similarity,** we group together things that have a similar look (or sound, or feel, and so on). So, when you watch a football game, you use the colors of the uniforms to group the players into two teams because of their similarity, even when they are mixed together during a play. Likewise, in Figure 4.22A you see that the Xs and Os form distinct columns, rather than rows, because of similarity. Any such tendency to perceive things as belonging together because they share common features reflects the law of similarity. You can also hear the law of similarity echoed in the old proverb, "Birds of a feather flock together," which is a commentary not only on human and avian behavior but also on the assumptions we make about perceptual grouping.

Now, suppose that, on one drowsy morning, you mistakenly put on two different-colored socks because they were together in the drawer and you assumed that they were a pair. Your mistake was merely Wertheimer's **law of proximity** (nearness) at work. The proximity principle says that we group things together that are near each other, as you can see in the pairings of the Xs with the Os in Figure 4.22B. On the level of person perception, your parents were invoking the law of proximity when they cautioned you, "You're known by the company you keep."

The Gestalt **law of continuity** can be seen in Figure 4.22C, where the straight line is seen as a single, continuous line, even though it is cut repeatedly by the curved line. In general, the law of continuity says that we prefer smoothly connected and continuous figures to disjointed ones. Continuity also operates in the realm of person perception, where we commonly make the assumption of continuity in the personality of an individual whom we haven't seen for some time. So, despite interruptions in our contact with that person, we will expect to find him or her to be essentially the same person we knew earlier.

There is yet another form of perceptual grouping that we cannot easily illustrate in the pages of a book because it involves motion. But you can easily conjure up your own image that exemplifies the **law of common fate:** Imagine a school of fish, a gaggle of geese, a clowder of cats, or a simply a marching band. When visual elements (the individual fish, geese, cats, or band members) are moving together, you perceive them as a single Gestalt.

According to the Gestalt perspective, each of these examples of perceptual grouping illustrates the profound idea that our perceptions are influenced by

Law of similarity The Gestalt principle that we tend to group similar objects together in our perceptions.

Law of proximity The Gestalt principle that we tend to group objects together when they are near each other. *Proximity* means "nearness."

Law of continuity The Gestalt principle that we prefer perceptions of connected and continuous figures to disconnected and disjointed ones.

Law of common fate The Gestalt principle that we tend to group similar objects together that share a common motion or destination.

innate patterns in the brain. These inborn mental processes, in a top-down fashion, determine the organization of the individual parts of the percept, just as mountains and valleys determine the course of a river. Moreover, the Gestalt psychologists suggested, the laws of perceptual grouping exemplify a more general principle known as the **law of Prägnanz** ("meaningfulness"). This principle states that we perceive the simplest pattern possible—the percept requiring the least mental effort. The most general of all the Gestalt principles, Prägnanz (pronounced *PRAYG-nonce*) has also been called the *minimum principle of perception.* The law of Prägnanz is what makes proofreading so hard to do, as you will find when you examine Figure 4.23. On the other hand, computers are not very good a perceiving patterns, a fact that is exploited by e-mail advertisers to get terms like *C*A*S*H* or *v.i.a.g.r.a* through your computer's "spam" filter undetected.

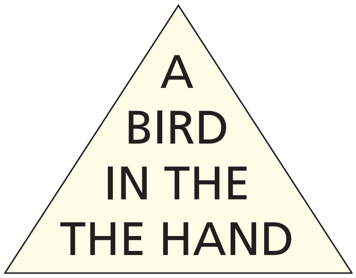


FIGURE 4.23 A Bird in the . . .
We usually see what we expect to see–not what is really there. Look again.

The Nature of Depth Perception Are we born with the ability to perceive depth, or must we learn it? As we will see in our discussion of development in Chapter 11, depth perception appears early, although the idea of being cautious when there is danger of falling seems to develop later in infancy. In a famous demonstration, psychologists Eleanor Gibson and Richard Walk placed infants on a Plexiglas-topped table that appeared to drop off sharply on one end. (See the accompanying photo.) Reactions to the *visual cliff* occurred mainly in infants older than 6 months—old enough to crawl. Most readily crawled across the "shallow" side of the table, but they were reluctant to go over the "edge" of the visual cliff—indicating not only that they could perceive depth but that they associated the drop-off with danger (Gibson & Walk, 1960). Developmental psychologists believe that crawling and depth perception are linked in that crawling helps infants develop their understanding of the three-dimensional world.

Apprehension about the "visual cliff" develops at about the same time an infant is learning to crawl.

Using another technique, Bower (1971) found evidence of depth perception in infants only 2 weeks old. By fitting his subjects with 3-D goggles, Bower produced powerful "virtual reality" images of a ball moving about in space. When the ball image suddenly appeared to move directly toward the infant's face, the reaction was increased heart rate and obvious anxiety. This suggests that some ability for depth perception is probably inborn or heavily influenced by genetic programming that unfolds in the course of early development. Other depth cues must be learned, as we will see. The result is that everyday depth perception in older children and adults involves a combination of cues. Some of these are *binocular cues,* whereas others are *monocular cues*.

Binocular Cues Certain depth cues, the **binocular cues,** depend on the use of two eyes. You can demonstrate this to yourself: Hold one finger about 6 inches from your eyes and look at it. Now move it about a foot farther away. Do you feel the change in your eye muscles as you focus at different distances? This feeling serves as one of the main cues for depth perception when looking at objects that are relatively close. The term for this, *binocular convergence,* suggests how the lines of vision from each eye converge at different angles on objects at different distances.

Another binocular depth cue, *retinal disparity,* arises from the difference in perspectives of the two eyes. To see how this works, hold a finger about 12 inches from your face and look at it alternately with one eye and then with the other. Notice how you see a different view of your finger with each eye. Because we see greater disparity when looking at nearby objects than we do

Law of Prägnanz The most general Gestalt principle, which states that the simplest organization, requiring the least cognitive effort, will emerge as the figure. *Prägnanz* shares a common root with *pregnant,* and so it carries the idea of a "fully developed figure." That is, our perceptual system prefers to see a fully developed Gestalt, such as a complete circle–as opposed to a broken circle.

Binocular cues Information taken in by both eyes that aids in depth perception, including binocular convergence and retinal disparity.

Air pollution has one useful feature: It provides atmospheric perspective, which helps dwellers in cities such as Los Angeles to judge distance. If you can see it clearly, it must be close!

when viewing distant objects, these image differences coming from each eye provide us with depth information.

Monocular Cues for Depth Perception Not all cues for depth perception require both eyes. A one-eyed pilot we know, who manages to perceive depth well enough to maneuver the airplane safely during takeoffs and landings, lives as proof that one-eye cues convey a great deal of depth information. Here are some of the **monocular cues** that a one-eyed pilot (or a two-eyed pilot, for that matter) could learn to use while flying:

- If two objects that are assumed to be the same size cast different-sized images on the retina, observers usually judge them to lie at different distances. So, a pilot flying low can learn to use the *relative size* of familiar objects on the ground as a cue for depth and distance. Because of this cue, automakers who install wide-angle rear-view mirrors always inscribe the warning on them: "Objects in the mirror are closer than they appear."
- Lighter-colored objects seem closer to us, and darker objects seem farther away. Thus, *light and shadow* work together as a distance cue. You will notice this the next time you drive your car at night, with the headlights on: Objects that reflect the most light appear to be nearer than more dimly lit objects in the distance.
- We assume that closer objects will cut off our vision of more distant objects behind them, a distance cue known as *interposition*. So, we know that partially hidden objects are more distant than the objects that hide them. You can see this effect right in front of you now, as your book partially obscures the background, which you judge to be farther away.
- As you move, objects at different distances appear to move through your field of vision at a different rate or with a different *relative motion*. Look for this one from your car window. Notice how the power poles or fence posts along the roadside appear to move by at great speed, while more distant objects stay in your field of view longer, appearing to move by more slowly. With this cue, pilots learn to set up a perfect glide path to landing by adjusting their descent so that the end of the runway appears to stay at a fixed spot on the windshield: More distant points appear to move upward, and everything nearer seems to move downward.
- Haze or fog makes objects in the distance look fuzzy, less distinct, or invisible, creating another learned distance cue called *atmospheric perspective*. In the accompanying photo you can see that more distant buildings lack clarity through the Los Angeles smog. At familiar airports, most pilots have identified a landmark three miles away. If they cannot see the landmark, they know that they must fly on instruments.

Learning-Based Inference: The *Nurture* of Perception In 1866, Hermann von Helmholtz pointed out the important role of learning (or nurture) in perception. His theory of **learning-based inference** emphasized how people use prior learning to interpret new sensory information. Based on this learning, the observer makes *inferences*—guesses or predictions—about what the sensations mean. This theory explains, for example, why you infer a birthday party when you see lighted candles on a cake.

Ordinarily, such perceptual inferences are fairly accurate. On the other hand, we have seen that confusing sensations and ambiguous arrangements

Monocular cues Information about depth that relies on the input of just one eye—includes relative size, light and shadow, interposition, relative motion, and atmospheric perspective.

Learning-based inference The view that perception is primarily shaped by learning (or experience), rather than by innate factors.

can create perceptual illusions and erroneous conclusions. Our perceptual interpretations are, in effect, hypotheses about our sensations. For example, babies learn to expect faces to have certain features in fixed arrangements (pair of eyes above nose, mouth below nose) and that expressions are most easily perceived in the right-side-up arrangement. In fact, we so thoroughly learn about faces in their usual orientation that we fail to "see" facial patterns that violate our expectations. When you look at the two inverted portraits of Britney Spears (Figure 4.24), do you detect any important differences between them? Turn the book upside down for a surprise.

What determines how successful we will be in forming an accurate percept? The most important factors include the *context,* our *expectations,* and our *perceptual set.* We will see that each of these involves a way of narrowing our search of the vast store of concepts in long-term memory.

Quickly scan this photo. Then look away and describe as much as you recall. Turn to page 150 to learn what you, or other perceivers, might not have seen.

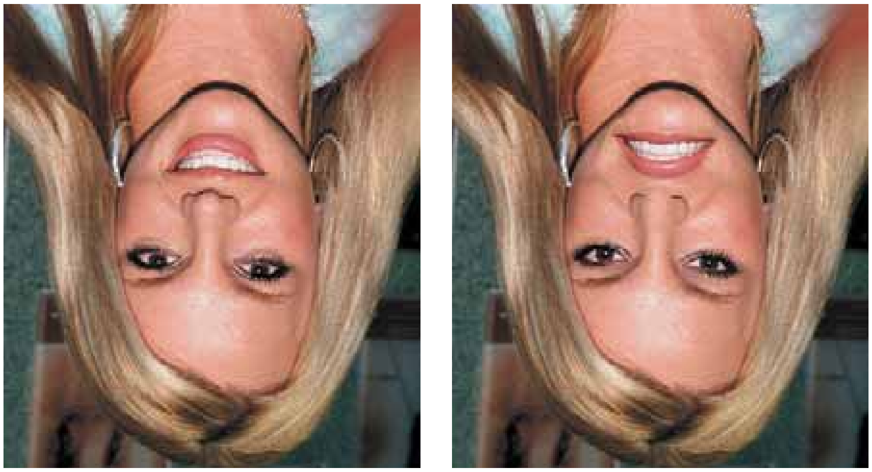
Context and Expectations Once you identify a context, you form expectations about what persons, objects, and events you are likely to experience (Biederman, 1989). For example, you have probably had difficulty recognizing people you know in situations where you didn't expect to see them, such as in a different city or a new social group. This experience undoubtedly made you realize that it is much harder to recognize people outside their usual setting. The problem, of course, is not that they looked different but that the context was unusual: You didn't expect them to be there. Thus, perceptual identification depends on context and expectations as well as on an object's physical properties. To give a more immediate illustration of our expectations being influenced by the context, take a look at the following:

It says THE CAT, right? Now look again at the middle letter of each word. Physically, these two letters are exactly the same, yet you perceived the first as an H and the second as an A. Why? Clearly, your perception was affected by what you know about words in English. The context provided by T__E makes an H highly likely and an A unlikely, whereas the reverse is true of the context of C__T (Selfridge, 1955).

Although context can fool you into misperceiving some stimuli, as in this demonstration, context is an enormously useful cue to identify ambiguous stimuli, such as in recognizing objects in a dimly lit room or deciphering hard-to-read handwriting. So, if you receive a scenic postcard from a friend whose scrawled note describes "having a wonderful time on v____," you rely on context cues to guess that the V-word is probably vacation, and probably not any of the alternatives such as *video, Valium,* or *Venus!*

● **FIGURE 4.24** Two Perspectives on Britney Spears

Although one of these photos clearly has been altered, they look similar when viewed this way. However, turn the book upside down and look again.



Perceptual Set Another way learning serves as a platform from which context and expectation exert an influence on perception involves **perceptual set.** Under the influence of perceptual set we have a readiness to notice and respond to certain stimulus cues—like a sprinter anticipating the starter's pistol. In general, perceptual set involves a focused alertness for a particular stimulus in a given context. For example, a new mother is set to hear the cries of her child. Likewise, if you drive a sporty red car, you probably know how the highway patrol has a perceptual set to notice speeding sporty red cars.

Often, a perceptual set leads you to transform an ambiguous stimulus into the one you were expecting. To experience this yourself, read quickly through the series of words that follow in both rows:

FOX; OWL; SNAKE; TURKEY; SWAN; D?CK
BOB; RAY; DAVE; BILL; TOM; D?CK

Notice how the words in the two rows lead you to read D?CK differently in each row. The meanings of the words read prior to the ambiguous stimulus create a perceptual set. Words that refer to animals create a perceptual set that influences you to read D?CK as "DUCK." Names create a perceptual set leading you to see D?CK as DICK. Yet another illustration of perceptual set appears in the "Do It Yourself!" box "You See What You're Set to See."

Cultural Influences on Perception Cross-cultural psychologists have pointed to other ways that learning influences perception (Deregowski, 1980; Kitayama et al., 2003; Segall, 1994; Segall et al., 1966). Consider, for example, the famous Ponzo illusion, shown in Figure 4.25. In your opinion, which bar is longer: the one on top (marked A) or the one on the bottom (marked B)?

In actuality, both bars are the same length. (If you've developed a skeptical scientific attitude, you'll measure them!) Research shows, however, that responses to these figures depend strongly on culture-related experiences. Most readers of this book will report that the top bar is longer than the bottom bar, yet people from some cultural backgrounds are not so easily fooled. Why the difference?

The world you have grown up in probably included many structures featuring parallel lines that seemed to converge in the distance: long buildings, airport runways, and tunnels. You may even have stood on a straight railroad track and mused how the rails seem to meet at a faraway point. Psychologists call this *linear perspective* (which is yet another distance cue). Such experiences leave you vulnerable to images, such as the Ponzo illusion (see Figure 4.25), in which cues for size and distance are unreliable.

■ **Perceptual set** Readiness to detect a particular stimulus in a given context—as when a person who is afraid interprets an unfamiliar sound in the night as a threat.

DO IT YOURSELF! You See What You're Set to See

Labels create a context that can impose a perceptual set for an ambiguous figure. Have a friend look carefully at the picture of the "young woman" in part A of the accompanying figure, and have another friend examine the "old woman" in part B. (Cover the other pictures while they do this.) Then have them look together at part C. What do they see? Each will probably see something different, even though it's the same stimulus pattern. Prior exposure to the picture with a specific label will usually affect a person's perception of the ambiguous figure.

(A) Young woman (B) Old woman (C) Now what do you see?

But what about people from cultures where individuals have had far less experience with this cue for distance? Research on this issue has been carried out on the Pacific island of Guam, where there are no Ponzolike railroad tracks (Brislin, 1974, 1993). There, too, the roads are so winding that people have few opportunities to see roadsides "converge" in the distance. People who have spent their entire lives on Guam, then, presumably have fewer opportunities to learn the strong perceptual cue that converging lines indicate distance.

And, sure enough—just as researchers had predicted—people who had lived all their lives on the island of Guam were less influenced by the Ponzo illusion than were respondents from the mainland United States. That is, they were less likely to report that the top line in the figure was longer. These results strongly support the argument that people's experiences affect their perceptions—as Helmholz had theorized. Another example of how culture can affect perception comes from an experiment with Zulu tribes in Africa. In 1966, Segall, Campbell, and Herskovitz conducted an experiment in which they showed the Müller–Lyer illusion similar to that shown on page 141 (see Figure 4.19) to some Zulu tribes in Africa. At that time, the Zulu people they were testing lived in round huts with arched doorways. The people they tested were not as affected by the illusion as people living in Western cultures with lots of buildings and angles. Segall et al. argued that living in a "circular culture" affected perception.

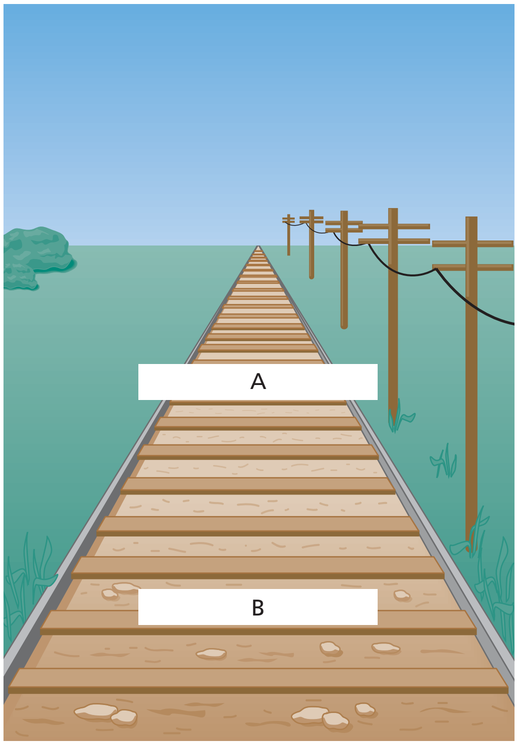


FIGURE 4.25 The Ponzo Illusion
The two white bars superimposed on the railroad track are actually identical in length. Because A appears farther away than B, we perceive it as longer.

Which of the two theories about perception that we have been discussing—Helmholtz's learning theory or the Gestaltists' innate theory—is correct? Both of them are. That is, our perceptual processes show the influence of both nature and nurture. Although both theories emphasize top-down processes, Gestalt theory proposes that the brain is innately disposed to influence perception in specific ways. But we can also say with confidence that perception is influenced by experience and learning, as Helmholtz concluded.

Attention is a key component of sensation and perception. Without attention and attentional processes, all the sensations in the world will not mean a thing. In fact, sensation and perception without attention are just light and noise. Think about being in a class and just drifting off. If the teacher is saying something important, and you are not paying attention, the information is gone. You sensed it, you even perceived that the teacher was talking, but because you were not paying attention, all of the body's automatic sensation and perception activities went for naught. In order for sensation and perception to have any value, there *must* be attention as well.

PSYCHOLOGY IN YOUR LIFE: SEEING AND BELIEVING

Magicians count on the difference between appearance and reality.

If you assume, as most people do, that your senses give you an accurate and undistorted picture of the outside world, you are mistaken (Segall et al., 1990). Magicians, who base their careers on the difference between appearance and reality, count on fooling people for whom "seeing is believing." And you may have noticed that politicians and marketing experts rely on influencing people's interpretations of events, as well. So we hope that this chapter has shaken your faith in your senses and perceptions . . . just a bit.

Unlike magicians, politicians, and advertisers, perceptual psychologists are happy to reveal how sensation and perception play tricks on all of us (Hyman, 1989). They have developed a number of demonstrations that show how your vivid impressions of the world are really highly processed and interpreted images. We have already seen this in many visual illusions presented in the chapter. But, to drive the point home, consider this statement (which, unfortunately, was printed backwards):

.rat eht saw tac ehT

Please turn it around in your mind: What does it say? At first most people see a sensible sentence that says, "The cat saw the rat." But take another look. The difficulty lies in the power of expectations to shape your interpretation of stimulation.

This demonstration illustrates once again that we don't merely *sense* the world as it is, we *perceive* it. The goal of the process by which stimulation becomes sensation and, finally, perception is to find meaning in our experience. But it is well to remember that we impose our own meanings on sensory experience.

Differences in the ways we interpret our experiences explain why two people can look at the same sunset, the same presidential candidates, or the same religions and perceive them so differently. Perceptual differences make us unique individuals. An old Spanish proverb makes the point elegantly:

En este mundo traidor
No hay verdad ni mentira;
Todo es según el color
Del cristál con que se mira.

In this treacherous world
There is neither truth nor lie;
All is according to the color
Of the lens through which we spy.

Did you see a woman committing suicide in the photo entitled "The Moment before Death" on page 147? Most people have difficulty identifying the falling woman in the center of the photo because of the confusing background and because they have no perceptual schema that makes them expect to see a person positioned horizontally in midair.

CHECK YOUR UNDERSTANDING

1. **RECALL:** Which of the following is an example of the kind of information that top-down processing contributes to perception?
   - **a.** looking for a friend's face in a crowd
   - **b.** constructing an object from memory
   - **c.** hearing a painfully loud noise
   - **d.** feeling a pinprick
   - **e.** having to wait for your eyes to adjust to the dark in a theater

2. **RECALL:** The illusion in the Hermann grid (Figure 4.16) operates at the level of
   - **a.** figure and ground.
   - **b.** perception.
   - **c.** sensation.
   - **d.** stimulation.
   - **e.** the subconscious.

3. **RECALL:** The Gestalt theory proposes that many of our perceptions are determined by
   - **a.** ambiguity.
   - **b.** bottom-up factors.
   - **c.** top-down factors.
   - **d.** illusions.
   - **e.** innate factors.

4. **RECALL:** The faces/vase image (in Figure 4.17A) illustrates
   - **a.** closure.
   - **b.** attention as a gateway to consciousness.
   - **c.** figure and ground.
   - **d.** interposition
   - **e.** similarity.

5. **APPLICATION:** When two close friends are talking, other people may not be able to follow their conversation because it has many gaps, which the friends can mentally fill in from their shared experience. Which Gestalt principle is illustrated by the friends' ability to fill in these conversational gaps?
   - **a.** ambiguity
   - **b.** similarity
   - **c.** closure
   - **d.** common fate
   - **e.** proximity

6. **UNDERSTANDING THE CORE CONCEPT:** Which of the following best illustrates the idea that perception is not an exact internal copy of the world?
   - **a.** the Ponzo illusion
   - **b.** a bright light
   - **c.** jumping in response to a pinprick
   - **d.** bottom-up processing
   - **e.** the sound of a familiar tune

ANSWERS: 1. a 2. c 3. e 4. c 5. c 6. a

SENSATION AND PERCEPTION: THE STATE OF THE ART

After more than a century of study, the details of sensation are pretty well known. Perception, on the other hand, has its murky spots. The one great, indisputable finding of perceptual psychology is this: Perception is not a duplicate of reality. And its corollary is the fact that most people still believe that their senses and perceptions don't deceive them. In addition, we know many specifics about the psychology of perception, as identified by Helmholtz, the Gestalt psychologist, and others following in their traditions. It's in the basic neuroscience of perception that the great gaps in our knowledge occur. In particular, the binding problem—the puzzle of how stimulus features, memories, and emotions are combined into a single percept—remains one of psychology's deepest mysteries.

USING PSYCHOLOGY TO LEARN PSYCHOLOGY

Studying for the Gestalt

One of the most mistaken notions about studying and learning is that students should set aside a certain amount of time for study every day. This is not to suggest that you shouldn't study regularly. Rather, it is to say that you shouldn't focus on just putting in your time. So where should you place your emphasis? (And what does this have to do with perceptual psychology?)

Recall the concept of *Gestalt*, the idea of the meaningful pattern, encountered in this chapter. The Gestalt psychologists taught that we have an innate tendency to understand our world in terms of meaningful patterns. Applied to your studying, this means that your emphasis should be on finding meaningful patterns—Gestalts—in your course work.

In this chapter, for example, you will find that your authors have helped you by dividing the material into three major sections. You can think of each section as a conceptual Gestalt, built around a Core Concept that ties it together and gives it meaning.

The psychological message is this: Organize your study around meaningful units of material. That is, identify a major concept or section of your book, and study that until it makes sense.

And forget about the clock.

CHAPTER SUMMARY

KEY QUESTION CORE CONCEPT

HOW DOES STIMULATION BECOME SENSATION?

The most fundamental step in sensation involves the transduction by the sense organs of physical stimuli into neural messages, which are sent onward in the sensory pathways to the appropriate part of the brain for further processing. Sensory adaptation occurs when the senses discontinue processing unchanging stimuli.

Not all stimuli become sensations, because some fall below the absolute threshold. Further, changes in stimulation are noticed only if they exceed the difference threshold, making a just-noticeable difference (JND). Classical psychophysics focused on identifying thresholds for sensations and for just-noticeable differences, but a newer approach, called signal detection theory, explains sensation as a process involving context, physical sensitivity, and judgment. And while subliminal perception of stimuli near the absolute threshold is possible under certain conditions, there is no evidence that it has been—or could be—used successfully in the mass media.

The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.

HOW ARE THE SENSES ALIKE? AND HOW ARE THEY DIFFERENT?

All the senses involve transduction of physical stimuli into nerve impulses. In vision, photoreceptors in the retina transduce light waves into neural codes, which retain frequency and amplitude information. This visual information is then transmitted by the optic nerve to the brain's occipital lobes, which converts the neural signals into sensations of color and brightness. Both the trichromatic theory and the opponent process theory are required to explain how visual sensations are extracted. Vision makes use of only a tiny "window" in the electromagnetic spectrum.

In the ear, sound waves in the air are transduced into neural energy in the cochlea and then sent on to the brain's temporal lobes, where frequency and amplitude information are converted to sensations of pitch, loudness, and timbre. Neither our sensations of light or sound are properties of the original stimulus but are creations of the brain.

Other senses include position and movement (the vestibular and kinesthetic senses), smell, taste, the skin senses (touch, pressure, and temperature), and pain. Like vision and hearing, these other senses are especially attuned to detect changes in stimulation. Further, all sensation is carried to the brain by neural impulses, but we experience different sensations because the impulses are processed by different sensory regions of the brain.

The experience of pain can be the result of intense stimulation in any of several sensory pathways. While we don't completely understand pain, the gate-control theory explains how pain can be suppressed by competing sensations or other mental processes. Similarly, the ideal analgesic—one without unwanted side effects—has not been discovered, although placebos work exceptionally well for some people.

The senses all operate in much the same way, but each extracts different information and sends it to its own specialized sensory processing region in the brain.

WHAT IS THE RELATIONSHIP BETWEEN SENSATION AND PERCEPTION?

There is no exact dividing line between sensation and perception, but psychologists define perception as the stage at which meaning is attached to sensation. We derive meaning from "bottom-up" stimulus cues picked up by feature detectors and from "top-down" processes, especially those involving expectations. What remains unclear is how the brain manages to combine the output of many sensory circuits into a single percept: This is called the binding problem.

By studying illusions and constancies, researchers can learn about the factors that influence and distort the construction of perceptions. Illusions demonstrate that perception does not necessarily form an accurate representation of the outside world.

Perception has been explained by theories that differ in their emphasis on the role of innate brain processes versus learning—nature versus nurture. The Gestalt theory emphasizes innate factors that help us organize stimulation into sensation. In particular, the Gestaltists have described the processes that help us distinguish figure from ground, to identify contours and apply closure, and to group stimuli according to similarity, proximity, continuity, and common fate. Some aspects of depth perception, such as retinal disparity and convergence, may be innate as well. The theory of learning-based inference also correctly points out that perception is influenced by experience, such as context, perceptual set, and culture. Many aspects of depth perception, such as relative motion and atmospheric perspective, seem to be learned.

Despite all we know about sensation and perception, many people uncritically accept the evidence of their senses (and perceptions) at face value. This allows magicians, politicians, and marketers an opening through which they can manipulate our perceptions and, ultimately, our behavior.

● **Perception brings *meaning* to sensation, so perception produces an interpretation of the world, not a perfect representation of it.**

REVIEW TEST

For each of the following items, choose the single correct or best answer. The correct answers appear at the end.

1. What is the process that converts physical energy, such as sound waves, into neural signals?
   a. conduction
   b. kinesthesis
   c. sensory adaptation
   d. transduction
   e. psychophysics

2. Luisa agrees to look after her friends' new baby while they run an errand. Luisa tries to read with the stereo on but keeps listening for signs that the baby might be crying in the bedroom. Several times, Luisa thinks she can hear whimpering—but when she checks the baby, she usually finds her sound asleep. Which of the following best explains why Luisa's sensations are not always accurate?
   a. classical absolute threshold theory
   b. signal detection theory
   c. the law of Prägnanz
   d. Steven's power law
   e. Weber's law

3. Which of these sensory structures does not belong with the others?
   a. visual cortex
   b. rods
   c. retina
   d. ganglion cells
   e. basilar membrane

4. Place theory and frequency theory are explanations for processes involved in the sensation of
   a. different olfactory stimuli.
   b. the hue created by a light's wavelength.
   c. the pitch of sound.
   d. tactile stimuli.
   e. the timbre of sound.

5. Which one of the following is the only sense that does not relay information through the thalamus?
   a. the vestibular sense
   b. audition
   c. olfaction
   d. vision
   e. kinesthesis

6. At a crime scene, a detective finds a slip of paper with three symbols printed on it in ink. She cannot identify the source of the figures or which orientation is up. Thus she cannot determine whether the figures are the numbers 771 or the letters ILL. Because she has to guess at the meaning of the figures, her perception of them is
   a. bottom-up.
   b. data-driven.
   c. perception-driven.
   d. stimulus-driven.
   e. top-down.

7. Which one of the following is most commonly experienced when a stimulus is ambiguous, information is missing, elements are combined in unusual ways, or familiar patterns are not apparent?
   a. proximity
   b. a correct rejection
   c. a false alarm
   d. common fate
   e. an illusion

8. According to Gestalt explanations of how perceptual processes work, when a person encounters an unfamiliar collection of stimuli, he or she will try to
   a. analyze each stimulus component separately to ascertain its meaning.
   b. assemble the parts into a meaningful whole or pattern that makes sense.
   c. compartmentalize their findings.
   d. judge whether each stimulus matches a familiar signal.
   e. make guesses about its symbolism until finding a matching concept.

9. Research has shown that cultural factors can influence people's perception of
   a. distance.
   b. sensory adaptation.
   c. pitch.
   d. timbre.
   e. subliminal stimulation.

10. Although the markings in the ceiling tiles are of all different shapes and sizes, you notice that larger, darker spots seem to stand out against a background made up of smaller, lighter ones. Which principle of perceptual grouping explains this distinction?
    a. the principle of closure
    b. the law of common fate
    c. the law of Prägnanz
    d. the law of proximity
    e. the law of similarity

ANSWERS: 1.d 2.b 3.e 4.c 5.c 6.e 7.e 8.b 9.a 10.e

KEY TERMS

Sensation (p. 110)
Perception (p. 111)
Transduction (p. 112)
Sensory adaptation (p. 113)
Absolute threshold (p. 114)
Difference threshold (p. 114)
Just noticeable difference (JND) (p. 115)
Weber's law (p. 115)
Fechner's law (p. 115)
Steven's power law (p. 115)
Signal detection theory (p. 116)
Retina (p. 119)
Photoreceptors (p. 119)
Rods (p. 120)
Cones (p. 120)
Fovea (p. 120)
Optic nerve (p. 120)
Blind spot (p. 121)
Brightness (p. 121)
Color (p. 123)
Electromagnetic spectrum (p. 123)
Visible spectrum (p. 123)
Trichromatic theory (p. 124)
Opponent-process theory (p. 124)
Afterimages (p. 124)
Color blindness (p. 124)
Frequency (p. 126)
Amplitude (p. 126)
Tympanic membrane (p. 126)
Cochlea (p. 126)
Basilar membrane (p. 126)
Pitch (p. 127)
Loudness (p. 128)
Timbre (p. 128)
Conduction deafness (p. 128)
Nerve deafness (p. 128)
Vestibular sense (p. 130)
Kinesthetic sense (p. 130)
Olfaction (p. 130)
Pheromones (p. 130)
Gustation (p. 131)
Skin senses (p. 132)
Gate-control theory (p. 133)
Placebo effect (p. 134)
Percept (p. 135)
Feature detectors (p. 136)
Binding problem (p. 136)
Bottom-up processing (p. 136)
Top-down processing (p. 136)
Perceptual constancy (p. 137)
Illusion (p. 138)
Ambiguous figures (p. 139)
Gestalt psychology (p. 142)
Figure (p. 143)
Ground (p. 143)
Closure (p. 143)
Laws of perceptual grouping (p. 143)
Law of similarity (p. 144)
Law of proximity (p. 144)
Law of continuity (p. 144)
Law of common fate (p. 144)
Law of Prägnanz (p. 145)
Binocular cues (p. 145)
Monocular cues (p. 146)
Learning-based inference (p. 146)
Perceptual set (p. 148)

AP* REVIEW: VOCABULARY

Match each of the following vocabulary terms to its definition.

1. Sensation
2. Transduction
3. Sensory adaptation
4. Absolute threshold
5. Difference threshold
6. Trichromatic theory
7. Opponent-process theory
8. Feature detectors
9. Closure
10. Law of proximity

_____ **a.** Loss of responsiveness in receptor cells after stimulation has remained unchanged for a while.

_____ **b.** The smallest amount by which a stimulus can be changed and the difference be detected 50% of the time.

_____ **c.** The Gestalt principle that we tend to group objects together when they are near each other.

_____ **d.** The Gestalt principle that we tend to fill in gaps in figures and to see incomplete figures as complete.

_____ **e.** The idea that cells in the visual system process colors in complementary pairs, such as red or green or as yellow or blue.

_____ **f.** The process by which simulation of a sensory receptor produces neural impulses that the brain interprets as a sound, a visual image, an odor, a taste, a pain, or other sensory image.

_____ **g.** Cells in the cortex that specialize in extracting certain features of a stimulus.

_____ **h.** The amount of stimulation necessary for a stimulus to be detected 50% of the time.

_____ **i.** The idea that colors are sensed by three different types of cones sensitive to light in the red, blue, and green wavelengths.

_____ **j.** Transformation of one form of energy into another—especially, the transformation of stimulus information into nerve signals by the sense organs.

KEY 1.f 2.j 3.a 4.h 5.b 6.i 7.e 8.g 9.d 10.c

AP* REVIEW: ESSAY

Use your knowledge of the chapter concepts to answer the following essay question.

A common thread among all sensory modalities involves both sensation and perception. In a concise discussion, define and describe how each of the following applies to a sensory modality of your choice:

a. receptor
b. sensation
c. transduction
d. perception
e. resultant behavior

OUR RECOMMENDED BOOKS AND VIDEOS

BOOKS

Ackerman, D. (1990). *A natural history of the senses.* New York: Vintage. Poet Diane Ackerman's essays discuss smell, touch, taste, hearing, vision, and synesthesia (experiencing a sensation in the "wrong" sense, such as feeling a color or seeing a sound). The book is vivid and inspiring as well as informative.

Cytowic, R. L. (1998). *The man who tasted shapes.* Cambridge, MA: MIT Press. One in 100,000 people experience *synesthesia,* a condition of blended sensory perceptions: Different tastes have distinctive shapes, musical notes have color and form. Better understood than ever before, synesthesia demonstrates the active exploration of the brain and the literally memorable experiences of synesthetes themselves.

Sacks, O. (1998). *The island of the colorblind.* New York: Vintage Books. The latest by the author of *The Man Who Mistook His Wife for a Hat* and *An Anthropologist on Mars,* this fascinating, touching, and funny book describes Sacks's journey to a small island in Micronesia, where all the residents are colorblind yet experience and describe their world with richness, vividness, and acceptance.

Sheldrake, R. (2003). *The sense of being stared at: And other aspects of the extended mind.* New York: Crown Publishing. In a previous work, Rupert Sheldrake explored whether some dogs know when their owners are coming home. Here he extends his interest in supersensory awareness, examining people's claims of "knowing" when others are about to call them; parents' sensitivity to absent children's experiences; or, as the title suggests, our awareness of being watched and studied.

VIDEOS

Immortal Beloved. (1994, color, 125 min.). Directed by Bernard Rose; starring Gary Oldman, Jeroen Krabbe, Isabella Rossellini, Johanna Ter Steege. Ludwig van Beethoven's late-life deafness is explained in this musically rich biography, focusing on the question of the identity of the composer's great love. A few scenes are stunning to both watch and hear, a nice change from films with forgettable scores and soundtracks. (*Rating R*)

Rashomon. (1950, black-and-white, 88 min.; Japanese). Directed by Akira Kurosawa; starring Toshiro Mifune. A classic film by a master director, *Rashomon* tells the tale of a rape and murder from the perspectives of four very different witnesses, illustrating the intertwining of perception with motivation and emotion. What you see and remember is what you expect, based on your perception of the world—and of yourself. (*Rating PG-13*)