chapter five

Sensation and Perception

CHAPTER OUTLINE

Myth or Reality?

Subliminal Stimuli Can Program Our Minds (page 133)

Need to improve your study habits? Quit smoking? Enhance your sex life? Many people try subliminal programming as a means to self-improvement. Subliminal stimuli can be embedded in advertisements and political ads. How much can stimuli that don't register in awareness influence our thoughts, attitudes, and behaviors?

> I walked up to an ice cream vendor and asked what flavors she sold. But she answered in such a tone that a whole pile of coals, of black cinders, came bursting out of her mouth and I couldn't bring myself to buy any ice cream after she answered that way.

Nature gives us a marvelous set of sensory connections with our world. If our sense organs are not defective, we experience light waves as colors and levels of brightness, air vibrations as sounds, pressure as touch sensations, chemical substances as colors or tastes, and so on. However, such is not the case for people with a rare condition called **synesthesia,** *which means, quite literally, "mixing of the senses"* (Cytowic, 2002; Harrison & Baron-Cohen, 1997). Individuals with synesthesia may experience sounds as colors or tastes as touch sensations of different shapes. One man reported that when he listens to an orchestra, he doesn't just hear music; he also sees it. The sounds of a violin trigger a shiny rich burgundy color, like a red wine, whereas a cello's music produces a flowing golden yellow hue, like honey (CNN, 2009, February 9).

Russian psychologist A. R. Luria (1968) studied a highly successful writer and musician whose life was a perpetual stream of mixed-up sensations. On one occasion, Luria asked him to report on his experiences while listening to electronically generated musical tones. In response to a medium-pitched tone, the man experienced a brown strip with red edges, together with a sweet and sour flavor. A very high-pitched tone evoked the following sensation: "It looks something like a fire-works tinged with a pink-red hue. The strip of color feels rough and unpleasant, and it has an ugly taste—rather like that of a briny pickle. . . . You could hurt your hand on this." Mixed sensations like these frequently occurred in the man's daily life, and they were sometimes disconcerting, as in his description of his encounter with the ice cream vendor.

How is it possible for sensory experience to become so jumbled, for sensory input to somehow get routed to the wrong parts of the brain? The answer to this question is not fully understood, but its answer will require knowledge of the sensory systems—what stimulates them, how they operate, and how sensory input is sent to the brain and transformed into the perceptual experiences we take so much for granted. By the time you finish this chapter, you'll be able to answer many of these questions.

People who experience synesthesia provide glimpses into different aspects of how we sense and understand our world. These processes, previewed in Figure 5.1, begin when specific types of stimuli activate specialized sensory receptors. Whether the stimulus is light, sound waves, a chemical molecule, or pressure, your sensory receptors must translate the information into the only language your nervous system understands: the language of nerve impulses. This process is called *transduction*. Once this translation occurs, specialized neurons called *feature detectors* break down and analyze the specific features of the stimulus. At the next stage, these numerous stimulus features are reconstructed into a neural representation that is then compared with previously stored information, such as our knowledge of how particular objects look, smell, or feel. This matching of a new stimulus with our internal storehouse of knowledge allows us to recognize the stimulus and give it meaning. We then consciously experience a perception.

How does this process help us understand the mysterious mixing of the senses in synesthesia? We know that specific parts of the brain are specialized for different sensory functions. In people with synesthesia, there is some sort of cross-wiring, so that activity in one part of the brain evokes responses in another part of the brain dedicated to another sensory modality

(Ward, 2008). Functional MRI studies have shown that for people with synesthesia with word-color linkages, hearing certain words is associated with neural activity in parts of the visual cortex. This does not occur in people without synesthesia, even if they are asked to imagine colors in association with certain words (Nunn et al., 2002).

Several explanations have been offered for the sensory mixing (Cytowic & Eagleman, 2009; Hubbard & Ramachandran, 2005). One theory is that the pruning of neural connections that occurs in infancy has not occurred in people with synesthesia, so that brain regions retain connections that are absent in most people. In support of this theory, diffusion tensor imaging, which lights up white matter pathways in the brain, has revealed increased connectivity in patients with synesthesia (Rouw & Scholte, 2007). Another theory is that with synesthesia, there is a deficit in neural inhibitory processes in the brain that ordinarily keep input from one sensory modality from "overflowing" into other sensory areas and stimulating them.

Whatever the processes involved, both normal perceptual processes and synesthesia relate to one of the big mysteries in cognitive neuroscience called the "binding problem." How do we bind all of our perceptions into one complete whole while keeping its sensory elements separate? When you hold a rose in your hand, see its colored petals, feel their velvety quality, and smell its aroma, these disparate sensory experiences are somehow fused into your total experience of the rose. People with synesthesia may create additional perceptions of that rose that are inconsistent with its physical properties.

In some ways, sensation and perception blend together so completely that they are difficult to separate, for the stimulation we receive through our sense organs is instantaneously organized and transformed into the experiences that we refer to as perceptions. Nevertheless, psychologists do distinguish between them. **Sensation** *is the stimulus-detection process by which our sense organs respond to and translate environmental stimuli into nerve impulses that are sent to the brain.* **Perception**—*making "sense" of what our senses tell us—is the active process of organizing this stimulus input and giving it meaning* (Mather, 2006; May, 2007).

Because perception is an active and creative process, the same sensory input may be perceived in different ways at different times. For example, read the two sets of symbols in Figure 5.2. The middle symbols in both sets are exactly the same, and they sent identical input to your brain, but you probably perceived them differently. Your interpretation, or perception, of the characters was influenced by their context—that is, by the characters that preceded and followed them and by your learned expectation of what normally follows the letter A and the number 12. This is a simple illustration of how perception takes us a step beyond sensation.

SENSORY PROCESSES

The particular stimuli to which different animals are sensitive vary considerably. The sensory equipment of any species is an adaptation to the environment in which it lives. Many species have senses that humans lack altogether. Carrier pigeons, for example, use the earth's magnetic field to find their destination on cloudy nights when they can't navigate by the stars. Sharks sense electric currents leaking through the skins of fish hiding in undersea crevices, and rattlesnakes find their prey by detecting infrared radiation given off by small rodents. Whatever the source of stimulation, its energy must be converted into nerve impulses, the only language the nervous system understands (Liedtke, 2006). **Transduction** *is the process whereby the characteristics of a stimulus are converted into nerve impulses.* We now consider the range of stimuli to which humans and other mammals are attuned and the manner in which the various sense organs carry out the transduction process.

As a starting point, we might ask how many senses there are in humans. Certainly there appear to be more than the five classical senses: vision, audition (hearing), gustation (taste), olfaction (smell), and touch. For example, there are senses that provide information about balance and body position. Also, the sense of touch can be subdivided into separate senses of pressure,

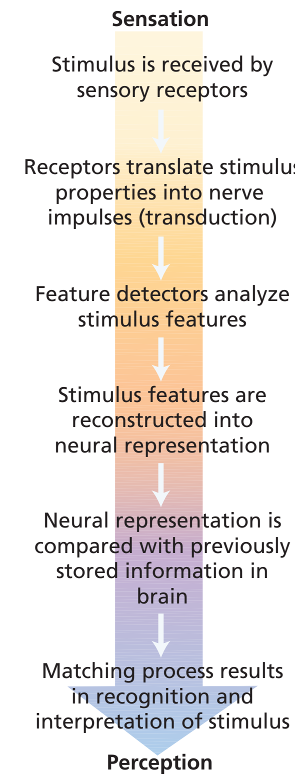


Figure 5.1

Sensation becomes perception. Sensory and perceptual processes proceed from the reception and translation of physical stimuli into nerve impulses. Then occurs the active process by which the brain receives the nerve impulses, organizes and confers meaning on them, and constructs a perceptual experience.

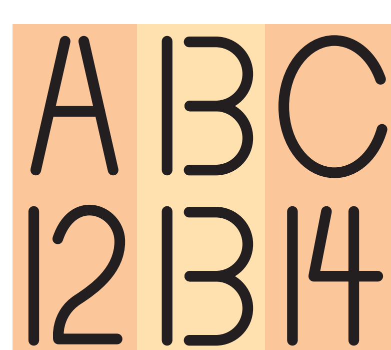


Figure 5.2

Context and perception. Quickly read these two lines of symbols out loud. Did your perception of the middle symbol in each line depend on the symbols that surrounded it?

pain, and temperature. Receptors deep within the brain monitor the chemical composition of our blood. The immune system also has sensory functions that allow it to detect foreign invaders and to receive stimulation from the brain.

Like those of other organisms, human sensory systems are designed to extract from the environment the information that we need to function and survive. Although our survival does not depend on having eyes like eagles or owls, noses like bloodhounds, or ears as sensitive as those of the worm-hunting robin, we do have specialized sensors that can detect many different kinds of stimuli with considerable sensitivity. The scientific area of **psychophysics,** *which studies relations between the physical characteristics of stimuli and sensory capabilities,* is concerned with two kinds of sensitivity. The first concerns the absolute limits of sensitivity. For example, what is the dimmest light, the faintest sound, or the weakest salt solution that humans can detect? The second kind of sensitivity has to do with differences between stimuli. What is the smallest difference between two tones that we can detect?

Stimulus Detection: The Absolute Threshold

How intense must a stimulus be before we can detect its presence? Researchers answer this question by systematically presenting stimuli of varying intensities to people and asking whether they can detect them. Researchers designate the **absolute threshold** *as the lowest intensity at which a stimulus can be detected 50 percent of the time.* Thus the lower the absolute threshold, the greater the sensitivity. From studies of absolute thresholds, we can estimate the general limits of human sensitivity for the five major senses. Some examples are presented in Table 5.1. As you can see, many of our absolute thresholds are surprisingly low. Yet some other species have sensitivities that far surpass those of humans. For example, a female silkworm moth who is ready to mate needs to release only a billionth of an ounce of an attractant chemical molecule per second to attract every male silkworm moth within a mile's radius.

At one time, scientists thought that although some people have greater sensory acuity than others, each person has a more or less fixed level of sensitivity for each sense. But psychologists who study stimulus detection found that an individual's apparent sensitivity can fluctuate quite a bit. The concept of a fixed absolute threshold is inaccurate because there is no single point on the intensity scale that separates nondetection from detection of a stimulus. There is instead a range of uncertainty, and people set their own **decision criterion,** *a standard of how certain they must be that a stimulus is present before they will say they detect it.* The decision criterion can also change from time to time, depending on such factors as fatigue, expectation (e.g., having watched a horror movie), and the potential significance of the stimulus. **Signal-detection theory** *is concerned with the factors that influence sensory judgments.*

In a typical signal-detection experiment, participants are told that after a warning light appears, a barely perceptible tone may or may not be presented. Their task is to tell the experimenter whether or not they hear the tone. Under these conditions, there are four possible outcomes, as shown in Figure 5.3. When the tone is in fact presented, the participant may say "yes" (a hit) or "no" (a miss). When no tone is presented, the participant may also say "yes" (a false alarm) or "no" (a correct rejection).

At low stimulus intensities, both the participant's and the situation's characteristics influence the decision criterion (Colonius & Dzhafarov, 2006; Methot & Huitema, 1998). Bold participants who frequently say "yes" have more hits, but they also

Table 5.1 Some Approximate Absolute Thresholds for Humans

Sensory Modality	Absolute Threshold
Vision	Candle flame seen at 30 miles on a clear, dark night
Hearing	Tick of a watch under quiet conditions at 20 feet
Taste	1 teaspoon of sugar in 2 gallons of water
Smell	1 drop of perfume diffused into the entire volume of a large apartment
Touch	Wing of a fly or bee falling on a person's cheek from a distance of 1 centimeter

Source: Based on Galanter, 1962.

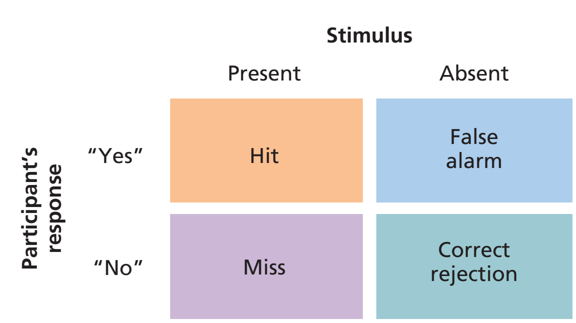


Figure 5.3

Signal-detection research.
This matrix shows the four possible outcomes in a signal-detection experiment in which participants decide whether a stimulus has been presented or not presented. The percentages of responses that fall within each category can be affected by both characteristics of the participants and the nature of the situation.

have more false alarms than do conservative participants. Researchers can influence participants to become bolder or more conservative by manipulating the rewards and costs for giving correct or incorrect responses. Increasing the rewards for hits or the costs for misses results in lower detection thresholds (more "yes" responses at low intensities). Thus a Navy radar operator may be more likely to notice a faint blip on her screen during a wartime mission—when a miss could have disastrous consequences—than during a peacetime voyage. Conversely, like physicians who will not perform a risky medical procedure without strong evidence to support their diagnosis, participants become more conservative in their "yes" responses as costs for false alarms are increased, resulting in higher detection thresholds (Irwin & McCarthy, 1998). Signal-detection research shows us that perception is, in part, a decision.

What happens when stimuli register in the nervous system but cannot be consciously perceived? Can they nonetheless affect our behavior? Is this myth or reality?

The Difference Threshold

Distinguishing between stimuli can sometimes be as important as detecting stimuli in the first place. When we try to match the colors of paints or clothing, small stimulus differences can be very important. Likewise, a slight variation in taste might signal that food is tainted or spoiled. Professional wine tasters and piano tuners make their living by being able to make subtle discriminations.

The **difference threshold** *is defined as the smallest difference between two stimuli that people can perceive 50 percent of the time.* The difference threshold is sometimes called the *just noticeable difference (jnd).* German physiologist Ernst Weber discovered in the 1830s that there is some degree of lawfulness in the range of sensitivities within our sensory systems. **Weber's law** *states that the difference threshold,*

Myth or Reality? Subliminal Stimuli Can Program Our Minds

Not all stimuli register in awareness. A **subliminal stimulus** *is one that is so weak or brief that although it is received by the senses, it cannot be perceived consciously.* (*Limen* is another term for absolute threshold.) There is little question that within certain ranges, subliminal stimuli can register in the nervous system (Kihlstrom, 2008). But can such stimuli program our minds without our awareness, thereby influencing our behavior? A multimillion-dollar business builds on this belief (Figure 5.4), a belief that is widely accepted—by 85 percent of college students in one survey (Taylor & Kowalski, 2004).

The answer to these questions appears to be yes—to a limited extent. For example, in a procedure called *priming*, researchers flash words or pictures on a display so briefly that they are seen only as a brief flash of light; they then assess the effects on various aspects of behavior. In one study, graduate students were asked to generate research ideas. They were then exposed to subliminal visual stimuli showing either the smiling face of a friendly professor they knew or the scowling face of their research supervisor. Without knowing why, those who saw the scowling face rated their own research ideas less favorably (Epley et al., 1999).

Interest (and concerns) about subliminal programming of behavior goes back a long way. In the late 1950s, James Vicary, a public relations executive, arranged to have subliminal messages flashed on a theater screen during a movie. The messages urged the audience to drink Coca-Cola and eat popcorn. Vicary's claim that the subliminal messages increased popcorn sales by 50 percent and soft drink sales by 18 percent aroused a public furor. Consumers and scientists feared the possible abuse of subliminal messages to covertly influence the buying habits of consumers. Government agencies were concerned such messages might be used for mind-control and brainwashing

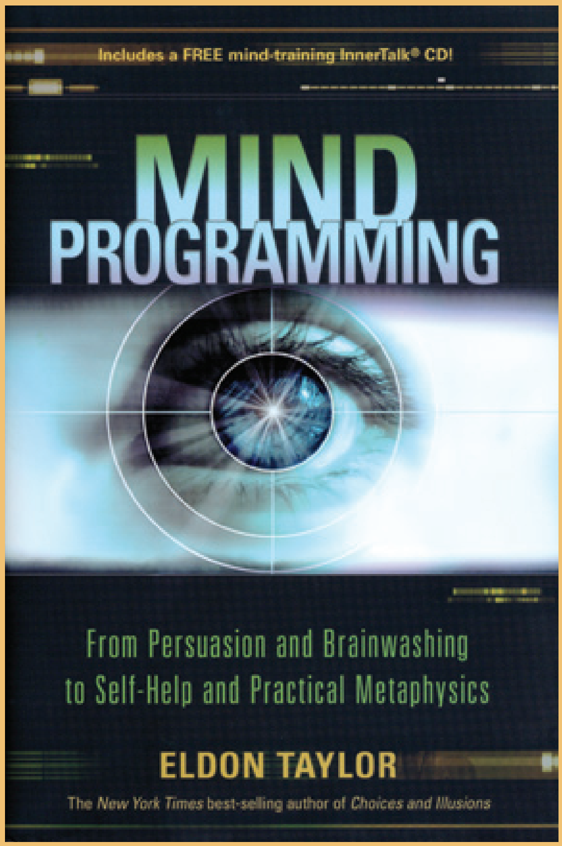


Figure 5.4
Subliminal self-improvement is a thriving industry.

Continued

purposes. The National Association of Broadcasters reacted by outlawing subliminal messages on American television. Canada soon followed suit.

The outcries were, in large part, false alarms. Several attempts to reproduce Vicary's results under controlled conditions failed, and many other studies conducted in laboratory settings, on TV and radio, and in movie theaters indicated that there is little reason to be concerned about significant or widespread control of consumer behavior through subliminal stimulation (Dixon, 1981; Durkin, 1998). Years later, Vicary admitted that his study was a hoax, designed to revive his foundering advertising agency. However, his false report did stimulate a great deal of useful research on the power of subliminal stimuli to influence behavior. Where consumer behavior is concerned, the conclusion is that persuasive stimuli above the perceptual threshold are far more influential than are subliminal attempts to sneak into our subconscious mind. Nonetheless, subliminal messages may have at least short-term behavioral effects if they are relevant to a person's momentary goal state. Thirsty participants exposed to subliminal Lipton Ice messages showed an increased desire for that drink relative to thirsty controls who saw other words, but the message had no effect on non-thirsty participants (Karremans et al., 2006).

Although subliminal stimuli cannot control consumer behavior, research suggests that such stimuli do affect more subtle phenomena, such as perceptions and attitudes (Greenwald & Banaji, 1995; Kihlstrom, 2008). In one study, college students who were exposed to subliminal presentations of aggressively toned words like *hit* and *attack* later judged ambiguous behaviors of others as more aggressive. They also were more likely to behave aggressively than were participants who had been exposed to subliminal nonaggressive words (Todorov & Bargh, 2002). There is little doubt that subliminal stimuli can also have subtle effects on attitudes, judgments, and behavior. Perhaps this explains the motivation behind a Republican attack ad shown on television during the 2000 presidential campaign. In the ad, criticizing the health care reform plan proposed by Al Gore and running mate Joseph Lieberman, a very brief subliminal flash of the word *RATS* was closely associated in time with images of Gore and Lieberman (Figure 5.5). When the image was discovered through a frame-by-frame analysis of the ad, Democrats cried foul and accused the Republicans of waging subliminal warfare against their candidates. The ad's producer denied any wrongdoing, claiming that the word's appearance was simply a production error in which a fragment of the word *BUREAUCRATS*, which also appeared in the ad (but in much smaller letters), had mysteriously found its way into the finished product. Technical experts declared that explanation most unlikely (Della Sala, 2007).

Would you like to improve your self-concept, program yourself for success, enhance your sex life, or quit smoking? Many people believe that subliminal methods can also be a means to

Figure 5.5

This subliminal frame was embedded in a 2000 political ad attacking the Gore-Lieberman proposal to reform health care.

self-improvement by programming the unconscious mind to guide one's adaptive behavior. To test the efficacy of subliminal self-improvement, Anthony Greenwald and coworkers (1991) purchased two commercially marketed subliminal tapes, one for memory improvement, the other to increase self-esteem. They then recruited participants who said they wanted to improve in one of those areas and gave them memory and self-esteem tests. Each person seeking memory improvement was then given a subliminal tape labeled "memory improvement" and told to use it once a day for a month. Similarly, the self-esteem seekers were each given a tape labeled "self-esteem improvement." Unbeknownst to the participants, however, half of each group actually received the other tape.

A month later, the researchers brought the people back and retested them on the memory and self-esteem measures. Theoretically, if change were being produced by the subliminal messages, people should improve only in the area addressed by the tape they actually heard. But that's not what the researchers found. Participants improved in both areas, but self-esteem improvement was actually greater for those who listened to the memory-improvement tape, and those who listened to the self-esteem tape improved more in memory than they did in self-esteem. Thus the power of an expectancy, or a placebo effect, explains the results better than does the power of subliminal programming of the unconscious mind. Although subliminal products may appeal to some people as a relatively effortless way to change, they remain unproven scientifically, especially in comparison with other behavior-change methods (Lilienfeld et al., 2010). Personally, we have much greater faith in the effectiveness of the techniques presented in this book's "Applying Psychological Science" features, because they're backed by scientific evidence.

Table **5.2** **Weber Fractions for Various Sensory Modalities**

Sensory Modality	Weber Fraction
Audition (tonal pitch)	1/333
Vision (brightness, white light)	1/60
Kinesthesis (lifted weights)	1/50
Pain (heat produced)	1/30
Audition (loudness)	1/20
Touch (pressure applied to skin)	1/7
Smell (India rubber)	1/4
Taste (salt concentration)	1/3

Source: Based on Teghtsoonian, 1971.

or jnd, is directly proportional to the magnitude of the stimulus with which the comparison is being made and can be expressed as a *Weber fraction.* For example, the jnd value for weights is a Weber fraction of approximately 1/50 (Teghtsoonian, 1971). This means that if you lift a weight of 50 grams, a comparison weight must be at least 51 grams in order for you to be able to judge it as heavier. If the weight were 500 grams, a second weight would have to be at least 510 grams (i.e., 1/50 = 10 g/500 g) for you to discriminate between them.

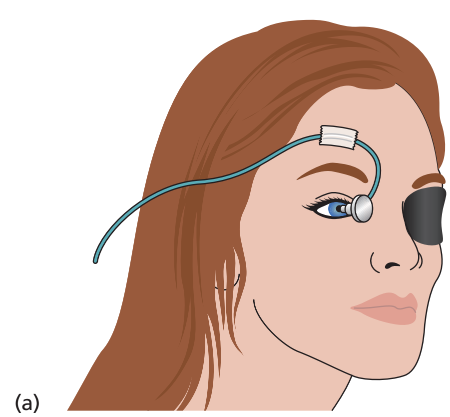
Although Weber's law breaks down at extremely high and low intensities of stimulation, it holds up reasonably well within the most frequently encountered range, thereby providing a useful barometer of our abilities to discern differences in the various sensory modalities. Table 5.2 lists Weber fractions for the various senses. The smaller the fraction, the greater the sensitivity to differences. As highly visual creatures, humans show greater sensitivity in their visual sense than they do in, for example, their sense of smell. Undoubtedly many creatures who depend on their sense of smell to track their prey would show quite a different order of sensitivity. Weber fractions also show that humans are highly sensitive to differences in the pitch of sounds but far less sensitive to loudness differences.

Sensory Adaptation

From a survival perspective, it's important to know when some new development requires your attention. If you were relaxing outdoors, you would want to be aware of the whine of an approaching mosquito. Because changes in our environment are usually noteworthy, sensory systems are finely attuned to changes in stimulation (Rensink, 2002). Sensory neurons are engineered to respond to a constant stimulus by decreasing their activity, and *the diminishing sensitivity to an unchanging stimulus is called* **sensory adaptation.**

Adaptation (sometimes called *habituation*) is a part of everyday experience. After a while, monotonous background sounds are largely unheard. The feel of your wristwatch against your skin recedes from awareness. When you dive into a swimming pool, the water may feel cold at first because your body's sensors respond to the change in temperature. Over time, however, you become used to the water temperature.

Adaptation occurs in all sensory modalities, including vision. Indeed, were it not for tiny involuntary eye movements that keep images moving about the retina, stationary objects would simply fade from sight if we stared at them. In an ingenious demonstration of this type of adaptation, R. M. Pritchard (1961) attached a tiny projector to a contact lens worn by each participant (Figure 5.6a). This procedure guaranteed that visual images presented through the projector would maintain a constant position on the retina, even when the eye moved. When a stabilized image was projected through the lens onto the retina, participants reported that the image appeared in its entirety for a time and then began to vanish and reappear as parts of the original stimulus (Figure 5.6b).



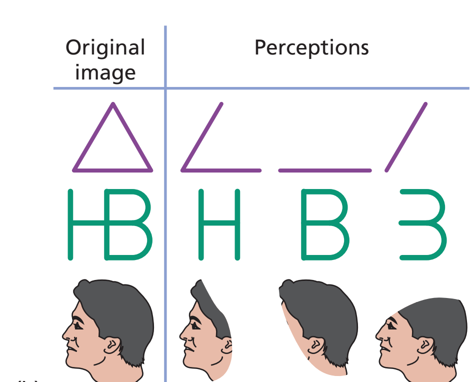


Figure 5.6

Demonstrating visual adaptation. (a) To create a stabilized retinal image, a person wears a contact lens to which a tiny projector has been attached. Despite tiny eye movements, images are cast on the same region of the retina. (b) Under these conditions, the stabilized image is clear at first and then begins to fade and reappear in meaningful segments as the receptors fatigue and recover.
Source: Adapted from Pritchard, 1961.

Although sensory adaptation may reduce our overall sensitivity, it is adaptive, for it frees our senses from the constant and the mundane, allowing them to pick up informative changes in the environment that could be important to our well-being or survival.

VISION

The normal stimulus for vision is electromagnetic energy, or light waves, which are measured in nanometers (nm), or one billionth of a meter. In addition to that tiny portion of light waves that humans can perceive, the electromagnetic spectrum encompasses X-rays, television and radio signals, and infrared and ultraviolet rays (Figure 5.7). Bees are able to see ultraviolet light, and rattlesnakes, as mentioned earlier, can detect infrared energy. Our visual system is sensitive only to wavelengths extending from about 700 nanometers (red) down to about 400 nanometers (blue-violet). (You can remember the order of the spectrum, from higher wavelengths to lower ones, with the name ROY G. BIV—red, orange, yellow, green, blue, indigo, and violet.)

The Human Eye

Light waves enter the eye through the *cornea,* a transparent protective structure at the front of the eye (Figure 5.8). Behind the cornea is the *pupil,* an adjustable opening that can dilate or constrict to control the amount of light that enters the eye. The pupil's size is controlled by muscles in the colored *iris* that surrounds the pupil. Low levels of illumination cause the pupil to dilate, letting more light into the eye to improve optical clarity; bright light makes the pupil constrict.

Behind the pupil is the **lens,** *an elastic structure that becomes thinner to focus on distant objects and thicker to focus on nearby objects.* Just as the lens of a camera focuses an image on a photosensitive material (film), so the lens of the eye focuses the visual image on the **retina,** *a multilayered light-sensitive tissue at the rear of the fluid-filled eyeball.* As seen in Figure 5.8a, the lens reverses the image from right to left and top to bottom when it is projected upon the retina, but the brain reverses the visual input into the image that we perceive.

The ability to see clearly depends on the lens's ability to focus the image directly onto the retina (Pedrotti & Pedrotti, 1997). If you have good vision for nearby objects but have difficulty seeing faraway objects, you probably suffer from *myopia* (nearsightedness). In nearsighted people, the lens focuses the visual image in front of the retina (or too near the lens), resulting in a blurred image for faraway objects. This condition generally occurs because the eyeball is longer (front to back) than normal. In contrast, some people have excellent distance vision but have difficulty seeing close-up objects clearly. *Hyperopia* (farsightedness) occurs when the lens does not thicken enough and the image is therefore focused on a point behind the retina (or too far from the lens). Eyeglasses and contact lenses are designed to correct for the natural lens's inability to focus the visual image directly onto the retina.

Photoreceptors: The Rods and Cones

The retina, with its specialized sensory neurons, is actually an extension of the brain (Bullier, 2002). It contains two types of light-sensitive receptor cells, called *rods* and *cones* because of their shapes (see Figure 5.8b). There are about 120 million rods and 6 million cones in the human eye.

The **rods,** *which function best in dim light, are primarily black-and-white brightness receptors.* They are about 500 times more sensitive to light than are the cones, but they do not give rise to color sensations. The retinas of some nocturnal creatures, such as owls, contain only rods, giving them exceptional vision in very dim light but no color vision (Dossenbach & Dossenbach, 1998). The **cones,** *which are color receptors, function best in bright illumination.* Some creatures that are active

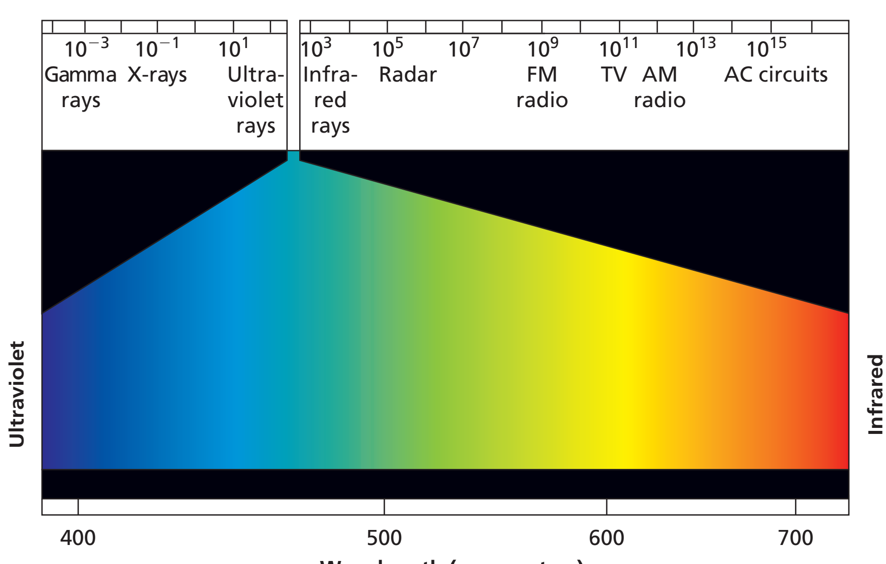


Figure 5.7

Light energy.
Of the full spectrum of electromagnetic radiation, only the narrow band between 400 and 700 nanometers (nm) is visible to the human eye. One nanometer equals one 1,000,000,000th of a meter.

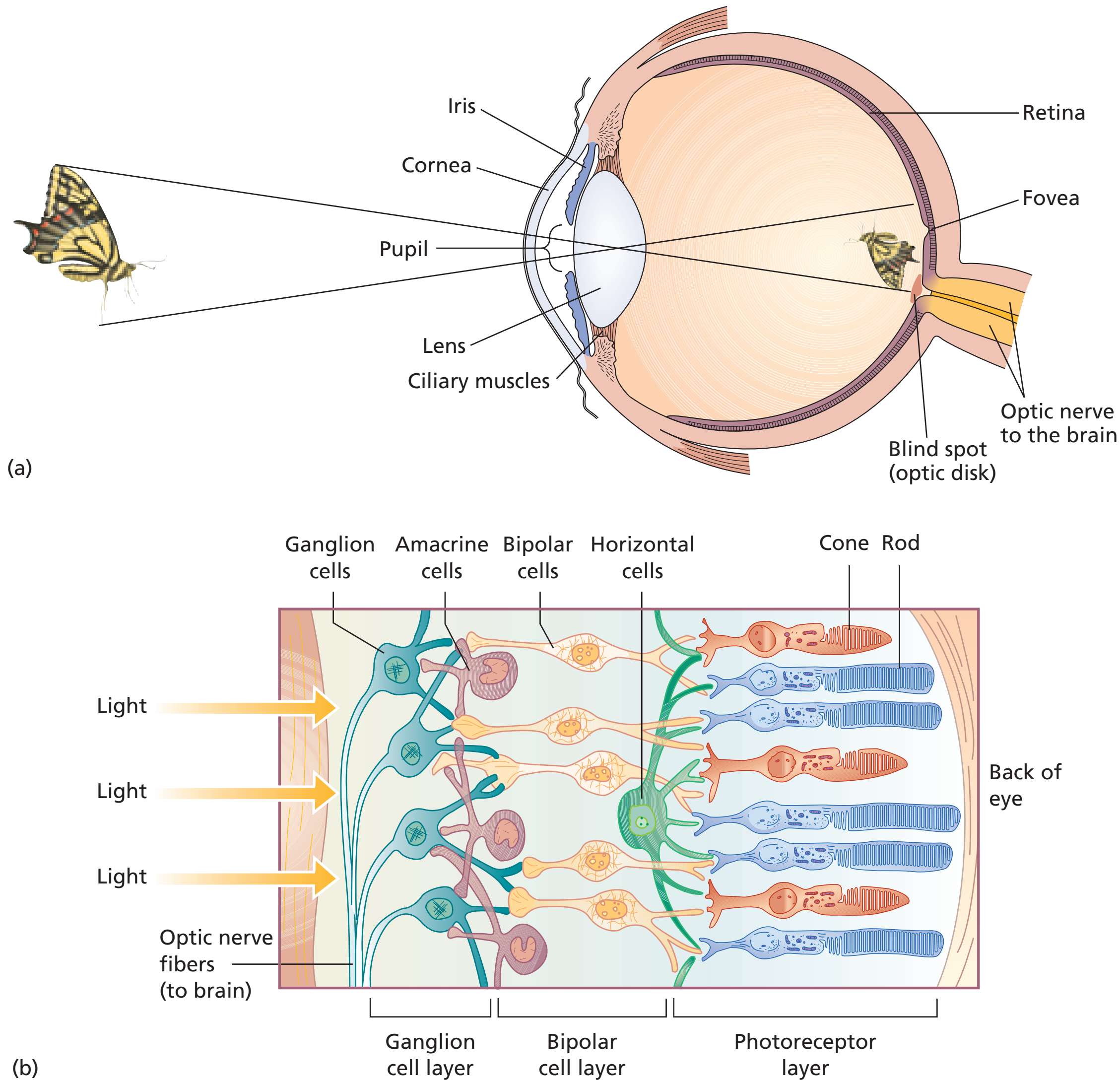


Figure 5.8

The human eye.

(a) This cross section shows the major parts of the human eye. The iris regulates the size of the pupil. The ciliary muscles regulate the shape of the lens. The image entering the eye is reversed by the lens and cast on the retina, which contains the rod and cone photoreceptor cells. The optic disk, where the optic nerve exits the eye, has no receptors and produces a blind spot, as demonstrated in Figure 5.9. (b) Photoreceptors in the retina, the rods and cones, synapse with bipolar cells, which in turn synapse with ganglion cells whose axons form the optic nerve. The horizontal and amacrine cells allow sideways integration of retinal activity across areas of the retina.

only during the day, such as pigeons and chipmunks, have only cones in their retinas, so they see the world in living color but have very poor night vision (Dossenbach & Dossenbach, 1998). Animals that are active both day and night, as humans are, have a mixture of rods and cones. In humans, rods are found throughout the retina except in the **fovea,** *a small area in the center of the retina that contains no rods but many densely packed cones.* Cones decrease in concentration the farther away they are from the center of the retina, and the periphery of the retina contains mainly rods.

Rods and cones send their messages to the brain via two additional layers of cells. The rods and cones have synaptic connections with *bipolar cells,* which in turn synapse with a layer of about 1 million *ganglion cells, whose axons are collected into a bundle to form the* **optic nerve.** Thus input from more than 126 million rods and cones is eventually funneled into only 1 million traffic lanes leading out of the retina toward higher visual centers. Figure 5.8b shows how the rods and cones are connected to the bipolar and ganglion cells. One interesting aspect of these connections is the fact that the rods and cones not only form the rear layer of the retina, but their light-sensitive ends actually point away from the direction of the entering light so that they receive only a fraction of the light energy that enters the eye.

The manner in which the rods and cones are connected to the bipolar cells accounts for both the greater importance of rods in dim light and our greater ability to see fine detail in bright illumination, when the cones are most active. Typically, many rods are connected to the same bipolar cell. They can therefore combine, or funnel, their individual electrical messages to the bipolar cell, where the additive effect of the many signals may be enough to fire it. That is why we can more easily detect a faint stimulus, such as a dim star, if we look slightly to one side so that its image falls not on the fovea but on the peripheral portion of the retina, where the rods are packed most densely.

Like the rods, the cones that lie in the periphery of the retina share bipolar cells. In the fovea, however, the densely packed cones each have their own "private line" to a single bipolar cell. As a result, our **visual acuity,** *or ability to see fine detail,* is greatest when the visual image projects directly onto the fovea. Such focusing results in the firing of a large number of cones and their private-line bipolar cells. Some birds of prey, such as eagles and hawks, are blessed with two foveas in each eye, contributing to a visual acuity that allows them to see small prey on the ground as they soar hundreds of feet above the earth (Tucker, 2000).

The optic nerve formed by the axons of the ganglion cells exits through the back of the eye not far from the fovea, producing a blind spot where there are no photoreceptors. You can demonstrate the existence of your blind spot by following the directions in Figure 5.9. Ordinarily, we are unaware of the blind spot because our perceptual system fills in the missing part of the visual field (Rolls & Deco, 2002).

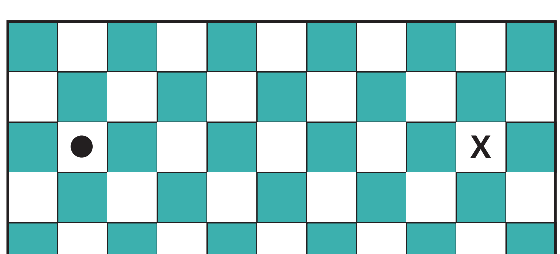


Figure 5.9

Find your blind spot.

Close your left eye and, from a distance of about 12 inches, focus steadily on the dot with your right eye as you slowly move the book toward your face. At some point the image of the X will cross your optic disk (blind spot) and disappear. It will reappear after it crosses the blind spot. Note how the checkerboard remains wholly visible even though part of it falls on the blind spot. Your perceptual system fills in the missing information.

Visual Transduction: From Light Waves to Nerve Impulses

Rods and cones translate light waves into nerve impulses through the action of protein molecules called **photopigments** (Stryer, 1987; Wolken, 1995). The absorption of light by the photopigments produces a chemical reaction that changes the rate of neurotransmitter release at the receptor's synapse with the bipolar cells. The greater the change in transmitter release, the stronger the signal passed on to the bipolar cell and, in turn, to the ganglion cells whose axons form the optic nerve. If a stimulus triggers nerve responses at each of the three levels (rod or cone, bipolar cell, and ganglion cell), the message is instantaneously on its way to the visual relay station in the thalamus and then on to the visual cortex of the brain.

Brightness Vision and Dark Adaptation

As noted earlier, rods are far more sensitive than cones under conditions of low illumination. Nonetheless, the sensitivity of both the rods and the cones to light intensity depends in part on the wavelength of the light. Research has shown that rods have a much greater sensitivity than cones throughout the color spectrum except at the red end, where rods are relatively insensitive. Cones are most sensitive to low illumination in the greenish-yellow range of the spectrum (Valberg, 2006). These findings have prompted many cities to change the color of their fire engines from the traditional red (to which rods are insensitive) to a greenish yellow in order to increase the vehicles' visibility to both rods and cones in dim lighting.

Although the rods are by nature sensitive to low illumination, they are not always ready to fulfill their function. Perhaps you have had the embarrassing experience of entering a movie theater on a sunny day, groping around in the darkness, and finally sitting down in someone's lap. Although one can meet interesting people this way, most of us prefer to stand in the rear of the theater until our eyes adapt to the dimly lit interior.

Dark adaptation *is the progressive improvement in brightness sensitivity that occurs over time under conditions of low illumination.* After absorbing light, a photoreceptor is depleted of its pigment molecules for a period of time. If the eye has been exposed to conditions of high illumination, such as bright sunlight, a substantial amount of photopigment will be depleted. During dark adaptation, the photopigment molecules are regenerated and the receptor's sensitivity increases greatly.

Vision researchers have plotted the course of dark adaptation as people move from conditions

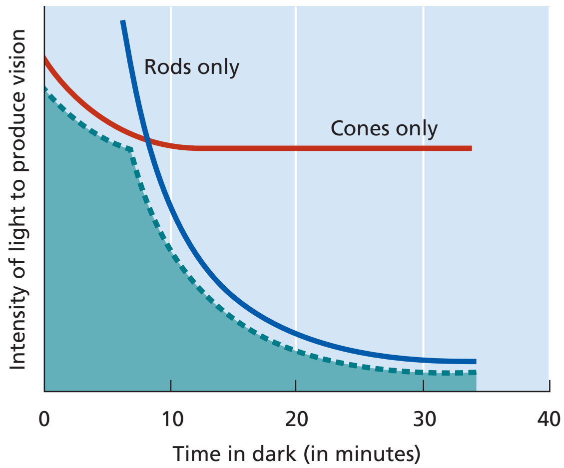


Figure 5.10

Adapting to the dark.
The course of dark adaptation is graphed over time. The curve has two parts, one for the cones and one for the rods. The cones adapt completely in about 10 minutes, whereas the rods continue to increase their sensitivity for another 20 minutes.

of bright light into darkness (Carpenter & Robson, 1999). By focusing light flashes of varying wavelengths and brightness on the fovea (which contains only cones) or on the periphery of the retina (where rods reside), they discovered the two-part curve shown in Figure 5.10. The first part of the curve is due to dark adaptation of the cones. As you can see, the cones gradually become sensitive to fainter lights as time passes, but after about 5 to 10 minutes in the dark, their sensitivity has reached its maximum. The rods, whose photopigments regenerate more slowly, do not reach their maximum sensitivity for about half an hour. It is estimated that after complete adaptation, rods are able to detect light intensities 1/10,000 as great as those that could be detected before dark adaptation began (May, 2007).

Color Vision

We are blessed with a world rich in color. The majesty of a glowing sunset, the rich blues and greens of a tropical bay, the brilliant colors of fall foliage are all visual delights. Human vision is finely attuned to color; our difference thresholds for light wavelengths are so small that we are able to distinguish an estimated 7.5 million hue variations (Medieros, 2006). Historically, two different theories of color vision have tried to explain how this occurs.

The Trichromatic Theory

Around 1800 it was discovered that any color in the visible spectrum can be produced by some combination of the wavelengths that correspond to the colors blue, green, and red. This fact was the basis for an important trichromatic (three-color) theory of color vision advanced by Thomas Young, an English physicist, and Hermann von Helmholtz, a German physiologist. According to the **Young-Helmholtz trichromatic theory,** *there are three types of color receptors in the retina.* Although all cones can be stimulated by most wavelengths to varying degrees, individual cones are most sensitive to wavelengths that correspond to either blue, green, or red (Figure 5.11). Presumably, each of these receptor classes sends messages to the brain, based on the extent to which they are activated by the light energy's wavelength. The visual system then combines the signals to re-create the original hue. If all three cones are equally activated, a pure white color is perceived.

Although the Young-Helmholtz theory was consistent with the laws of color mixture, there are several facts that did not fit the theory. Take our perception of yellow, for example. According to the theory, yellow is produced by the activity of red and green receptors. Yet certain people with red-green color blindness, who are unable to perceive either color, are somehow able to experience yellow. A second phenomenon that posed

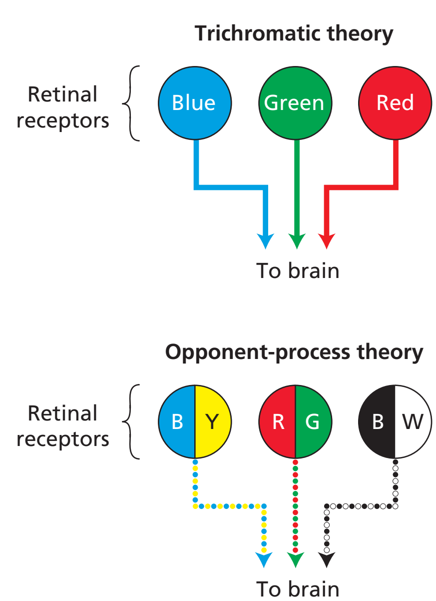


Figure 5.11

Two classic theories of color vision.
The Young-Helmholtz trichromatic theory proposed three different receptors, one for blue, one for green, and one for red. The ratio of activity in the three types of cones yields our experience of a particular hue, or color. Hering's opponent-process theory also assumed that there are three different receptors: one for blue-yellow, one for red-green, and one for black-white. Each of the receptors can function in two possible ways, depending on the wavelength of the stimulus. Again, the pattern of activity in the receptors yields our perception of the hue.

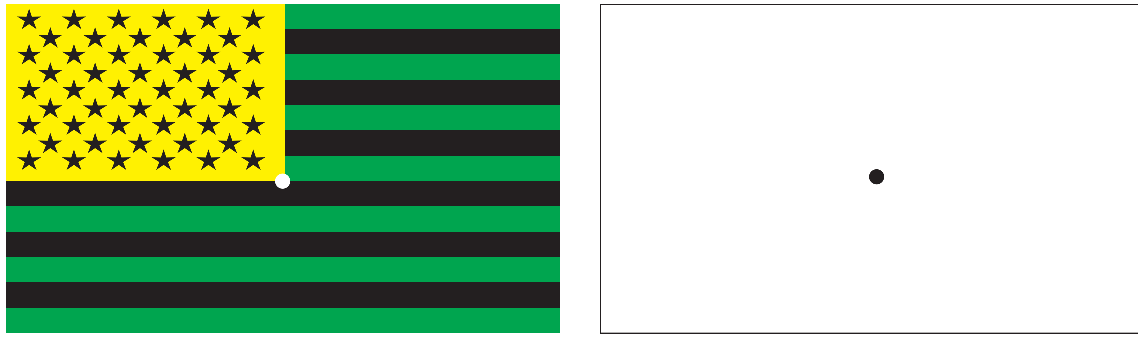


Figure 5.12

Opponent processes at work.

Negative color afterimages demonstrate opponent processes occurring in the visual system. Stare steadily at the white dot in the center of the flag for about a minute, then shift your gaze to the dot in the blank space. The opponent colors should appear.

problems for the trichromatic theory was the color afterimage, in which an image in a different color appears after a color stimulus has been viewed steadily and then withdrawn. To experience an afterimage, follow the instructions for Figure 5.12. Trichromatic theory cannot account for what you'll see.

Opponent-Process Theory

A second influential color theory, formulated by Ewald Hering in 1870, also assumed that there are three types of cones. **Hering's opponent-process theory** *proposed that each of the three cone types responds to two different wavelengths.* One type responds to blue or yellow, another to red or green, and a third to black or white. For example, a red-green cone responds with one chemical reaction to a green stimulus and with its other chemical reaction (opponent process) to a red stimulus (see Figure 5.11). You have experienced one of the phenomena that support the existence of opponent processes if you did the exercise in Figure 5.12. The afterimage that you saw in the blank space contains the colors specified by opponent-process theory: The green portion of the flag appeared as red; the black, as white; and the yellow, as blue. According to opponent-process theory, as you stared at the green, black, and yellow colors, the neural processes that register those colors became fatigued. Then when you cast your gaze on the white surface, which reflects all wavelengths, a rebound opponent reaction occurred as each receptor responded with its opposing red, white, or blue reactions.

Dual Processes in Color Transduction

Which theory—the trichromatic theory or the opponent-process theory—is correct? Two centuries of research have yielded verifying evidence for each theory. Today's **dual-process theory** *combines the trichromatic and opponent-process theories to account for the color transduction process* (Valberg, 2006).

The trichromatic theorists Young and Helmholtz were right about the cones. The cones do indeed contain one of three different protein photopigments that are most sensitive to wavelengths roughly corresponding to the colors blue, green, and red (Valberg, 2006). Different ratios of activity in the blue-, green-, and red-sensitive cones can produce a pattern of neural activity that corresponds to any hue in the spectrum (Backhaus et al., 1998). This process is similar to that which occurs on your TV screen, where color pictures (including white hues) are produced by activating combinations of tiny blue, green, and red dots.

Hering's opponent-process theory was also partly correct, but opponent processes do not occur at the level of the cones, as he maintained. When researchers began to use microelectrodes to record from single cells in the visual system, they discovered that ganglion cells in the retina, as well as neurons in visual relay stations and the visual cortex, respond in an opponent-process fashion by altering their rate of firing (Knoblauch, 2002). For example, if a red light is shone on the retina, an opponent-process ganglion cell may respond with a high rate of firing, but a green light will cause the same cell to fire at a very low rate. Other neurons respond in a similar opponent fashion to blue and yellow stimuli.

The red-green opponent processes are triggered directly by input from the red- or green-sensitive cones in the retina (Figure 5.13). The blue-yellow opponent process is a bit more complex. Activity of blue-sensitive cones directly stimulates the blue process further along in the visual system. And yellow? The yellow opponent process is triggered not by a yellow-sensitive cone, as Hering proposed, but rather by simultaneous input from the red- and green-sensitive cones (Valberg, 2006).

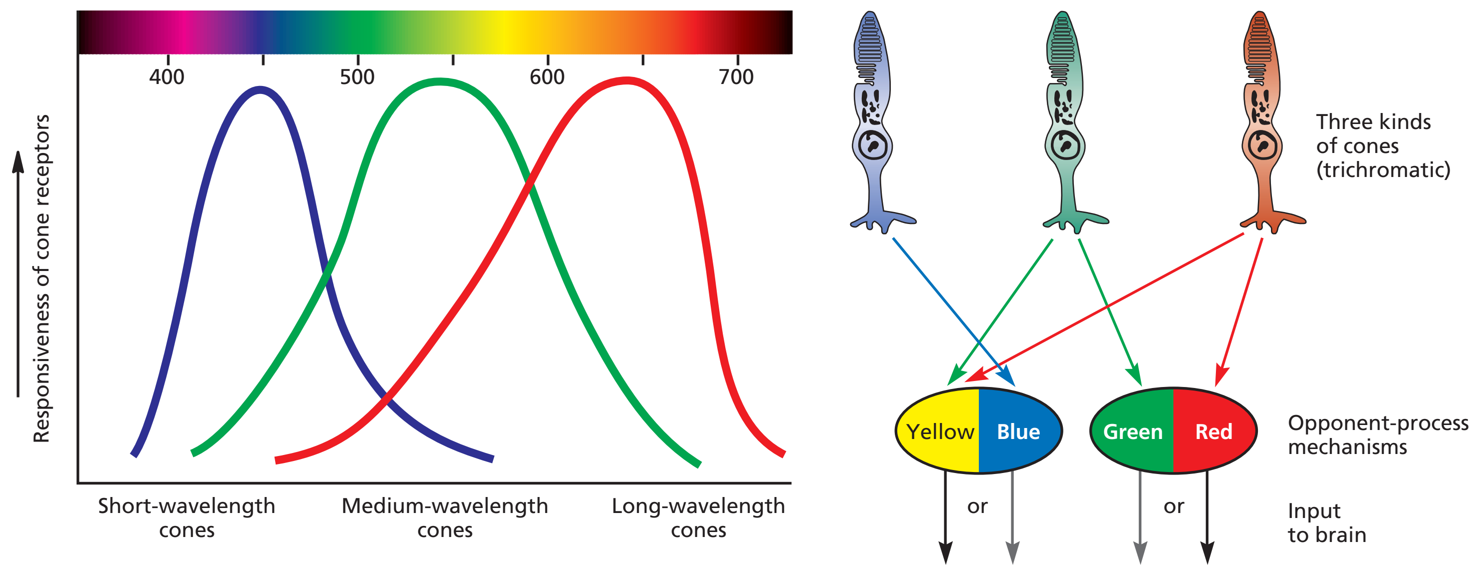


Figure 5.13

Dual color vision processes.

Color vision involves both trichromatic and opponent processes that occur at different places in the visual system. Consistent with trichromatic theory, three types of cones are maximally sensitive to short (blue), medium (green), and long (red) wavelengths, respectively. However, opponent processes occur further along in the visual system, as opponent cells in the retina, visual relay stations, and the visual cortex respond differentially to blue versus yellow, red versus green, and black versus white stimuli. Shown here are the inputs from the cones that produce the blue-yellow and red-green opponent processes.

Color-Deficient Vision

People with normal color vision are referred to as *trichromats*. They are sensitive to all three systems: blue-yellow, red-green, and black-white. However, about 7 percent of the male population and 1 percent of the female population have a deficiency in the blue-yellow system, the red-green system, or both. This deficiency is caused by an absence of hue-sensitive photopigment in certain cone types. A *dichromat* is a person who is color-blind in only one of the systems (blue-yellow or red-green). A *monochromat* is sensitive only to the black-white system and is totally color-blind. Most color-deficient people are dichromats and have their deficiency in the red-green system. Color-blindness tests typically employ sets of colored dots such as those in Figure 5.14. Depending on the type of deficit, a color-blind person cannot discern the numbers embedded in one of the two circles.

Analysis and Reconstruction of Visual Scenes

Once the transformation of light energy to nerve impulses occurs, the process of combining the messages received from the photoreceptors into the perception of a visual scene begins. As you read this page, nerve impulses from countless neurons are being analyzed and the visual image that you perceive is being reconstructed. Moreover, you know what these black squiggles on the page mean. How does this occur?

From the retina, the optic nerve sends impulses to a visual relay station in the thalamus, the brain's sensory switchboard. From there, the input is routed to various parts of the cortex, particularly the primary visual cortex in the occipital lobe at the rear of the brain. Microelectrode studies have shown that there is a point-to-point correspondence between tiny regions of the retina

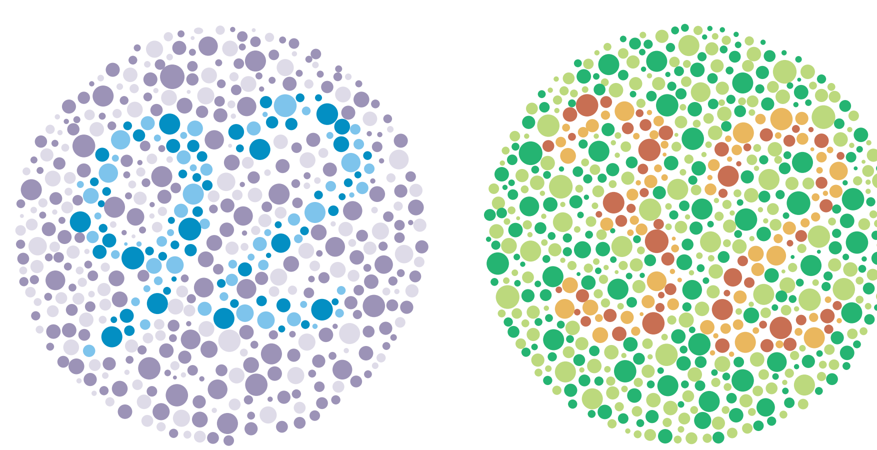


Figure 5.14

Test your color vision.

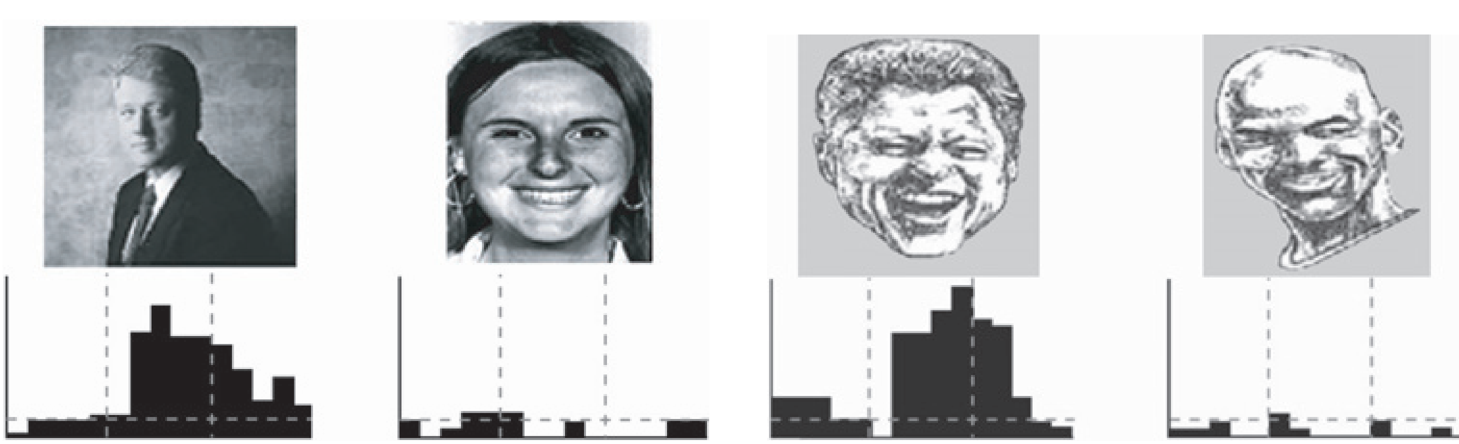
These dotted figures are used to test for color-deficient vision. The left one tests for blue-yellow color blindness, the right one for red-green color blindness. Because the dots in the picture are of equal brightness, color is the only available cue for perceiving the numbers in the circles. Can you see them?

and groups of neurons in the visual cortex. As you might expect, the fovea, where the one-to-one synapses of cones with bipolar cells produce high visual acuity, is represented by a disproportionately large area of the visual cortex. Somewhat more surprising is the fact that there is more than one cortical map of the retina; there are at least 10 duplicate mappings. Perhaps this is nature's insurance policy against damage to any one of them, or perhaps the duplicate maps are somehow involved in the integration of visual input (Bullier, 2002).

Groups of neurons within the primary visual cortex are organized to receive and integrate sensory nerve impulses originating in specific regions of the retina. Some of these cells, known as **feature detectors,** *fire selectively in response to visual stimuli that have specific characteristics* (May, 2007). Discovery of these feature detectors won David Hubel and Torsten Wiesel of Harvard University the 1981 Nobel Prize. Using tiny electrodes to record the activity of individual cells of the visual cortex of animals, Hubel and Wiesel found that certain neurons fired most frequently when lines of certain orientations were presented. One neuron might fire most frequently when a horizontal line was presented; another neuron, in response to a line of a slightly different orientation; and so on "around the clock." For example, the letter A could be constructed from the response of feature detectors that responded to three different line orientations: /, \, and –. Within the cortex, this information is integrated and analyzed by successively more complex feature-detector systems to produce our perception of objects (Palmer, 2002).

Other classes of feature detectors respond to color, to depth, or to movement (Livingstone & Hubel, 1994; Zanker, 2010). These feature-detector "modules" subdivide a visual scene into its component dimensions and process them simultaneously. Thus as a red, white, and green beach ball sails toward you, separate but overlapping modules within the brain are simultaneously analyzing its colors, shape, distance, and movement by engaging in parallel processing of the information and constructing a unified image of its properties (Hubel & Wiesel, 2005). The final stages in the process of constructing a visual representation occur when the information analyzed and recombined by the primary visual cortex is routed to other cortical regions known as the *visual association cortex,* where features of the visual scene are combined and interpreted in light of our memories and knowledge (Grossberg et al., 2005). If all goes correctly, a process that began with nerve impulses from the rods and cones now ends with our recognizing the beach ball for what it is and catching it. Quite another conscious experience and response would probably occur if we interpreted the oncoming object as a water balloon.

Recently, scientists have discovered that neurons in the brain respond selectively not only to basic stimulus characteristics like corners and colors, but also to complex stimuli that have acquired special meaning through experience. For example, brain scientists at the University of California–Los Angeles who were recording from single neurons in the amygdala of a brain-damaged patient found a neuron that responded electrically to only 3 of 50 visual scenes. All of the 3 scenes involved former president Bill Clinton, but they differed considerably. One was a portrait, another a group picture that included Clinton, and the third was a cartoonist's representation of the president. Pictures of other celebrities, animals, landscapes, and geometric forms evoked no response (Figure 5.15). This neuron was likely part of a neural circuit that was created within the brain to register this particular celebrity (Koch, 2004).



Neuron's Electrical Response

Figure 5.15

A Bill Clinton feature detector? Single-neuron electrical recording in a patient's amygdala (which receives extensive visual input) revealed a neuron that responded to depictions of Bill Clinton but not to 47 other pictures showing other presidents, celebrities (e.g., Michael Jordan, *far right*), objects, landscapes, and geometric shapes. This neuron was apparently part of a neuronal network that had learned to recognize and represent the former president.
SOURCE: Koch, 2004.

test yourself — Sensory Processes and Vision

Match each numbered term to the correct definition on the right.

1. cones	a. opponent processes
2. feature detectors	b. acronym for the color spectrum
3. optic nerve	c. sensory relay station in brain
4. ROY G BIV	d. retinal color receptors
5. Hering's theory	e. respond to specific stimulus characteristics
6. thalamus	f. information conduit from the visual receptors to the brain
7. jnd	g. key concept of Weber's law

ANSWERS: 1-d, 2-e, 3-f, 4-b, 5-a, 6-c, 7-g

AUDITION

The stimuli for our sense of hearing are sound waves, a form of mechanical energy. What we call *sound* is actually pressure waves in air, water, or some other conducting medium. When a stereo's volume is high enough, you can actually see cloth speaker covers moving in and out. The resulting vibrations cause successive waves of compression and expansion among the air molecules surrounding the source of the sound. These sound waves have two characteristics: frequency and amplitude (Figure 5.16).

Frequency *is the number of sound waves, or cycles, per second.* The **hertz (Hz)** *is the technical measure of cycles per second; 1 hertz equals 1 cycle per second.* The sound waves' frequency is related to the pitch that we perceive; the higher the frequency (hertz), the higher the perceived pitch. Humans are capable of detecting sound frequencies from 20 to 20,000 hertz (about 12,000 hertz in older people). Most common sounds are in the lower frequencies. Among musical instruments, the piano can play the widest range of frequencies, from 27.5 hertz at the low end of the keyboard to 4,186 hertz at the high end. An operatic soprano's voice, in comparison, has a range of only about 250 to 1,100 hertz (Aiello, 1994).

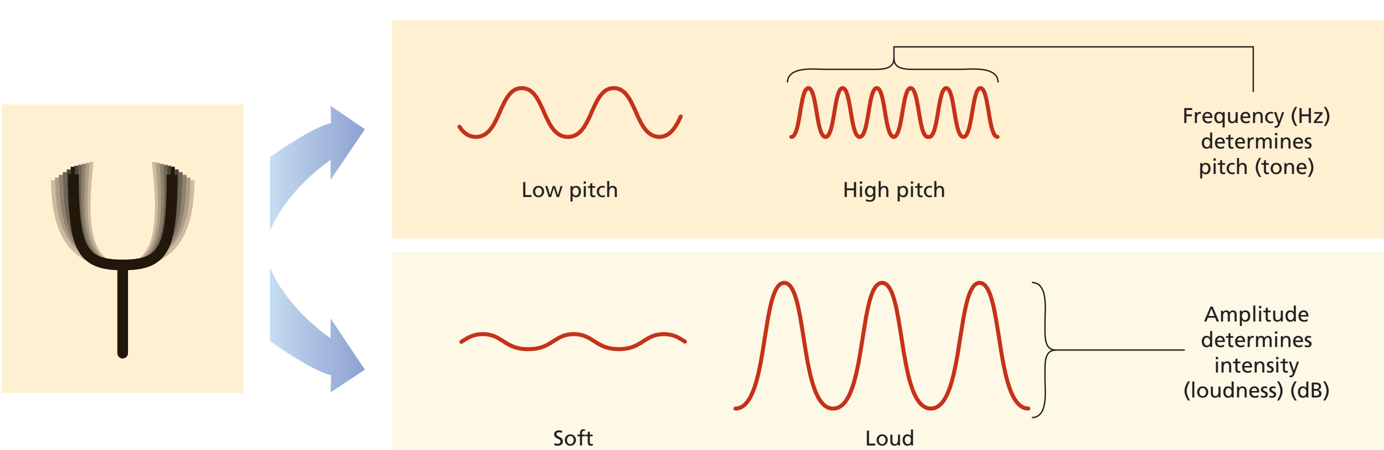


Figure 5.16

Auditory stimuli.
Sound waves are a form of mechanical energy. As the tuning fork vibrates, it produces successive waves of compression and expansion of air molecules. The number of maximum compressions per second (cycles per second) is its frequency, measured in hertz (Hz). The height of the wave above zero air pressure represents the sound's amplitude. Frequency determines pitch; amplitude determines loudness, measured in decibels (dB).

Table 5.3 Decibel Scaling of Common Sounds

Level in Decibels (dB)	Common Sounds	Threshold Levels
140	50-horsepower siren at a distance of 100 feet, jet fighter taking off 80 feet away	Potential damage to auditory system
130	Boiler shop	
120	Air hammer at position of operator, portable music player at maximum volume, jet aircraft at 500 feet overhead	Human pain threshold
110	Trumpet automobile horn at 3 feet	
100	Crosscut saw at position of operator	
90	Inside subway car	Hearing damage with prolonged exposure
80	Train whistle at 500 feet	
70	Inside automobile in city	
60	Downtown city street (Chicago), average traffic	
50	Restaurant, business office	
40	Classroom, church	
30	Hospital room, quiet bedroom	
20	Recording studio	Threshold of hearing (young men)
10		
0		Minimum threshold of hearing

NOTE: The decibel scale relates a physical quantity—sound intensity—to the human perception of that quantity—sound loudness. It is a logarithmic scale—that is, each increment of 10 dB represents a tenfold increase in loudness. The table indicates the decibel ranges of some common sounds as well as thresholds for hearing, hearing damage, and pain. Prolonged exposure at 150 dB causes death in laboratory rats.

Amplitude *refers to the vertical size of the sound waves—that is, the amount of compression and expansion of the molecules in the conducting medium.* The sound wave's amplitude is the primary determinant of the sound's perceived loudness. Differences in amplitude are expressed as **decibels (dB),** *a measure of the physical pressures that occur at the eardrum.* The absolute threshold for hearing is arbitrarily designated as 0 decibels, and each increase of 10 decibels represents a tenfold increase in loudness. Table 5.3 shows various sounds scaled in decibels.

Auditory Transduction: From Pressure Waves to Nerve Impulses

The transduction system of the ear is made up of tiny bones, membranes, and liquid-filled tubes designed to translate pressure waves into nerve impulses (Figure 5.17). At a speed of about 750 mph, sound waves travel into an auditory canal leading to the *eardrum,* a membrane that vibrates in response to the sound waves. Beyond the eardrum is the *middle ear,* a cavity housing three tiny bones (the smallest in the body, each the size of a grain of rice). The vibrating activity of these bones—the *hammer (malleus), anvil (incus),* and *stirrup (stapes)*—amplifies the sound waves more than 30 times. The first bone, the hammer, is attached firmly to the eardrum, and the stirrup is attached to another membrane, the *oval window,* which forms the boundary between the middle ear and the inner ear.

The inner ear contains the **cochlea,** *a coiled, snail-shaped tube about 3.5 centimeters (1.4 inches) in length that is filled with fluid and contains the* **basilar membrane,** *a sheet of tissue that runs its length.* Resting on the basilar membrane is the **organ of Corti,** *which contains about 16,000 tiny hair cells that are the actual sound receptors.* The tips of the hair cells are attached to another membrane, the *tectorial membrane,* that overhangs the basilar membrane along the entire length of the cochlea. The hair cells synapse with the neurons of the auditory nerve, which in turn send impulses via an auditory relay station in the thalamus to the temporal lobe's auditory cortex (Ando, 2009).

When sound waves strike the eardrum, pressure created at the oval window by the hammer, anvil, and stirrup of the middle ear sets the fluid inside the cochlea into motion. The fluid waves that result vibrate the basilar membrane and the tectorial membrane, causing a bending of the hair cells in the organ of Corti (see Figure 5.17b). This bending of the hair cells triggers the release of neurotransmitters into the synaptic space between the hair cells and the neurons of the auditory nerve, resulting in nerve impulses that are sent to the brain. Within the auditory cortex are feature-detector neurons that respond to specific kinds of auditory input, much as occurs in the visual system (Musiek & Baran, 2006).

Coding of Pitch and Loudness

The auditory system transforms the sensory qualities of wave amplitude and frequency (experienced by us as loudness and pitch) into the language of nerve impulses (Syka & Merzenich, 2005). In the case of intensity, high-amplitude sound waves cause the hair cells to bend more and release more neurotransmitter substance at the point where they synapse with auditory nerve cells, resulting in a higher rate of firing within the auditory nerve. Also, certain receptor neurons have higher thresholds than others, so that they will fire only when the hair cells bend considerably in response to an intense sound. Thus what

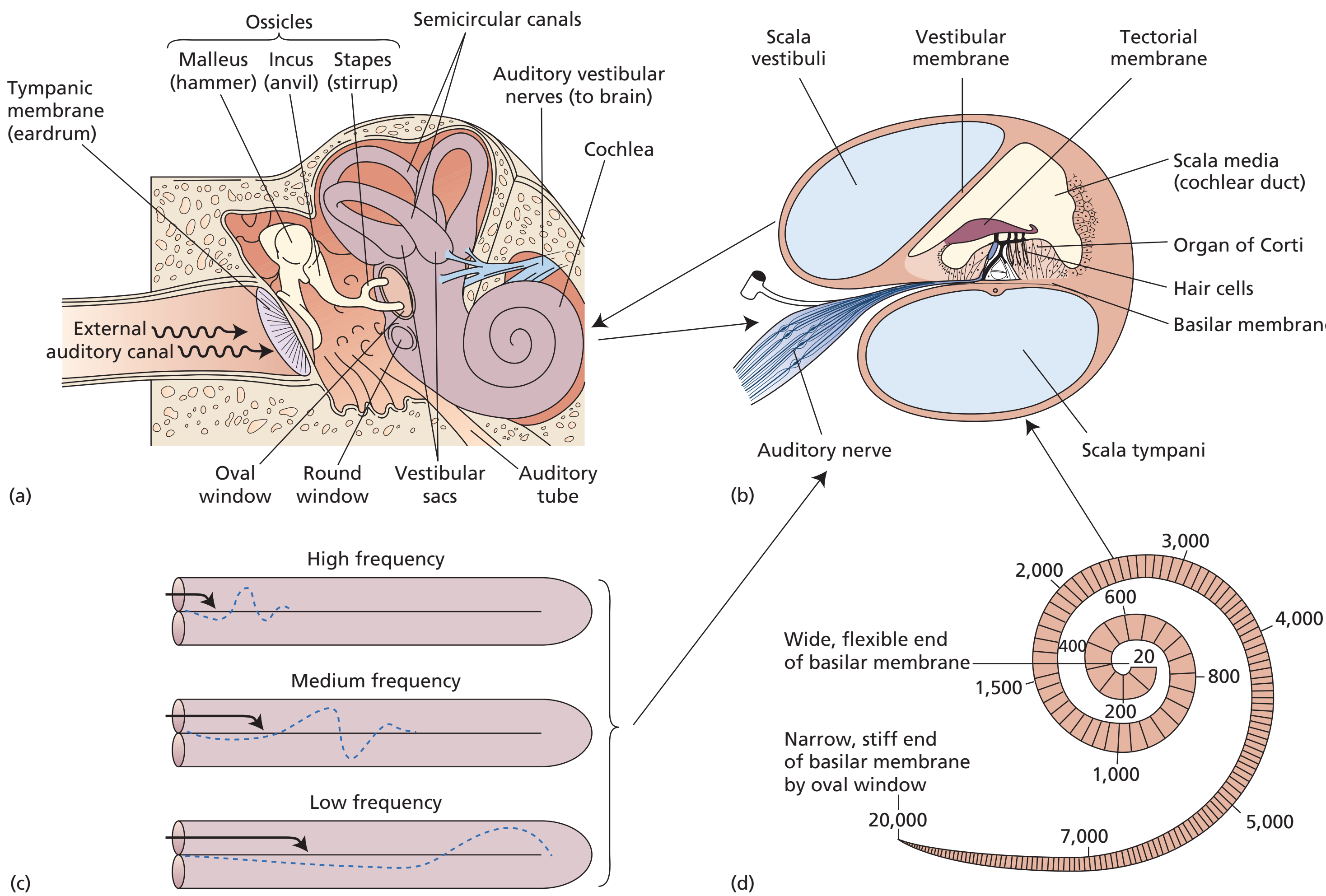


Figure 5.17

The ear.

(a) A cross section of the ear shows the structures that transmit sound waves from the auditory canal to the cochlea. (b) In the cochlea, sound waves are translated into fluid waves that stimulate hair cells in the organ of Corti. The resulting nerve impulses reach the brain via the auditory nerve. The semicircular canals and vestibular sacs of the inner ear contain sense organs for equilibrium. (c) Fluid waves are created by different sound frequencies. (d) Varying frequencies maximally stimulate different areas of the basilar membrane. High-frequency waves peak quickly and stimulate the membrane close to the oval window.

we experience as loudness is coded in terms of both the rate of firing in the axons of the auditory nerve and the specific hair cells that are sending messages (Carney, 2002).

The coding of wave frequency that produces our perception of pitch also involves two different processes, one for frequencies below about 1,000 hertz (two octaves below the top of the piano keyboard) and another for higher frequencies. Historically, as in the case of color vision, two competing theories were advanced to account for pitch perception. According to the **frequency theory of pitch perception,** *nerve impulses sent to the brain match the frequency of the sound wave.* Thus a 30-hertz (30 cycles per second) sound wave from a piano should send 30 volleys of nerve impulses per second to the brain.

Unfortunately, frequency theory encounters a major problem. Because neurons are limited in their rates of firing, individual impulses or volleys of impulses fired by groups of neurons cannot produce high enough frequencies of firing to match sound-wave frequencies above 1,000 hertz. How then do we perceive higher frequencies, such as a 4,000-hertz note from the same piano? Experiments conducted by Georg von Bekesy (1957) uncovered a second mechanism for coding pitch that earned him the 1961 Nobel Prize. Bekesy cut tiny holes in the cochleas of guinea pigs and human cadavers and observed through a microscope what happened inside the fluid-filled cochlea when he stimulated the eardrum with tones of varying frequencies. He found that high-frequency sounds produced an abrupt fluid wave (Figure 5.17c) that peaked close to the oval window, whereas lower-frequency vibrations produced a slower fluid wave that peaked farther down the cochlear canal. Bekesy's observations supported a **place theory of pitch perception,** *suggesting that the specific point in the cochlea where the fluid wave peaks and most strongly bends the hair cells serves as a frequency coding cue* (Figure 5.17d). Researchers later found that, similar to the manner in which the retina is mapped onto the visual cortex, the auditory cortex has a tonal-frequency map that corresponds to specific areas of the cochlea. By analyzing the specific location of the cochlea from which auditory nerve impulses are being received, the brain can code pitches like our 4,000-hertz piano note (Musiek & Baran, 2006).

Thus, like trichromatic and opponent-process theories of color vision, which were once thought to contradict one another, frequency and place theories of pitch perception both proved applicable in their own ways. At low frequencies, frequency theory holds true; at higher frequencies, place theory provides the mechanism for coding the frequency of a sound wave.

Sound Localization

Have you ever wondered why you have two ears, one located on each side of your head? As is usually the case in nature's designs, there is a good reason. Our very survival can depend on our ability to locate objects that emit sounds. The nervous system uses information concerning the time and intensity differences of sounds arriving at the two ears to locate the source of sounds in space (Luck & Vecera, 2002).

Sounds arrive first and loudest at the ear closest to the sound. When the source of the sound is directly in front of us, the sound wave reaches both ears at the same time and at the same intensity, so the source is perceived as being straight ahead. Our binaural (two-eared) ability to localize sounds is amazingly sensitive. For example, a sound 3 degrees to the right arrives at the right ear only 300 millionths of a second before it arrives at the left ear, and yet we can tell which direction the sound is coming from (Yin & Kuwada, 1984).

Other animals have even more exotic sound-localization systems. For example, the barn owl comes equipped with ears that are exquisitely tailored for pinpoint localization of its prey during night hunting. Its right ear is directed slightly upward, its left ear slightly downward. This allows it to localize sounds precisely in both the vertical and horizontal planes and thereby to zero in on its prey with deadly accuracy.

thinking **critically**

NAVIGATING IN FOG: PROFESSOR MAYER'S TOPOPHONE

The device shown in Figure 5.18 is called a *topophone.* It was used in the late 1880s to help sailors locate sounds while navigating in thick fog. Based on what you've learned about the principles of sound localization, can you identify two features of this instrument that would assist sailors in detecting and locating sounds? Think about it, then see page 172.

Figure 5.18

An early "hearing aid."
The topophone, used in the late 1800s by sailors to increase their ability to locate sounds while navigating in thick fog, assisted in two ways. Can you identify the relevant principles?

Hearing Loss

In the United States alone, more than 20 million people suffer from impaired hearing. Of these, 90 percent were born with normal hearing (Sataloff & Thayer, 2006). They suffer from two major types of hearing loss. **Conduction deafness** *involves problems with the mechanical system that transmits sound waves to the cochlea.* For example, a punctured eardrum or a loss of function in the tiny bones of the middle ear can reduce the ear's capacity to transmit vibrations. Use of a hearing aid, which amplifies the sounds entering the ear, may correct many cases of conduction deafness.

An entirely different matter is **nerve deafness,** *caused by damaged receptors within the inner ear or damage to the auditory nerve itself.* Nerve deafness cannot be helped by a hearing aid because the problem does not lie in the transmission of sound waves to the cochlea. Although aging and disease can produce nerve deafness, exposure to loud sounds is one of its leading causes. Repeated exposure to loud sounds of a particular frequency (as might be produced by a machine in a factory) can eventually cause the loss of hair cells at a particular point on the basilar membrane, thereby causing hearing loss for that frequency.

Extremely loud music can also take a serious toll on hearing (Naff, 2010). Even brief exposure to sounds exceeding 140 decibels can cause irreversible damage to the receptors in the inner ear, as can more continuous sounds at lower decibel levels. In 1986, a rock concert by The Who reached 120 decibels at a distance of 164 feet from the speakers. Although this earned The Who a place in the Guinness Book of Records for the all-time loudest concert, it inflicted severe and permanent hearing damage to many in the audience. The Who's lead guitarist, Pete Townshend, eventually suffered severe hearing loss from prolonged noise exposure. An iPod or similar portable music player can generate this decibel level through its earphones (Ballard, 2010).

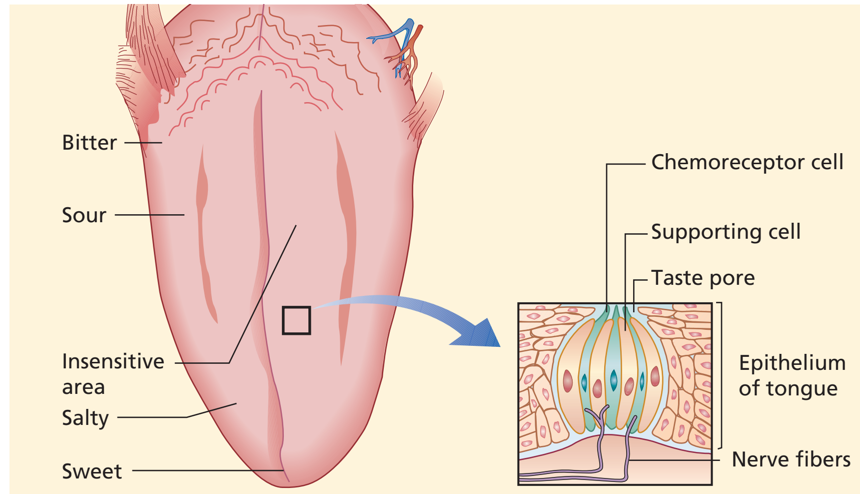


Figure 5.19

Taste organs.

The receptors for taste are specialized cells located in the tongue's taste buds. The tongue's 9,000 taste buds are found on the tip, back, and sides of the tongue. As this figure shows, certain areas of the tongue are especially sensitive to chemical stimuli that produce particular taste sensations. However, these different sensitivities are a matter of degree, as all kinds of taste buds are found in most areas of the tongue. The center of the tongue is relatively insensitive to chemical stimuli for taste.

TASTE AND SMELL: THE CHEMICAL SENSES

Gustation, *the sense of taste,* and **olfaction,** *the sense of smell,* are chemical senses; their receptors are sensitive to chemical molecules rather than to some form of energy. These senses are so intertwined that some scientists consider them a "common chemical sense" (Halpern, 2002). Enjoying a good meal usually depends on the simultaneous activity of taste and odor receptors, as becomes apparent when we have a stuffy nose and our food tastes bland. People who lose their sense of smell typically believe they have lost their sense of taste as well (Beauchamp & Bartoshuk, 1997).

Gustation: The Sense of Taste

People who consider themselves gourmets are frequently surprised to learn that their sense of taste responds to only four qualities: sweet, sour, salty, and bitter. Every other taste experience combines these qualities and those of other senses, such as smell, temperature, and touch. For example, part of the taste of popcorn includes its complex texture, its crunchiness, and its odor. In addition to its chemical receptors, the tongue is richly endowed with tactile (touch) and temperature receptors.

Taste buds *are chemical receptors concentrated along the tip, edges, and back surface of the tongue* (Figure 5.19). Each taste bud is most responsive to one or two of the basic taste qualities but responds weakly to the others as well. An additional taste sensation, called *umami,* increases the intensity of other taste qualities. This sensory response is activated by certain proteins, as well as by monosodium glutamate, a substance used by some restaurants for flavor enhancement.

Humans have about 9,000 taste buds, each one consisting of several receptor cells arranged like the segments of an orange. A small number of receptors are also found in the roof and back of the mouth, so that even people without a tongue can taste substances. Hairlike structures project from the top of each cell into the taste pore, an opening to the outside surface of the tongue. When a substance is taken into the mouth, it interacts with saliva to form a chemical solution that flows into the taste pore and stimulates the receptor cells. A taste results from complex patterns of neural activity produced by the four types of taste receptors (Halpern, 2002).

The sense of taste not only provides us with pleasure but also has adaptive significance in discriminating between nutrients and toxins (Scott, 1992). Our response to some taste qualities is innate. For example, newborn infants respond positively to sugar water placed on the tongue and negatively to bitter substances such as quinine

(Davidson & Fox, 1988). Many poisonous substances in nature have bitter tastes, so this emotional response seems to be hardwired into our physiology. In nature, sweet substances are more likely to occur in high-calorie (sugar-rich) foods. Unfortunately, many humans now live in an environment that is different from the food-scarce environment in which preferences for sweet substances evolved (Scott & Giza, 1993). As a result, people in affluent countries overconsume sweet foods that are good for us only in small quantities.

Olfaction: The Sense of Smell

Humans are visually oriented creatures, but the sense of smell (olfaction) is of great importance for many species. Bloodhounds, for example, have poor eyesight but a highly developed olfactory sense that is about 2 million times more sensitive than ours (Thomas, 1974). A bloodhound can detect a person's scent in a footprint that is four days old, something no human could do.

The receptors for smell are long cells that project through the lining of the upper part of the nasal cavity and into the mucous membrane. Humans have about 40 million olfactory receptors, dogs about 1 billion. Unfortunately, our ability to discriminate among different odors is not well understood. The most popular current theory is that olfactory receptors recognize diverse odors individually rather than by mixing the activity of a smaller number of basic receptors, as occurs in taste (Wilson et al., 2004). Olfactory receptors have structures that resemble neurotransmitter binding sites on neurons. Any of the thousands of potential odor molecules can lock into sites that are tailored to fit them (Buck & Axel, 1991). The receptors that fire send their input to the **olfactory bulb,** *a forebrain structure immediately above the nasal cavity.* Each odorous chemical excites only a limited portion of the olfactory bulb, and odors are apparently coded in terms of the specific area of the olfactory bulb that is excited (Dalton, 2002).

The social and sexual behavior of animals is more strongly regulated by olfaction than is human behavior (Alcock, 2005). For example, many species use urine to mark their territories; we humans find other ways, such as erecting fences or spreading our belongings over the table we are using in the library. Nonetheless, like animals, we have special receptors in the nose that send impulses to a separate olfactory area in the brain that connects with brain structures involved in social and reproductive behavior. Some researchers believe that **pheromones,** *chemical signals found in natural body scents,* may affect human behavior in subtle ways (Beauchamp & Bartoshuk, 1997).

One interesting phenomenon known as **menstrual synchrony** *is the tendency of women who live together or are close friends to become more similar in their menstrual cycles.* Psychologist Martha McClintock (1971) tested 135 college women and found that during the course of an academic year, roommates moved from a mean of 8.5 days apart in their periods to 4.9 days apart. Another study of 51 women who worked together showed that close friends had menstrual onsets averaging 3.5 to 4.3 days apart, whereas those who were not close friends had onsets that averaged 8 to 9 days apart (Weller et al., 1999). Are pheromones responsible for synchrony? In one experiment, 10 women with regular cycles were dabbed under the nose every few days with underarm secretions collected from another woman. After 3 months, the recipients' cycles began to coincide with the sweat donor's cycles. A control group of women who were dabbed with an alcohol solution rather than sweat showed no menstrual synchrony with a partner (Preti et al., 1986). In other studies, however, menstrual synchrony was not found for cohabitating lesbian couples or for Bedouin women who spent most of their time together, indicating that prolonged and very intensive contact may not be conducive to menstrual synchrony (Weller et al., 1999; Weller & Weller, 1997).

Do odors make us sexually attractive? The marketers of various "pheromone" perfumes tell us they do. And if you have ever owned a dog or cat that went into heat, you can attest to the effects of such odors in animals. However, researchers have yet to find any solid evidence to back the claims of commercial products promising instant sexual attraction. For humans, it appears that a pleasant personality and good grooming are a better bet than artificially applied pheromones when it comes to finding a mate.

THE SKIN AND BODY SENSES

The skin and body senses include the senses of touch, kinesthesis (muscle movement), and equilibrium. The last two are called *body senses* because they inform us of the body's position and movement. They tell us, for example, if we are running or standing still, lying down or sitting up.

The Tactile Senses

Touch is important to us in many ways. Sensitivity to extreme temperatures and to pain enables us to escape external danger and alerts us to disorders within our body. Tactile sensations are also a source of many of life's pleasures, including sexual orgasm. As discussed in Chapter 3, massage enhances newborn babies' development (Cigales et al., 1997; Field, 2000). Conversely, it has been shown that a lack of tactile contact with a caretaking adult retards physical, social, and emotional development (Harlow, 1958).

Humans are sensitive to at least four tactile sensations: pressure (touch), pain, warmth, and cold. These sensations are conveyed by receptors in the skin and in our internal organs. Mixtures of these four sensations form the basis for all other common skin sensations, such as itch.

Considering the importance of our skin senses, surprisingly little is known about how they work. The skin, a multilayered elastic structure that covers 2 square yards and weighs between 6 and 10 pounds, is the largest organ in our body. As shown in Figure 5.20, it contains a variety of receptor structures, but their role in specific sensations is less clear than for the other senses. Many sensations probably depend on specific patterns of activity in the various receptors (Schiff & Foulke, 2010). We do know that the primary receptors for pain and temperature are the *free nerve endings*, simple nerve cells beneath the skin's surface that resemble bare tree branches (Gracely et al., 2002). *Basket cell fibers* situated at the base of hair follicles are receptors for touch and light pressure (Heller & Schiff, 1991).

The brain can locate sensations because skin receptors send their messages to the point in the somatosensory cortex that corresponds to the area of the body where the receptor is located. As we saw in Chapter 4, the amount of cortex devoted to each area of the body is related to that part's sensitivity. Our fingers, lips, and tongue are well represented, accounting for their extreme sensitivity to stimulation (Figure 5.21; see also Figure 4.15).

Sometimes the brain "locates" sensations that cannot possibly be present. This occurs in the puzzling phantom-limb phenomenon, in which amputees experience vivid sensations coming from the missing limb (Warga, 1987). Apparently an irritation of the nerves that used to originate in the limb fools the brain into interpreting the resulting nerve impulses as real sensations. Joel Katz and Ronald Melzack (1990) studied 68 amputees who insisted that they experienced pain from the amputated limb that was as vivid and real as any pain they had ever felt. This pain was not merely a recollection of what pain used to feel like in the limb; it was actually experienced in the present. The phantom-limb phenomenon can be quite maddening. Imagine having an intense itch that you never can scratch or an ache that you cannot rub. When amputees are fitted with prosthetic limbs and begin using them, phantom pain tends to disappear (Gracely et al., 2002).

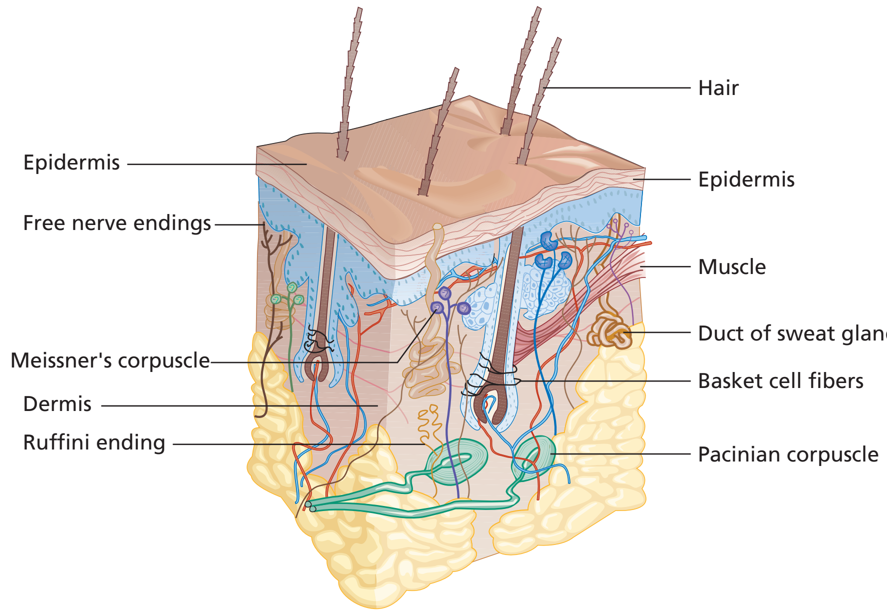


Figure 5.20

Skin receptors.

A variety of sensory receptors in the human skin and internal tissues allow us to sense touch and temperature. Basket cell fibers around hair follicles detect bending of the hair in light touch, and Meissner's corpuscles provide the same information in hairless areas. Pacinian corpuscles and Ruffini endings provide deeper touch sensations, and the free nerve endings respond to temperature and painful stimuli. Source: Adapted from Smith, 1998.

Figure 5.21

World-renowned percussionist Evelyn Glennie became deaf many years ago. She now uses her tactile sense to detect distinct vibrations that correspond with individual tones. Though deaf, she is capable of perfect tonal discrimination.

Pain

Pain receptors are found in all body tissues with the exception of the brain, bones, hair, nails, and nonliving parts of the teeth. Free nerve endings in the skin and internal organs respond to intense mechanical, thermal, or chemical stimulation and then send nerve impulses into the spinal cord, where sensory tracts carry pain information to the brain. Once in the brain, the sensory information about pain intensity and location is relayed by the thalamus to the somatosensory and frontal areas of the cerebral cortex (Fields, 2005). Reflecting the adaptive value of pain, brain recordings reveal that cerebral processing of pain occurs faster than for other kinds of tactile stimuli, permitting a more rapid response (Ploner et al., 2006). Other tracts from the thalamus direct nerve impulses to the limbic system, which is involved in motivation and emotion. These tracts seem to control the emotional component of pain (Zanker, 2010). Thus pain has both a sensory and an emotional component. *Suffering* occurs when both painful sensations and a negative emotional response are present (Fordyce, 1988; Turk, 2001).

Spinal and Brain Mechanisms

Gate control theory, developed by Canadian psychologist Ronald Melzack and physiologist Patrick Wall (1982), was a major advance in the study of pain. **Gate control theory** *proposes that the experience of pain results from the opening and closing of gating mechanisms in the nervous system* (Turk & Melzack, 2001). Events in the spinal cord can open a system of spinal cord "gates" and allow the nerve impulses to travel toward the brain. However, other sensory input can partially or completely close the gates and blunt our experiencing of pain. For example, rubbing a bruise or scratching an itch can produce relief. Gate control theorists also suggest that acupuncture achieves its pain-relieving effects because the acupuncture needles stimulate mostly tactile receptors that close the pain gates.

From a psychological perspective, perhaps the most intriguing feature of gate control theory is that nerve impulses in fibers descending from the brain can also influence the spinal gates, thereby increasing or decreasing the flow of pain stimulation to the brain. This *central control mechanism* allows thoughts, emotions, and beliefs to influence the experience of pain and helps explain why pain is a psychological phenomenon as well as a physical one.

Gate control and other theorists have traditionally viewed pain as solely reflecting the action of neurons. However, the immune system also plays a role in pain. Recent research has shown that *glial cells*, which structurally support and service neurons within the spinal cord, are involved in the creation and maintenance of pathological pain (Watkins & Maier, 2003). These glial cells become activated by immune challenges (viral or bacterial infection) and by substances released by neurons within the pain pathway. They then amplify pain by releasing *cytokines* (messenger molecules) that promote inflammation. This may help account for that "ache all over" sensation that many of us experience when we are ill.

The Endorphins

In 1680, an English physician wrote, "Among the remedies which it has pleased Almighty God to give man to relieve his suffering, none is so universal and so efficacious as opium" (quoted in Snyder, 1977). Opiates (such as opium, morphine, and heroin) have been used for centuries to relieve pain, and they strongly affect the brain's pain and pleasure systems. In the 1970s, scientists discovered that opiates produce their effects by locking into specific receptor sites in brain regions associated with pain perception.

But why would the brain have built-in receptors for opiates unless there were some natural chemical in the brain for the receptor to receive? Later research disclosed what had to be true: the nervous system has its own built-in analgesics (painkillers) with opiatelike properties. These natural opiates were named **endorphins** (meaning *endogenous, or internally produced, morphines*). Endorphins exert some of their painkilling effects by inhibiting the release of neurotransmitters involved in the synaptic transmission of pain impulses from the spinal cord to the brain (Fields, 2005). Endorphins are of great interest to psychologists because they may help explain how psychological factors "in the head" can have such strong effects on pain and suffering.

In 2001, John-Kar Zubieta and coworkers published a landmark study that showed the endorphins in action within the brain. They injected a radioactive form of an endorphin into volunteer participants, then stimulated them with painful injections of saltwater into the jaw muscles. Brain scans allowed the researchers to see which areas of the brain lit up from endorphin activity and to relate this activity to pain reports given by the participants every 15 seconds. The scans revealed a surge of endorphin activity within several brain regions, including the thalamus (the sensory switchboard), the amygdala (an emotion center), and a sensory area of the cortex. As the endorphin surge continued over 20 minutes of

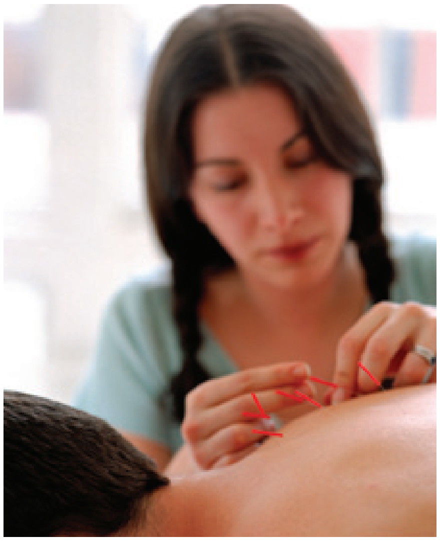


Figure 5.22

Acupuncture is a proven pain-reduction procedure. Gate control theory attributes its effects to the stimulation of sensory fibers that close sensory gates in the pain system. In addition, there is evidence that acupuncture stimulates endorphin release.

pain stimulation, participants reported decreased sensory and emotional ratings of pain.

Acupuncture (Figure 5.22) is an effective pain-reduction technique that ultimately may be understood in terms of endorphin mechanisms. Injections of naloxone, a drug that counteracts the effects of endorphins, greatly decrease the pain-reducing effects of acupuncture (Oleson, 2002). This suggests that acupuncture normally releases endorphins to blunt pain sensations.

The Body Senses

We would be totally unable to coordinate our body movements were it not for the sense of **kinesthesis,** *which provides us with feedback about our muscles' and joints' positions and movements.* Kinesthetic receptors are nerve endings in the muscles, tendons, and joints. The information this sense gives us is the basis for making coordinated movements. Cooperating with kinesthesis is the **vestibular sense,** *the sense of body orientation, or equilibrium.*

The vestibular receptors are located in the vestibular apparatus of the inner ear (see Figure 5.17). One part of the equilibrium system consists of three semicircular canals, which contain the receptors for head movement. Each canal lies in a different plane: left-right, backward-forward, or up-down. These canals are filled with fluid and lined with hairlike cells that function as receptors. When the head moves, the fluid in the appropriate canal shifts, stimulating the hair cells and sending messages to the brain. The semicircular canals respond only to acceleration and deceleration; when a constant speed is reached (no matter how high), the fluid and the hair cells return to their normal resting state. That's why airplane takeoffs and landings give a sense of movement whereas cruising along at 500 miles per hour does not. Located at the base of the semicircular canals, the vestibular sacs also contain hair cells that respond to the position of the body and tell us whether we are upright or tilted at an angle. These structures form the second part of the body-sense system (Dolins & Mitchell, 2010).

You have now learned a considerable amount about the principles underlying stimulus detection and transduction. As the following "Applying Psychological Science" section shows, these principles have not only informational value for understanding how our sensory systems operate, but also applied value in helping people with sensory impairments.

Applying Psychological Science

Sensory Prosthetics: Restoring Lost Functions

Millions of people suffer from blindness and deafness, living in sightless or soundless worlds. War, accidents, or illness result in amputations that cost others important aspects of their sense of touch. Psychological research on the workings of the sensory systems is now being combined with technical advances in bioengineering, resulting in **sensory prosthetic devices** *that provide sensory input that can, to some extent, substitute for what cannot be supplied by a person's sensory receptors* (Patil & Turner, 2008). In considering these devices, we should remind ourselves that we don't see with the eyes, hear with the ears, or feel with touch receptors. We see, hear, and feel with our brain. The nerve impulses sent from the retina, the organ of Corti, or the skin are no different from those sent from anywhere else in the body.

SEEING WITH THE EARS

One device, known as a Sonicguide, provides new "eyes" through the ears, capitalizing on principles of auditory localization. The Sonicguide (Figure 5.23) works on the same principle as *echolocation,* the sensory tool used by bats to navigate in total darkness. A pair of eyeglasses contains a transmitter that emits high-frequency sound waves beyond the range of human hearing. These waves bounce back from objects in the environment and are transformed by the Sonicguide

Continued

Figure 5.23

The Sonicguide allows a blind person to perceive the size, distance, movement, shape, and texture of objects through sound waves that represent the visual features of objects.

into sounds that can be heard through earphones. Different sound qualities match specific features of external objects, and the wearer must learn to interpret the sonic messages. For example, the sound's pitch tells the person how far away an object is; a low pitch signals a nearby object and becomes higher as the distance to the object increases. The loudness of the sound tells how large the object is, and the clarity of the sound (ranging from a staticlike sound to a clear tone) signals the texture of the object, from very rough to very smooth. Finally, the sound-localization principle described earlier tells the person where the object is located in the environment by means of differences in the time at which sounds arrive at the two ears.

In the first laboratory tests of the Sonicguide, psychologists Stuart Aitken and T. G. R. Bower (1982) used the apparatus with six blind babies who ranged in age from 5 to 16 months. Within hours or days, all of the babies using the Sonicguide could reach for objects, walk or crawl through doorways, and follow the movements of their own hands and arms. Moreover, abilities such as reaching for objects, recognizing favorite toys, and reaching out to be picked up when mother (but not someone else) approached seemed to occur on the same developmental timetable as in sighted children. Aitken and Bower concluded that blind infants can extract the same information from sonic cues as sighted babies do from visual cues.

Older children and adults can learn to use the device too, but not as easily as babies can. Children trained with the device can easily find objects, such as water fountains and specific toys. They can thread their way through crowded school corridors and can even play hide-and-seek. The Sonicguide is now being used by visually impaired children in schools and other natural settings, as well as by adults (Hill et al., 1995).

THE SEEING TONGUE

At the University of Wisconsin, Paul Bach-y-Rita (2004) developed a tactile tongue-based, electrical input sensor as a substitute for visual input. The tongue seems an unlikely substitute for the eye, hidden as it is in the dark recess of the mouth. Yet in many ways it may be the second-best organ for providing detailed input, for it is densely packed with tactile receptors, thus allowing the transmission of high-resolution data. Moreover, its moist surface is a good conducting medium for electricity, meaning that minimum voltage is required to stimulate the receptors.

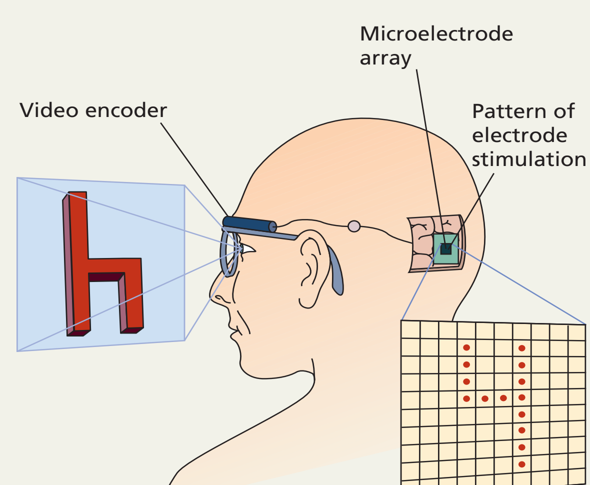
The current stimulator, shown in Figure 5.24a, receives digital data from a camera and provides patterns of stimulation to the tongue through a 144-electrode array. The array can transmit shapes that correspond to the main features of the visual stimulus. Initial trials with blindfolded sighted people and blind people show that with about 9 hours of training, users can "read" the letters of a Snellen eye chart with an acuity of 20/430, a modest but noteworthy beginning (Simpaio et al., 2001).

With continued development, a miniature camera attached to eyeglasses will transmit wireless data to a more densely packed electrode array attached to a dental retainer. In addition to helping people who are blind, the device could have both military and civilian applications. For example, it could help soldiers locate objects in pitch-black environments, such as caves, where night-vision devices are useless. It could also aid firefighters as they search smoke-filled buildings for people to rescue.

Figure 5.24

Two approaches to providing artificial vision for the blind. (a) Bach-y-Rita's device converts digitized stimuli from a camera to a matrix of electrodes, which stimulate tactile receptors in the tongue to communicate spatial information to the brain. (b) Tiny electrodes implanted into individual neurons in the visual cortex produce patterns of phosphenes that correspond to the visual scene observed through the video camera and encoder. Note how the cortical image is reversed as in normal visual input.

(a)



(b)

CORTICAL IMPLANTS

When cells in the visual cortex are stimulated electrically, discrete flashes of light called *phosphenes* are experienced by both sighted and blind people. Because sensory neurons in the visual cortex are arranged in a manner that corresponds to the organization of the retina, a specific pattern of stimulation applied to individual neurons in the cortex can form a phosphene pattern that conforms to the shapes of letters or objects (Weiland & Humayun, 2008). The acuity of the pattern depends on the area of the visual cortex that is stimulated (the portion receiving input from the densely packed fovea produces greatest acuity) and on the number of stimulating electrodes in the array.

Building on this approach, researchers have developed the device shown in Figure 5.24b. It consists of a silicon strip containing thousands of tiny stimulating electrodes that penetrate directly into individual neurons in the visual cortex, where they can stimulate phosphene patterns. Eventually, a tiny television camera mounted in specially designed eyeglasses will provide visual information to a microcomputer that will analyze the scene and then send the appropriate patterns of electrical stimulation through the implanted electrodes to produce corresponding phosphene patterns in the visual cortex. The researchers have shown that sighted participants who wear darkened goggles that produce phosphenelike patterns of light flashes like those provided by cortical stimulation can quickly learn to navigate through complex environments and are able to read text at about two thirds their normal rate (Liu et al., 2008; Normann et al., 1996, 1999). Blind people with the stimulating electrodes implanted in the visual cortex have also been able to learn a kind of cortical Braille for reading purposes. Although still experimental, a commercially available intracortical prosthetic device should appear in the near future.

COCHLEAR IMPLANTS

People with hearing impairments have also been assisted by the development of prosthetic devices. The cochlear implant is for people suffering from nerve deafness, who cannot be helped by mere sound amplification provided by normal hearing aids. A set of 22 electrodes is implanted in coillike fashion around the cochlea in order to directly stimulate the auditory nerve. A microphone sends sound waves to a processor implanted in the bone behind the ear, and the processor breaks the sound down into its principal frequencies and sends electrical signals to cochlear areas associated with particular frequencies (Fayad et al., 2008). Electrical recording of cortical responses to sounds in people who had been deaf for more than two decades showed that in the months following installation of a cochlear implant, sounds increasingly "registered" in the auditory cortex (Pantev et al., 2006). With a cochlear implant, deaf people like radio personality Rush Limbaugh can hear everyday sounds such as sirens, and many can understand speech (Meyer et al., 1998; Parkinson et al., 1998). Although the substitution of 22 electrodes for the more than 16,000 hair cells that populate the intact cochlea cannot produce normal auditory experience, cochlear implants have helped many people partially restore their sense of hearing.

THE BIONIC HAND THAT RESTORES TACTILE SENSATIONS

In 2009, researchers in Sweden and Italy announced the development of the SmartHand, a prosthetic device that restores the sense of touch in people who have lost their hands (*ScienceDaily,* 2009, November 11). The SmartHand contains 40 sensors that are connected to the sensory nerves in the arm of an amputee (Figure 5.25). Four motors, also linked to the brain through their attachment to motor nerves in the arm, allow patients to move the fingers in very precise ways. This is the first prosthetic hand that allows the level of control of movement that comes only through tactile feedback. With it, an amputee can actually experience the feeling of stroking a loved one's cheek and can handle delicate objects with just the right amount of pressure. Among the first to receive the device when it is available commercially will be returning soldiers from Iraq and Afghanistan who have lost their hands in battle.

Sensory prosthetics illustrate the ways in which knowledge about sensory phenomena such as phosphenes, the organization of the visual cortex, sound localization, and the place theory of pitch perception can provide the information needed to take advantage of new technological advances. Yet even with all our ingenuity, prosthetic devices are not substitutes for our normal sensory systems, a fact that should increase our appreciation for what nature has given us.

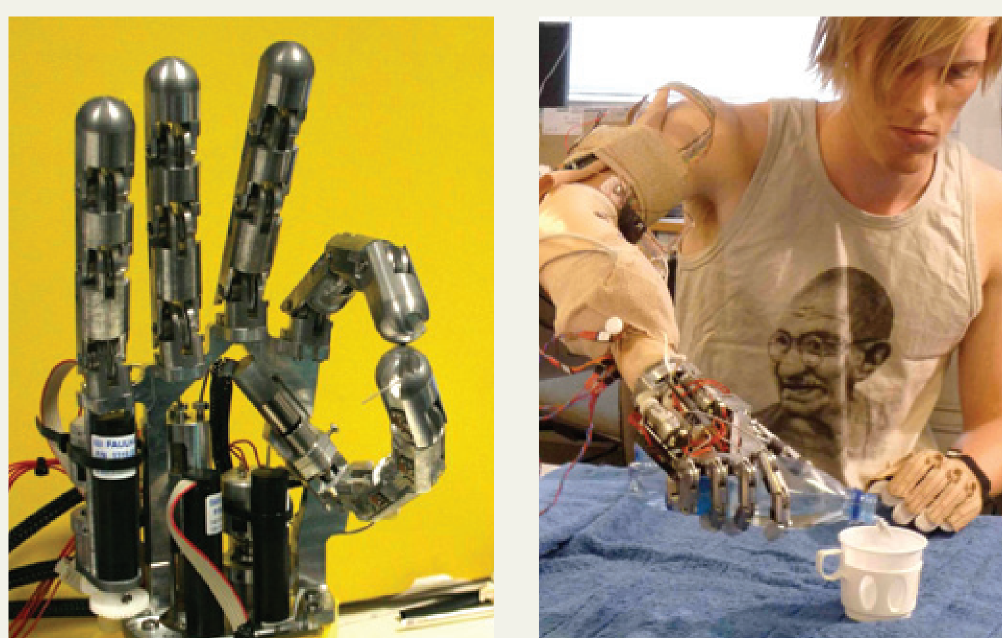


Figure 5.25

Shown here without its skinlike covering, the SmartHand's leads connect to both sensory and motor nerves in the arm. The resulting motor control, combined with sensory feedback from the bionic hand's movements, allows an amputee to perform this precision act without dropping or crushing the soft plastic bottle.

test yourself Audition, Chemical, Skin, and Body Senses

True or false?

1. The frequency theory of pitch perception is limited to frequencies up to about 4,000 hertz.
2. High-frequency sound stimulates the portion of the cochlea close to the oval window.
3. The absolute threshold of hearing for young men is at about 20 decibels.
4. Taste buds are found only on the edges of the tongue.
5. Free nerve endings are pain receptors.
6. Cochlear implants are used for conduction deafness.

ANSWERS: 1-false, 2-true, 3-true, 4-false, 5-true, 6-false

PERCEPTION: THE CREATION OF EXPERIENCE

Sensory systems provide the raw materials from which experiences are formed. Our sense organs do not select what we will be aware of or how we will experience it; they merely transmit as much information as they can through our nervous system. Yet our experiences are not simply a one-to-one reflection of what is external to our senses. Different people may experience the same sensory information in radically different ways, because perception is an active, creative process in which raw sensory data are organized and given meaning.

To create our perceptions, the brain carries out two different kinds of processing functions (Figure 5.26). In **bottom-up processing,** *the system takes in individual elements of the stimulus and then combines them into a unified perception.* Your visual system operates in a bottom-up fashion as you read. Its feature detectors analyze the elements in each letter of every word and then recombine them into your visual perception of the letters and words. In **top-down processing,** *sensory information is interpreted in light of existing knowledge, concepts, ideas, and expectations.* Top-down processing is occurring as you interpret the words and sentences constructed by the bottom-up process. Here you make use of higher-order knowledge, including what you have learned about the meaning of words and sentence construction. Indeed, a given sentence may convey a different personal meaning to you than to another person if you relate its content to some unique personal experiences. Top-down processing accounts for many psychological influences on perception, such as the roles played by our motives, expectations, previous experiences, and cultural learning.

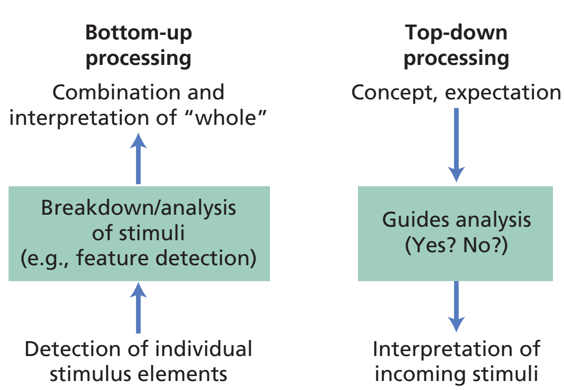


Figure 5.26

Perceptual processing.
Bottom-up perceptual processing builds from an analysis of individual stimulus features to a unified perception. Top-down processing begins with a perceptual whole, such as an expectation or an image of an object, then determines the degree of fit with the stimulus features.

Perception Is Selective: The Role of Attention

As you read these words, 100 million sensory messages may be clamoring for your attention. Only a few of these messages register in awareness; the rest you perceive either dimly or not at all. But you can shift your attention to one of those unregistered stimuli at any time. (For example, how does the big toe of your right foot feel right now?) Attention, then, involves two processes of selection: (1) focusing on certain stimuli and (2) filtering out other incoming information (Luck & Vecera, 2002).

These processes have been studied experimentally through a technique called *shadowing.* Participants wear earphones and listen simultaneously to two messages, one sent through each earphone. They are asked to repeat (or shadow) one of the messages word for word as they listen. Most participants can do this quite successfully, but only at the cost of not remembering what the other message was about. Shadowing experiments demonstrate that we cannot attend completely to more than one thing at a time. But we can shift our attention rapidly back and forth between the two messages, drawing on our general knowledge to fill in the gaps (Bonnel & Hafter, 1998; Sperling, 1984).

Inattentional Blindness

Electrical recording and brain-imaging studies have shown that unattended stimuli register in the nervous system but do not enter into immediate experience (Itti & Rees, 2005). In the visual realm, scientists have coined the term **inattentional blindness** *to refer to the failure of unattended stimuli to register in consciousness* (Mack, 2003). We can look right at something without "seeing" it if we are attending to something else. In one study, several experienced pilots training on flight simulators were so intent on watching the landing instruments, such as the air-speed indicator on the plane's windshield, that they directed their plane onto a runway containing another aircraft (Haines, 1991). In another instance, research participants who were counting the number of passes made during a videotaped basketball game did not notice a woman wearing a gorilla suit who walked across the court, even though she remained in clear sight for more than 5 seconds (Simons & Chabris, 1999). Inattentional blindness is surely relevant to findings that cell phone conversations significantly reduce driving performance in experimental studies (e.g., Golden et al., 2003). It's a bad idea to drive and yack at the same time. It's also a bad idea to drink and drive, as alcohol ingestion increases inattentional blindness (Clifasefi et al., 2006).

Environmental and Personal Factors in Attention

Attention is strongly affected by both the nature of the stimulus and by personal factors. Stimulus characteristics that attract our attention include intensity, novelty, movement, contrast, and repetition. Sexually oriented stimuli are especially attention-grabbing (Krishna, 2009). Advertisers use these properties in their commercials and packaging. Internal factors, such as our motives and interests, act as powerful filters and influence which stimuli in our environment we will notice. For example, when we are hungry, we are especially sensitive to food-related cues. A botanist walking through a park is particularly attentive to the plants; a landscape architect attends primarily to the layout of the park.

People are especially attentive to stimuli that have relevance to their well-being, a tendency that clearly has biological survival value (Oehman et al., 2001). This tendency is shown in experiments in which researchers measure how quickly people focus on and react to threatening versus nonthreatening stimuli. Thus people are quicker to identify an angry-looking face in a crowd than a smiling face (Hansen & Hansen, 1988). If a fearful face or figure is projected on one side of the visual field and a neutral face or figure on the other, measurements of eye movements show faster movements toward the fearful stimulus, showing the capacity of threat-relevant stimuli to capture visual attention (Bannerman et al., 2009).

In the sport of baseball, batters are sometimes forced to avoid pitched balls that might hit them. In an analog of this process, Jeffrey Lin and coworkers (2009) seated participants in front of a video display, then measured their reaction times in response to spherical images that sped from the background. The observers had significantly faster reaction times when the speeding object was coming toward their heads than when its trajectory would barely miss their heads. The investigators suggested that humans have developed a special visual system that unconsciously triggers protective responses to stimuli that are interpreted as threatening. As a real-life illustration of this principle, they point to the 2008 incident shown in Figure 5.27, when an Iraqi

Figure 5.27

President Bush reflexively ducks as an Iraqi reporter hurls a shoe toward the podium, but Iraqi Prime Minister al-Maliki does not.

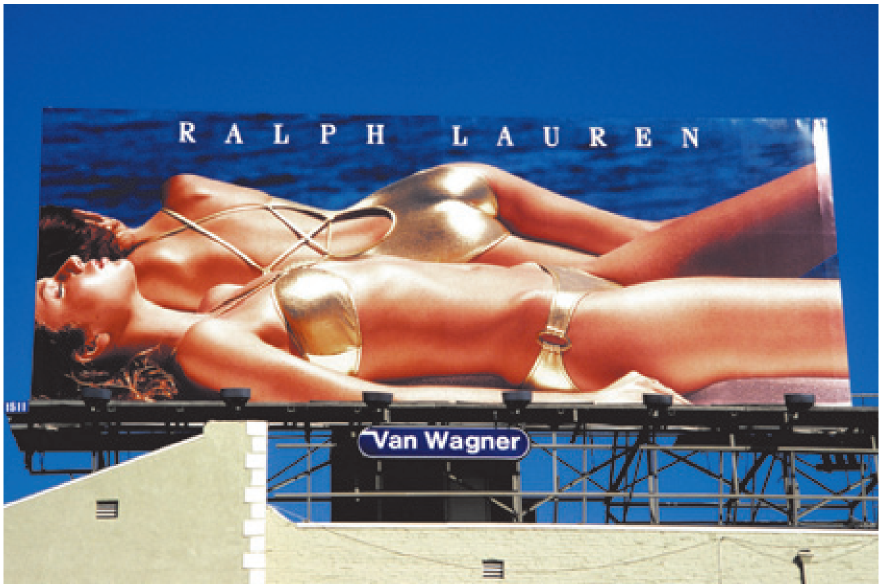


Figure 5.28

Advertisers use attention-attracting stimuli in their advertisements. Personal characteristics of potential customers are also important. What kinds of individuals would be most attentive to this ad?

reporter hurled his shoes at president George Bush during a joint news conference with Iraqi Prime Minister Nouri al-Maliki. Commenting on this scene, Lin stated, "If you look at the shoe-throwing video, you will see that the prime minister doesn't flinch at all. His brain has already categorized the shoe as non-threatening which does not require evasive action. But Bush has categorized the shoe as threatening and triggers an evasive dodge, all within a fraction of a second" (Schwarz, 2009).

Advertisers are adept at using attention-getting stimuli to attract potential customers to their products (Figure 5.28). Sometimes, however, the process backfires, as in the following case.

> A famous model glides down a staircase, removing articles of clothing as she goes. Once inside the car being promoted in this British advertisement, she removes her panties and flings them out the window. The only problem with this wildly popular ad? An informal survey by a Welsh psychologist revealed that the visual image was so compelling that virtually no one remembered the brand of car being advertised. (Clay, 2002, p. 38)

Perceptions Have Organization and Structure

Have you ever stopped to wonder why we perceive the visual world as being composed of distinct objects? After all, the information sent by the retina reflects nothing but an array of varying intensities and frequencies of light energy. The light rays reflected from different parts of a single object have no more natural "belongingness" to one another than those coming from two different objects. Yet we perceive scenes as involving separate objects, such as trees, buildings, and people. These perceptions must be a product of an organization imposed by our nervous system (Jenkin & Harris, 2005; Matthen, 2007). This top-down process of perceptual organization occurs so automatically that we take it for granted. But Dr. Richard, a prominent psychologist who suffered brain damage in an accident, no longer does.

> There was nothing wrong with his eyes, yet the input he received from them was not put together correctly. Dr. Richard reported that if he saw a person, he sometimes would perceive the separate parts of the person as not belonging together in a single body. But if all the parts moved in the same direction, Dr. Richard then saw them as one complete person. At other times, he would perceive people in crowds wearing the same color clothes as "going together" rather than as separate people. He also had difficulty putting sights and sounds together. Sometimes, the movement of the lips did not correspond to the sounds he heard, as if he were watching a badly dubbed foreign movie. Dr. Richard's experience of his environment was thus disjointed and fragmented. (Sacks, 1985, p. 76)

Another, more extreme example of perceptual organization gone awry is synesthesia, which we described at the beginning of this chapter. What, then, are the processes whereby sensory nonsense becomes perceptual sense?

Gestalt Principles of Perceptual Organization

Early in the 20th century, psychologists from the German school of Gestalt psychology set out to discover how we organize the separate parts of our perceptual field into a unified and meaningful whole. *Gestalt* is the German term for "pattern," "whole," or "form." Gestalt theorists were early champions of top-down processing, arguing that the wholes we perceive are often more than (and frequently different from) the sum of their parts. Thus your perception of the photo in Figure 5.29 is likely to be more than "people on a football field."

The Gestalt theorists emphasized the importance of **figure-ground relations,** *our tendency to organize stimuli into a central or foreground figure*

Figure 5.29

As Gestalt psychologists emphasized, what we perceive (in this case, the name spelled out by the band) is more than simply the sum of its individual parts.

and a background. In vision, the central figure is usually in front of or on top of what we perceive as background. It has a distinct shape and is more striking in our perceptions and memory than the background. We perceive borders or contours wherever there is a distinct change in the color or brightness of a visual scene, but we interpret these contours as part of the figure rather than background. Likewise, we tend to hear instrumental music as a melody (figure) surrounded by other chords or harmonies (ground).

Separating figure from ground can be challenging (Figure 5.30), yet our perceptual systems are usually equal to the task. Sometimes, however, what's figure and what's ground is not completely obvious, and the same stimulus can give rise to two different perceptions. Consider Figure 5.31, for example. If you examine it for a while, two alternating but equally plausible perceptions will emerge, one based on the inner portion and the other formed by the two outer portions. When the alternative perception occurs, what was previously the figure becomes the background.

In addition to figure-ground relations, the Gestalt psychologists were interested in how separate stimuli come to be perceived as parts of larger wholes. They suggested that people group and interpret stimuli in accordance with four **Gestalt laws of perceptual organization:** *similarity, proximity, closure, and continuity.* These organizing principles are illustrated in Figure 5.32.

What is your perception of Figure 5.32a? Do you perceive 16 unrelated dots or two triangles formed by different-sized dots? If you see triangles, your perception obeys the Gestalt *law of similarity*, which says that when parts of a configuration are perceived as similar, they will be perceived as belonging together. The *law of proximity* says that elements that are near each other are likely to be perceived as part of the same configuration. Thus most people perceive Figure 5.32b as three sets of two lines rather than six separate lines. Illustrated in Figure 5.32c is the *law of closure,* which states that people tend to close the open edges of a figure or fill in gaps in an incomplete figure, so that their identification of the form (in this case, a circle) is more complete than what is actually there. Finally, the *law of continuity* holds that people link individual elements together so they form a continuous line or pattern that makes sense. Thus Figure 5.32d is far more likely to be seen as combining components a-b and c-d rather than a-d and c-b, which have poor continuity. Or consider Fraser's spiral,

Figure 5.30

Figure-ground relations are important in perception. These amazing body paintings were created by Liu Bolin of Beijing. In a series known as "camouflage," the artist paints people from head to toe so they will blend in with the background.

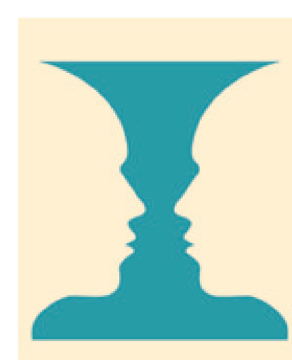
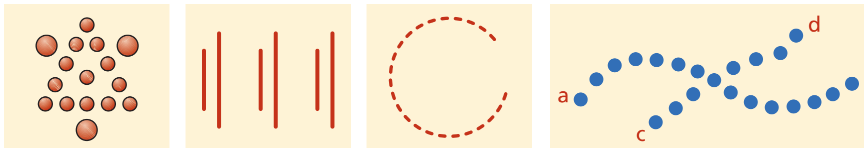


Figure 5.31

One stimulus, two perceptions. This reversible figure illustrates alternating figure-ground relations. It can be seen as a vase or as two people facing one another. Whichever percept exists at the moment is seen as figure against background.



(a) Similarity (b) Proximity (c) Closure (d) Continuity

Figure 5.32

Gestalt perceptual laws.

Among the Gestalt principles of perceptual organization are the laws of (a) similarity, (b) proximity, (c) closure, and (d) continuity. Each principle causes us to organize stimuli into wholes that are greater than the sums of their parts.

shown in Figure 5.33, which is not really a spiral at all! (To demonstrate, trace one of the circles with a pencil.) We perceive the concentric circles as a spiral because, to our nervous system, a spiral gives better continuity between individual elements than does a set of circles. The spiral is created by us, not by the stimulus.

Perception Involves Hypothesis Testing

Recognizing a stimulus implies that we have a **perceptual schema**—*a mental representation or image containing the critical and distinctive features of a person, object, event, or other perceptual phenomenon.* Schemas provide mental templates that allow us to classify and identify sensory input in a top-down fashion.

Imagine, for example, that a person approaches you and calls out your name. Who is this person? If the stimuli match your internal schemas of your best friend's appearance and voice closely enough, you identify the person as your friend (McAdams & Drake, 2002). Many political cartoonists have an uncanny ability to capture the most noteworthy facial features of famous people so that we can easily recognize the person represented by even the simplest line sketch.

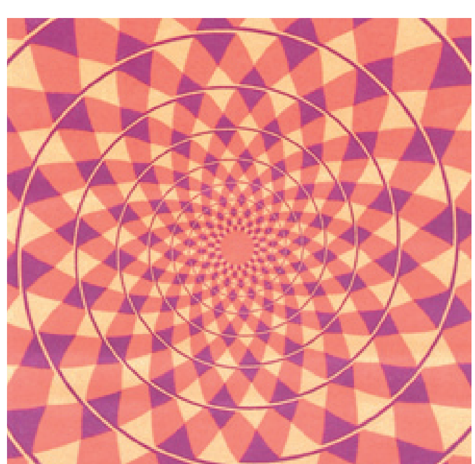


Figure 5.33

A spiral that isn't.

Fraser's spiral illustrates the Gestalt law of continuity. If you follow any part of the "spiral" with a pencil, you will find that it is not a spiral at all but a series of concentric circles. The "spiral" is created by your nervous system because that perception is more consistent with continuity of the individual elements.

Perception is, in this sense, an attempt to make sense of stimulus input, to search for the best interpretation of sensory information we can arrive at based on our knowledge and experience. Likening perception to the scientific process described in Chapter 2, Richard L. Gregory (1966, 2005) suggested that each of our perceptions is essentially a hypothesis about the nature of the object or, more generally, the meaning of the sensory information. The perceptual system actively searches its gigantic library of internal schemas for the interpretation that best fits the sensory data. In some instances, sensory information fits two different internal representations, and there is not enough information to permanently rule out one of them in favor of the other. For example, examine the Necker cube, shown in Figure 5.34. If you stare at the cube for a while, you will find that it changes before your very eyes as your nervous system tries out a new perceptual hypothesis.

Perception Is Influenced by Expectations: Perceptual Sets

During a Mideast crisis in 1988, the warship USS *Vincennes* was engaged in a pitched battle with several Iranian gunboats. Suddenly, the *Vincennes*'s advanced radar system detected an aircraft taking off from a military-civilian airfield in Iran and heading straight toward the American vessel. Radar operators identified the plane as an Iranian F-14 fighter, known to carry lethal missiles

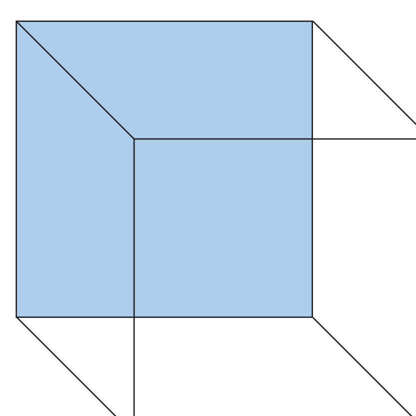


Figure 5.34

Reversible perceptions.

The same stimulus can give rise to different perceptions. Stare at this Necker cube for a while; the front of the cube will suddenly become the back, and it will appear as if you're viewing the cube from a different angle.

used earlier in a damaging attack on another U.S. warship. Repeated requests to the plane to identify itself yielded no response. The plane was now only 10 miles from the ship and, according to the crewmen watching the radar, descending toward the *Vincennes* on an attack course. When a final warning evoked no response, the *Vincennes*'s captain gave the command to fire on the plane. Two surface-to-air missiles streaked into the sky. Moments later, all that remained of the plane was a shower of flaming debris.

The jubilation and relief of the *Vincennes*'s crew was short-lived. Soon the awful truth was known. The plane they had shot down was not an attacking F-14 warplane but a commercial airliner carrying 290 passengers, all of whom died when the aircraft was destroyed. Moreover, videotape recordings of the electronic information used by the crew to identify the plane and its flight pattern showed conclusively that the aircraft was not an F-14 and that it had actually been climbing to its cruising altitude rather than descending toward the ship.

How could such a tragic error have been made by a well-trained and experienced crew with access to the world's most sophisticated radar equipment? At a congressional hearing on the incident, several prominent perception researchers reconstructed the psychological environment that could have caused the radar operators' eyes to lie.

Clearly, the situation was stressful and dangerous. The *Vincennes* was already under attack by Iranian gunboats, and other attacks could be expected. It was easy for the radar operators, observing a plane taking off from a military field and heading toward the ship, to interpret this as a prelude to an air attack. The *Vincennes*'s crew was determined to avoid the fate of the other American warship, producing a high level of vigilance for any stimuli that suggested an impending attack. Fear and expectation thus created a psychological context within which the sensory input from the computer system was interpreted in a top-down fashion. The perception that the aircraft was a warplane and that it was descending toward the ship fit the crew's expectations and fears, and it became the reality that they experienced. They had a **perceptual set**—*a readiness to perceive stimuli in a particular way.* Sometimes, believing is seeing.

Stimuli Are Recognizable under Changing Conditions: Perceptual Constancies

When a closed door suddenly swings open, it casts a different image on our retina, but we still perceive it as a door. Our perceptual hypothesis remains the same. Were it not for **perceptual constancies,** *which allow us to recognize familiar stimuli under varying conditions,* we would have to literally rediscover what something is each time it appeared under different conditions. Thus you can recognize a tune even if it is played in a different octave, as long as the relations among its notes are maintained. You can detect the flavor of a particular spice even when it occurs in foods having very different tastes.

In vision, several constancies are important. *Shape constancy* allows us to recognize people and other objects from many different angles, as in the case of the swinging door. Perhaps you have had the experience of sitting up front and off to one side of the screen in a crowded movie theater. At first the picture probably looked distorted, but after a while your visual system corrected for the distortion and objects on the screen looked normal again.

Because of *brightness constancy,* the relative brightness of objects remains the same under different conditions of illumination, such as full sunlight and shade. Brightness constancy occurs because the ratio of light intensity between an object and its surroundings is usually constant. The actual brightness of the light that illuminates an object does not matter, as long as the same light intensity illuminates both the object and its surroundings.

When we take off in an airplane, we know that the cars on the highway below are not shrinking and becoming the size of ants. *Size constancy* is the perception that the size of objects remains relatively constant even though images on our retina change in size with variations in distance. Thus a man who is judged to be 6 feet tall when standing 5 feet away is not perceived to be 3 feet tall at a distance of 10 feet, even though the size of his image on the retina is reduced to half its original size (Figure 5.35).

thinking critically

WHY DOES THAT RISING MOON LOOK SO BIG?

Just before bedding down for the night on a backpacking trip, a friend of ours poked his head outside of his tent and gasped to his wife, "Look at the moon! Just look at that moon!" Indeed, a gorgeous full moon had just come over the horizon, and it was so enormous that it dwarfed the mammoth peaks surrounding them. The couple gazed at it in wonder for a few minutes and then retired into their tent. Later that night, they looked outside again only to see a rather small, ordinary full moon approaching the zenith.

You too may have exclaimed over the size of a rising moon, only to notice later that the moon, well above the horizon, seemed to have shrunk. What can explain this phenomenon? Think about it, then see page 172.

Figure 5.35

Who's bigger?

Size constancy based on distance cues causes us to perceive the person in the background as being of normal size. When the same stimulus is seen in the absence of the distance cues, size constancy breaks down. The two men no longer look similar in size, nor do the photographic images of the man in the blue shirt.

Figure 5.36

The demands faced by a batter in judging the speed, distance, and movements of a pitched baseball within thousandths of a second underscore the capabilities of the visual perceptual system.

PERCEPTION OF DEPTH, DISTANCE, AND MOVEMENT

The ability to adapt to a spatial world requires that we make fine distinctions involving distances and the movement of objects within the environment. Humans are capable of great precision in making such judgments. Consider, for example, the perceptual task faced by a baseball batter (Figure 5.36). A fastball thrown by the pitcher at 90 miles per hour from 60 feet will reach the batter who is trying to hit it in about 42/100 of a second. A curveball thrown at 80 miles per hour will reach the hitting zone in 47/100 of a second, a difference of only 5/100 of a second but a world of difference for timing and hitting the pitch. Within the first 6 to 8 feet of a ball's flight from the pitcher's hand (an interval of about 25/1,000 of a second), the batter must correctly judge the speed, spin, and location of the pitch. If any of the judgments are wrong, the hitter will probably be unable to hit a fair ball, for the ball will be in the bat's contact zone for only 2/1,000 of a second (Adair, 1990). The perceptual demands of such a task are imposing indeed—as are the salaries earned by those who can perform this task consistently. How does the visual perception system make such judgments?

Depth and Distance Perception

One of the more intriguing aspects of visual perception is our ability to perceive depth. The retina receives information in only two dimensions (length and width), but the brain translates these cues into three-dimensional perceptions. It does this by using both **monocular depth cues,** *which require only one eye,* and **binocular depth cues,** *which require both eyes.*

Monocular Depth Cues

Judging the relative distances of objects is one important key to perceiving depth. When artists paint on a flat canvas, they depend on a variety of monocular cues to create perceptions of depth in their pictures. One such cue is *patterns of light and shadow.* The 20th-century artist M. C. Escher skillfully used light and shadow to create the three-dimensional effect shown in Figure 5.37. The depth effect is as powerful when you close one eye as it is when you use both.

Another cue, *linear perspective,* refers to the perception that parallel lines converge, or angle toward one another, as they recede into the distance. Thus, if you look down railroad tracks, they appear to angle toward one another with increased distance, and we use this as a depth cue. The same occurs with the edges of a highway or the sides of an elevator shaft. *Interposition,* in which objects closer to us may cut off part of our view of more distant objects, provides another cue for distance and depth.

An object's *height in the horizontal plane* provides another source of information. For example, a ship 5 miles offshore appears in a higher plane

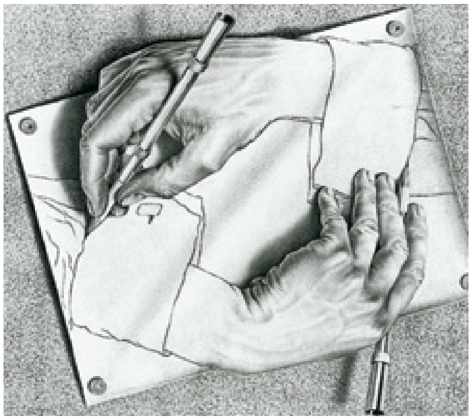


Figure 5.37

Patterns of light and shadow can serve as monocular depth cues, as shown in *Drawing Hands,* by M. C. Escher.

Figure 5.38

In this mural, painted on the Mississippi River flood wall at Cape Girardeau, Missouri, the artist has skillfully used seven monocular depth cues to create a striking 3-dimensional depth effect. (1) Linear perspective is produced by the converging lines of the plank. (2) The people and objects in the background are smaller than those in the foreground (relative size). (3) The background is in a higher horizontal plane than the foreground. (4, 5) The objects in the background are less detailed than the "closer" ones (texture and clarity). (6) The people and objects in the foreground cut off parts of those "behind" them in the background (interposition). (7) Light and shadow are also used to create a depth effect.

and closer to the horizon than does one that is only 1 mile from shore. *Texture* is a fifth cue, because the texture or grain of an object appears finer as distance increases. Likewise, *clarity* can be an important cue for judging distance; we can see nearby hills more clearly than ones that are far away, especially on hazy days.

Relative size is yet another basis for distance judgments. If we see two objects that we know to be of similar size, then the one that looks smaller will be judged to be farther away. For example, this cue may figure prominently in the moon illusion.

None of these monocular cues involve movement of the object(s), but a final monocular cue, *motion parallax,* tells us that if we are moving, nearby objects appear to move faster in the opposite direction than do faraway ones. Like the other monocular cues, motion provides us with information that we can use to make judgments about distance and therefore about depth.

Figure 5.38 illustrates all of the monocular cues just described, with the exception of motion parallax.

Binocular Depth Cues

The most dramatic perceptions of depth arise with binocular depth cues, which require the use of both eyes. For an interesting binocular effect, hold your two index fingers about 6 inches in front of your eyes with their tips about 1 inch apart. Focus on your fingers first, then focus beyond them across the room. Doing so will produce the image of a third finger between the other two. This third finger will disappear if you close either eye.

Most of us are familiar with the delightful depth experiences provided by View-Master slides and 3-D movies watched through special glasses. These devices make use of the principle of **binocular disparity,** *in which each eye sees a slightly different image.* Within the brain, the visual input from the two eyes is analyzed by feature detectors that are attuned to depth (Howard, 2002; Livingstone & Hubel, 1994). Some of the feature detectors respond only to stimuli that are either in front of or behind the point on which we are fixing our gaze. The responses of these depth-sensitive neurons are integrated to produce our perception of depth (Goldstein, 2002).

A second binocular distance cue, **convergence,** *is produced by feedback from the muscles that turn your eyes inward to view a close object.* You can experience this cue by holding a finger about 1 foot in front of your face and then moving it slowly toward you. Messages sent to your brain by the eye muscles provide it with a depth cue.

Perception of Movement

The perception of movement is a complex process, sometimes requiring the brain to integrate information from several different senses. To demonstrate, hold a pen in front of your face. Now, while holding your head still, move the pen back and forth. You will perceive the pen as moving. Now hold the pen still and move your head back and forth at the same rate of speed. In both cases, the image of the pen moved across your retina in about the same way. But when you moved your head, your brain took into account input from your kinesthetic and vestibular systems and concluded that you were moving but the pen was not.

The primary cue for perceiving motion is the movement of the stimulus across the retina (Sekuler et al., 2002). Under optimal conditions, a retinal image need move only about one fifth the diameter of a single cone for us to detect movement (Nakayama & Tyler, 1981). The relative movement of an object against a structured background is also a movement cue (Gibson, 1979). For example, if you fixate on a bird in flight, the relative motion of the bird against its background is a strong cue for perceived speed of movement.

The illusion of smooth motion can be produced if we arrange for the sequential appearance of two or more stimuli. Gestalt psychologist Max Wertheimer (1912) demonstrated this in his studies of **stroboscopic movement,** *illusory movement produced when a light is briefly flashed in darkness and then, a few milliseconds later, another light is flashed nearby.* If the timing is just right, the first light seems to move from one place to the other in a manner indistinguishable from real movement.

Stroboscopic movement (termed the "phi phenomenon" by Wertheimer) has been used commercially in numerous ways. For example, think of the strings of successively illuminated lights on theater marquees that seem to move endlessly around the border or that spell out messages in a moving script. Stroboscopic movement is also the principle behind motion pictures, which consist of a series of still photographs, or frames, that are projected on a screen in rapid succession with dark intervals in between (Figure 5.39). The rate at which the frames are projected is critical to our perception of smooth movement. Early movies, such as the silent films of the 1920s, projected the stills at only 16 frames per second, and the movements appeared fast and jerky. Today the usual speed is 24 frames per second, which more perfectly produces an illusion of smooth movement. Television presents at 30 images per second.

ILLUSIONS: FALSE PERCEPTUAL HYPOTHESES

Our analysis of perceptual schemas, hypotheses, sets, and constancies allows us to understand some interesting perceptual experiences known as **illusions,** *compelling but incorrect perceptions.* Such perceptions can be understood as erroneous perceptual hypotheses about the nature of a stimulus. Illusions are not only intriguing and sometimes delightful visual experiences, but they also provide important information about how our perceptual processes work under normal conditions (Gregory, 2005).

Ironically, most visual illusions can be attributed to perceptual constancies that ordinarily help us perceive more accurately (Frisby, 1980). For example, size constancy results in part from our ability to use distance cues to judge the size of objects. But as we saw in the discussion of the moon illusion, distance cues can sometimes fool us. In the Ponzo illusion, shown in Figure 5.40, the depth cues of linear perspective (the tracks converging) and height of the horizontal plane provide distance cues that make the upper bar appear farther away than the lower bar. Because it seems

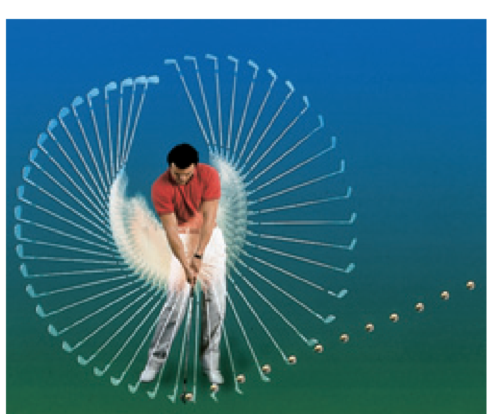


Figure 5.39

Stroboscopic movement is produced in moving pictures as a series of still photographs projected at a rate of 24 per second.

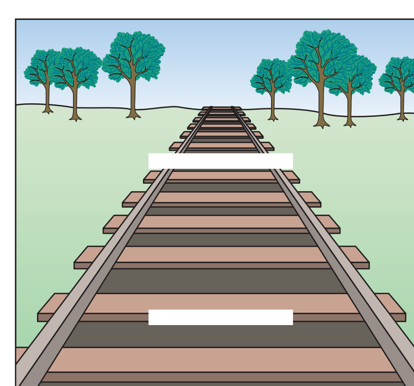


Figure 5.40

The Ponzo illusion.

Which of the white lines is longer? Measure them and see. The distance cues provided by the converging railroad tracks affect size perception and disrupt size constancy.

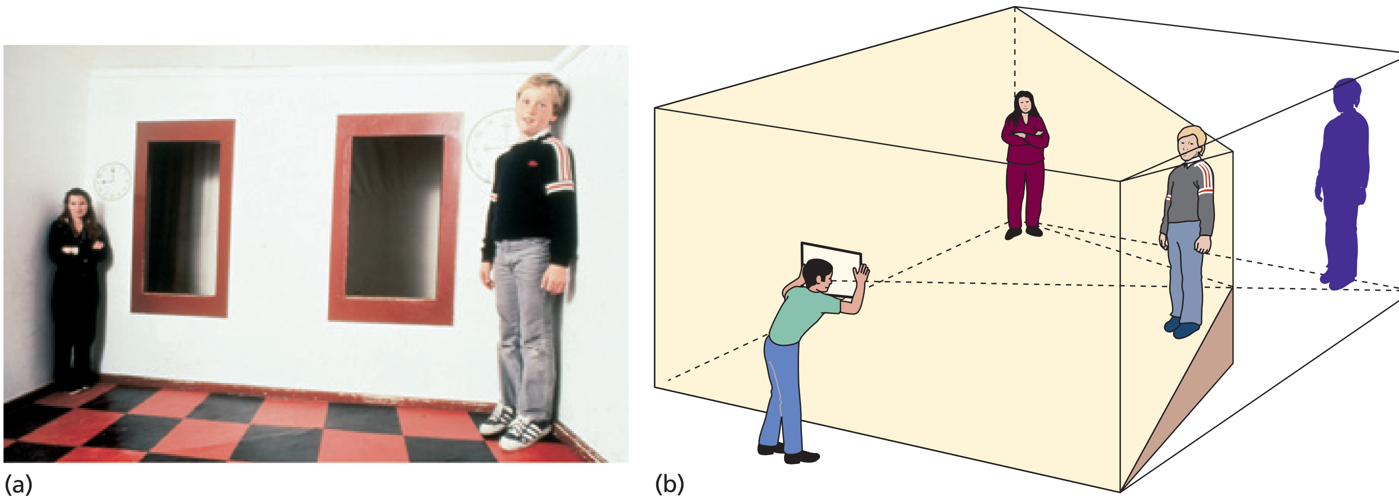


Figure 5.41

A size illusion.

(a) The Ames Room produces a striking size illusion because it is designed to appear rectangular. (b) The room, however, is actually trapezoidal, and the figure on the left is actually much farther away from the viewer than the one on the right and thus appears smaller. We perceive the boy as if he were the purple figure, making him appear very large.

thinking critically

EXPLAIN THIS STRIKING ILLUSION

We'd like you to experience a truly interesting illusion. To do so, all you need is a piece of fairly heavy paper and a little patience. Fold the piece of paper lengthwise down the middle, and set it on a table with one of the ends facing you like an open tent, as shown in Figure 5.43. Close one eye and, from slightly above the object, stare at a point midway along the top fold of the paper. After a while the paper will suddenly "stand up" and look like a corner viewed from the inside. When this happens, gently move your head back and forth while continuing to view with one eye. The movement will produce a striking perception. Can you explain what you now see? For a discussion of this illusion, see page 172.

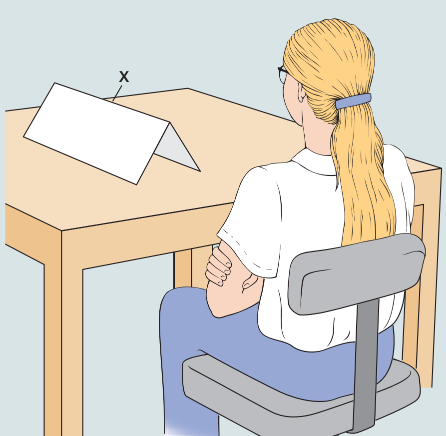
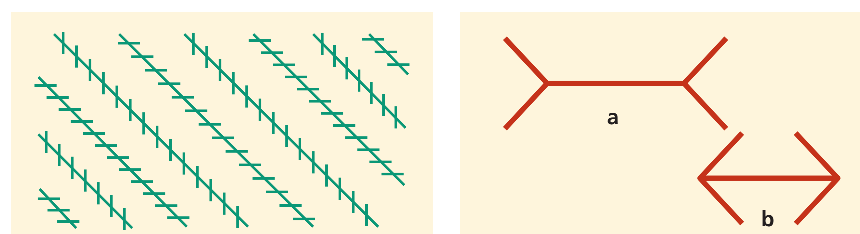


Figure 5.43

Try this visual experience.



The long lines are actually parallel, but the small lines make them appear crooked.

The Müller-Lyer illusion. Which line, a or b, is longer? Compare them with a ruler.

Figure 5.42

Context-produced geometric illusions.

farther away, the perceptual system concludes that the bar in the background must be larger than the bar in the foreground, despite the fact that the two bars cast retinal images of the same size.

Distance cues can be manipulated to create other size illusions. To illustrate this, Adelbert Ames constructed a special room. Viewed through a peephole with one eye, the room's scene presents a startling size reversal (Figure 5.41a). Our perceptual system assumes that the room has a normal rectangular shape because, in fact, most rooms do. Monocular depth cues do not allow us to see that, in reality, the left corner of the room is twice as far away as the right corner (Figure 5.41b). As a result, size constancy breaks down, and we base our judgment of size on the sizes of the retinal images cast by the two people.

The study of perceptual constancies shows that our perceptual hypotheses are strongly influenced by the context, or surroundings, in which a stimulus occurs. Figure 5.42 shows two

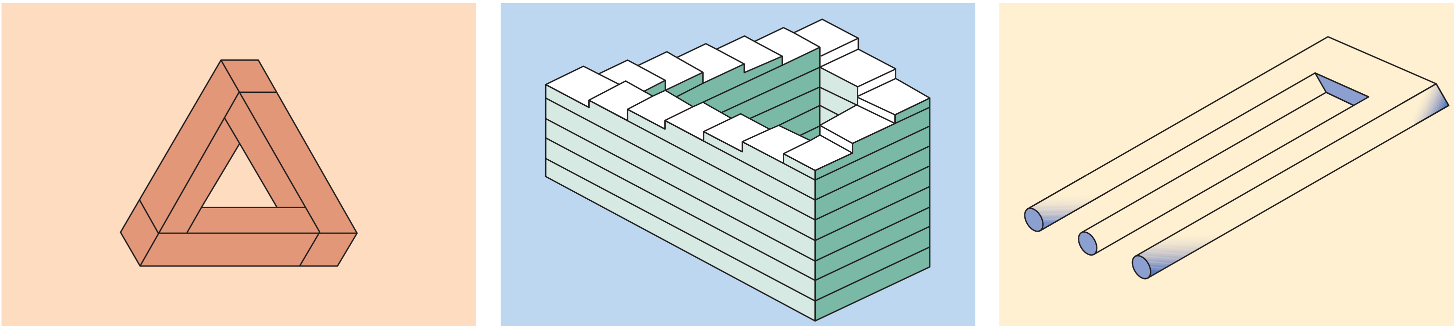


Figure 5.44

Things that couldn't be.
Monocular depth cues are cleverly manipulated to produce an impossible triangle, a never-ending staircase, and the "devil's tuning fork."

examples of how context can produce illusory perceptions.

Some of the most intriguing perceptual distortions are produced when monocular depth cues are manipulated to produce a figure or scene whose individual parts make sense but whose overall organization is "impossible" in terms of our existing perceptual schemas. Figure 5.44 shows three impossible figures. In each case, our brain extracts information about depth from the individual features of the objects, but when this information is put together and matched with our existing schemas, the percept that results simply doesn't make sense. The "devil's tuning fork," for example, could not exist in our universe. It is a two-dimensional image containing paradoxical depth cues. Our brain, however, automatically interprets it as a three-dimensional object and matches it with its internal schema of a fork—a bad fit indeed. The never-ending staircase provides another compelling example of an impossible scene that seems perfectly reasonable when we focus only on its individual elements.

Illusions are not only personally and scientifically interesting, but they can have important real-life implications. Our "Research Close-up" describes one scientist's search for an illusion having life-and-death implications.

Research Close-up

Stalking a Deadly Illusion

SOURCE: CONRAD L. KRAFT (1978). A psychophysical contribution to air safety: Simulator studies of illusions in night visual approaches. In H. L. Pick, Jr., H. W. Leibowitz, J. E. Singer, A. Steinschneider, and H. W. Stevenson (Eds.), *Psychology: From research to practice*. New York: Plenum.

INTRODUCTION

When the Boeing Company introduced the 727 jet airliner in the mid-1960s, it was the latest word in aviation technology. The plane performed well in test flights, but four fatal crashes soon after it was placed in service raised fears that there might be a serious flaw in its design.

The first accident occurred as a 727 made its approach to Chicago over Lake Michigan on a clear night. The plane plunged into the lake 19 miles offshore. About a month later, another 727 glided in over the Ohio River to land in Cincinnati. Unaccountably, it struck the ground about 12 feet below the runway elevation and burst into flames. The third accident occurred as an aircraft approached Salt Lake City over dark land. The lights of the city twinkled in the distance, but the plane made too rapid a descent and crashed short of the runway. Months later, a Japanese airliner approached Tokyo at night. The flight ended tragically as the plane, its landing gear not yet lowered, struck the waters of Tokyo Bay 6 miles from the runway.

Analysis of these four accidents, as well as others, suggested a common pattern. All occurred at night under clear weather conditions, so the pilots were operating under visual flight rules rather than performing instrument landings. In each instance, the plane was approaching city lights over dark areas of water or land. In all cases, the lights in the background terrain sloped upward to varying degrees. Finally, all of the planes crashed short of the runway. These observations led a Boeing industrial psychologist, Conrad L. Kraft,

Figure 5.45

Conrad Kraft, a Boeing psychologist, created an apparatus to study how visual cues can affect the simulated landings of airline pilots. Pilots approached Nightertown in a simulated cockpit. The computer-controlled city could be tilted to reproduce the illusion thought to be responsible for fatal air crashes.

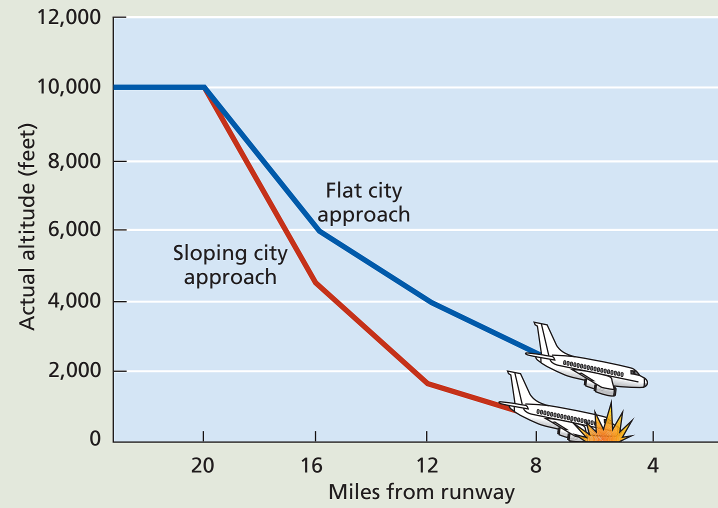


Figure 5.46

Misperceptions of experienced pilots.
The illusion created by upward-sloping city lights caused even highly experienced pilots to overestimate their altitude, and 11 of the 12 flight instructors crashed short of the runway. When the lights were flat, all the pilots made perfect approaches. Source: Based on Kraft, 1978.

to suspect that the cause of the crashes might be pilot error based on some sort of visual illusion.

METHOD

To test this possibility, Boeing engineers constructed an apparatus to simulate night landings (Figure 5.45). It consisted of a cockpit and a miniature lighted city named Nightertown. The city moved toward the cockpit on computer-controlled rollers, and it could be tilted to simulate various terrain slopes. The pilot could control simulated air speed and rate of climb and descent, and the Nightertown scene was controlled by the pilot's responses just as a true visual scene would be.

The participants were 12 experienced Boeing flight instructors who made virtual-reality landings at Nightertown under systematically varied conditions created by the computerized simulator. All of their landings were visual landings so as to be able to test whether a visual illusion was occurring. Every aspect of their approach and the manner in which they controlled the aircraft were measured precisely.

RESULTS

The flight instructors' landings were nearly flawless until Kraft duplicated the conditions of the fatal crashes by having the pilots approach an upward-sloping distant city over a dark area. When this occurred, the pilots were unable to detect the upward slope, assumed that the background city was flat, and consistently overestimated their approach altitude. On a normal landing, the preferred altitude at 4.5 miles from the runway is about 1,240 feet. As Figure 5.46 shows, the pilots approached at about this altitude when the simulated city was in a flat position. But when it was sloped upward, 11 of the 12 experienced pilot instructors crashed about 4.5 miles short of the runway.

CRITICAL DISCUSSION

This study, considered a classic by many psychologists, shows the value of studying behavior under highly controlled conditions and with precise measurements. By simulating the conditions under which the fatal crashes had occurred, Kraft identified the visual illusion that was the source of pilot error. He showed that the perceptual hypotheses of the flight instructors, like those of the pilots involved in the real crashes, were tragically incorrect. It would have been ironic if one of the finest jetliners ever built had been removed from service because of presumed mechanical defects while other aircraft remained aloft and at risk for tragedy.

Kraft's research not only saved the 727 from months—or perhaps years—of needless mechanical analysis but, more important, it also identified a potentially deadly illusion and the precise conditions under which it occurred. On the basis of Kraft's findings, Boeing recommended that pilots attend carefully to their instruments when landing at night, even under perfect weather conditions. Today, commercial airline pilots are required to make instrument landings not only at night but also during the day.

RESEARCH DESIGN

Question: Is a visual illusion causing fatal airline crashes?

Type of Study: *Experimental*

Independent Variable
Controlled variations in the terrain slope of Nightertown

→

Dependent Variable
Measures of flight instructors' landing approaches

EXPERIENCE, CRITICAL PERIODS, AND PERCEPTUAL DEVELOPMENT

Development of sensory and perceptual systems results from the interplay of biological and experiential factors. Genes program biological development, but this development is also influenced by environmental experiences. For example, if you were to be blinded in an accident and later learned to read Braille, the area of the somatosensory cortex that is devoted to the fingertips would enlarge over time as it borrowed other neurons to increase its sensitivity (Pool, 1994). By the time they are old enough to crawl, children placed on a "visual cliff" formed by a glass-covered table that suddenly drops off beneath the glass will not ordinarily venture over the edge (Figure 5.47). This aversion may result from the interaction of innate depth-perception abilities and previous experience (Gibson & Walk, 1960).

What might a lifetime of experience in a limited environment do to perceptual abilities that seem innate? Sometimes, conditions under which people live create natural experiments that help provide answers. For example, the BaMbuti pygmies, who live in the rain forests of Central Africa, spend their lives in a closed-in green world of densely packed trees without open spaces. The anthropologist C. M. Turnbull (1961) once brought a man named Kenge out of the forest to the edge of a vast plain. A herd of buffalo grazed in the distance. To Turnbull's surprise, Kenge remarked that he had never seen insects of that kind. When told that they were buffalo, not insects, Kenge was deeply offended and felt that Turnbull was insulting his intelligence. To prove his point, Turnbull drove Kenge in his jeep toward the animals. Kenge stared in amazement as the "insects" grew into buffalo before his eyes. To explain his perceptual experience to himself, he concluded that witchcraft was being used to fool him. Kenge's misperception occurred as a failure in size constancy. Having lived in an environment without open spaces, he had no experience in judging the size of objects at great distances.

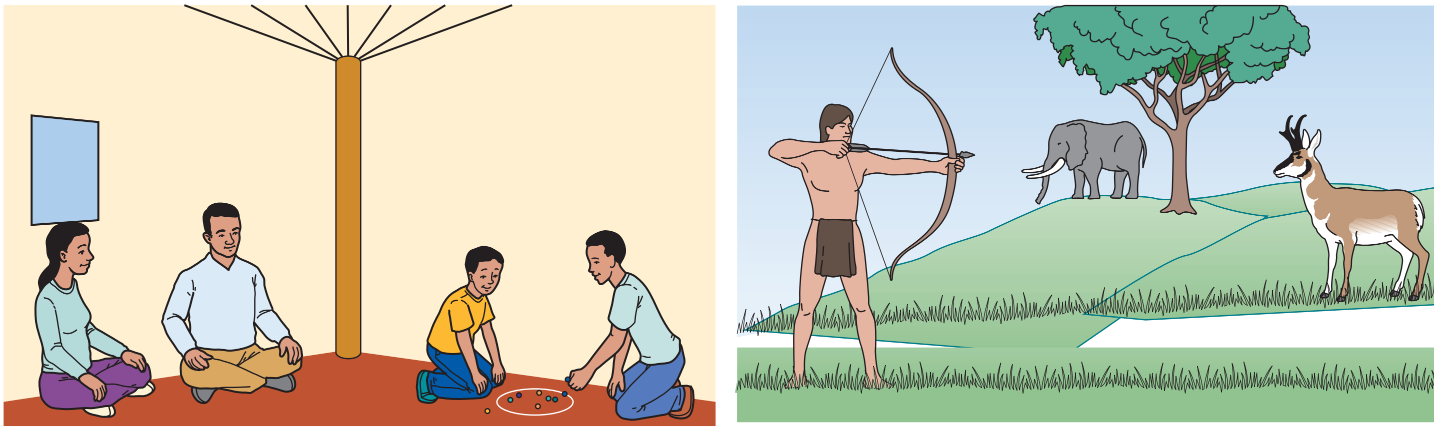
As noted earlier, when light passes through the lens of the eye, the image projected on the retina is reversed, so that right is left and up is down. In 1896, perception researcher George Stratton created a special set of glasses that undid this reversal, thereby becoming the first human ever to have a right-side-up image on his retina while standing upright. Reversing how nature and a lifetime of experience had fashioned his perceptual system disoriented Stratton at first. The ground and his feet were now up, and he had to put on his hat from the bottom up. He had to reach to his left to touch something he saw on his right. Stratton suffered from nausea and couldn't eat or get around for several days. Gradually, however, he adapted to his inverted world, and by the end of 8 days he was able to successfully reach for objects and walk around. Years later, people who wore inverting lenses for longer periods of time did the same. Some were able to ski down mountain slopes or ride motorcycles while wearing the lenses, even though their visual world remained upside down and never became normal for them. When they removed the inverting lenses, they had some initial problems but soon readapted to the normal visual world (Dolezal, 1982).

Figure 5.47

Eleanor Gibson and Richard Walk constructed this "visual cliff" with a glass-covered drop-off to determine whether crawling infants and newborn animals can perceive depth. Even when coaxed by their mothers, young children refuse to venture onto the glass over the cliff. Newborn animals also avoid the cliff.

Cross-Cultural Research on Perception

As far as we know, humans come into the world with the same perceptual abilities regardless of where they are born. From that point on, however, the culture they grow up in helps determine the kinds of perceptual learning experiences they



(a) (b)

Figure 5.48

Does culture influence perception?

(a) What is the object above the woman's head? East Africans had a far different answer than did North Americans and Europeans. (b) Cultural differences also occurred when people were asked which animal the archer was about to shoot. SOURCES: (a) Adapted from Gregory & Gombrich, 1973; (b) Adapted from Hudson, 1960.

have. Cross-cultural research can help identify which aspects of perception occur in all people, regardless of their culture, as well as perceptual differences that result from cultural experiences (Posner & Rothbart, 2007b). Although there are far more perceptual similarities than differences among the peoples of the world, the differences that do exist show us that perception can indeed be influenced by experience.

Consider the perception of a picture that depends on both the nature of the picture and characteristics of the perceiver. In Figure 5.48a, what is the object above the woman's head? In one study, most North Americans and Europeans instantly identified it as a window. They also tended to see the family sitting inside a dwelling. But when the same picture was shown to East Africans, nearly all perceived the object as a basket or box that the woman was balancing on her head. To them, the family was sitting outside under a tree (Gregory & Gombrich, 1973). These interpretations were more consistent with their own cultural experiences.

In our earlier discussion of monocular depth cues, we used paintings such as the flood wall mural in Figure 5.38 to illustrate monocular depth perception. In Western culture, we have constant exposure to two-dimensional pictures that our perceptual system effortlessly turns into three-dimensional perceptions. Do people who grow up in cultures that do not expose them to pictures have the same perceptions? When presented with the picture in Figure 5.48b and asked which animal the hunter was about to shoot, tribal African people answered that he was about to kill the "baby elephant." They did not use the monocular cues that cause Westerners to perceive the man as hunting the antelope and to view the elephant as an adult animal in the distance (Hudson, 1960).

Illusions occur when one of our common perceptual hypotheses is in error. Earlier we showed you the Müller-Lyer illusion (see Figure 5.42), in which a line appears longer when the V-shaped lines at its ends radiate outward rather than inward. Westerners are very susceptible to this illusion. They have learned that in their "carpentered" environment, which has many corners and square shapes, inward-facing lines occur when corners are closer and outward-facing lines occur when they are farther away. But when people from other cultures who live in more rounded environments are shown the Müller-Lyer stimuli, they are more likely to correctly perceive the lines as equal in length (Segall et al., 1966). They do not fall prey to a perceptual hypothesis that normally is correct in an environment like ours that is filled with sharp corners but wrong when applied to the lines in the Müller-Lyer illusion (Deregowski, 1989).

Cultural learning affects perceptions in other modalities as well. Our perceptions of tastes, odors, and textures are strongly influenced by our cultural experiences. A taste that might produce nausea in one culture may be considered delicious in another. The taste and gritty texture experienced when chewing a large raw insect or the rubbery texture of a fish eye may appeal far less to you than it would to a person from a culture in which that food is a staple.

Critical Periods: The Role of Early Experience

The examples in the preceding section suggest that experience is essential for the development of perceptual abilities. For some aspects of perception, there are also **critical periods** *during which certain kinds of experiences must occur if perceptual abilities and the brain mechanisms that underlie them are to develop normally.* If a critical period passes without the experience occurring, it is too late to undo the deficit that results.

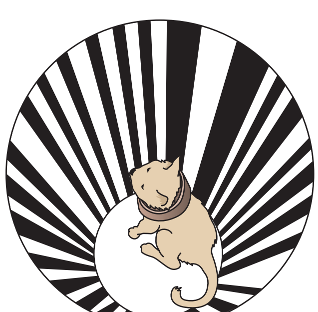
Earlier we saw that the visual cortex has feature detectors composed of neurons that respond only to lines at particular angles. What would happen if newborn animals grew up in a world in which they saw some angles but not others? In a classic experiment, British researchers Colin Blakemore and Grahame Cooper (1970) created such a world for newborn kittens. The animals were raised in the dark except for a 5-hour period each day during which they were placed in round chambers that had either vertical or horizontal stripes on the walls. Figure 5.49a shows one of the kittens in a vertically striped chamber. A special collar prevented the kittens from seeing their own bodies while they were in the chamber, guaranteeing that they saw nothing but stripes.

When the kittens were 5 months old, Blakemore and Cooper presented them with bars of light at differing angles and used microelectrodes to test the electrical responses of individual feature-detector cells in their visual cortex. The results for the kittens raised in the vertically striped environment are shown in Figure 5.49b. As you can see, the kittens had no cells that fired in response to horizontal stimuli, resulting in visual impairments. They also acted as if they could not see a pencil when it was held in a horizontal position and moved up and down in front of them. However, as soon as the pencil was rotated to a vertical position, the animals began to follow it with their eyes as it was moved back and forth.

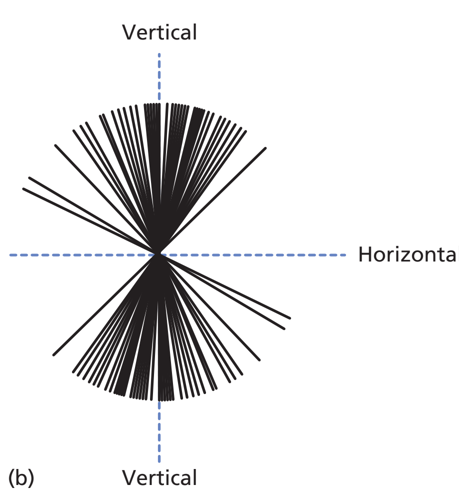
As you might expect, the animals raised in the horizontally striped environment showed the opposite effect. They had no feature detectors for vertical stimuli and did not seem to see them. Thus the cortical neurons of both groups of kittens developed in accordance with the stimulus features of their environments.

Other visual abilities also require early exposure to the relevant stimuli. Yoichi Sugita (2004) raised infant monkeys in rooms illuminated with only monochromatic light. As adults, these monkeys were clearly deficient in color perception. They had particular difficulty with color constancy, being unable to recognize the same colors under changing brightness conditions.

Some perceptual abilities are influenced more than others by restricted stimulation. In other research, monkeys, chimpanzees, and kittens were raised in an environment devoid of shapes. The animals distinguished differences in size, brightness, and color almost as well as normally reared animals do, but for the rest of their lives they performed poorly on more complex tasks, such as distinguishing different types of objects and geometric shapes (Riesen, 1965).



(a)



(b)

Figure 5.49

Effects of visual deprivation.
(a) Kittens raised in a vertically striped chamber, such as the one shown here, lacked cortical cells that fired in response to horizontal stimuli. (b) The kittens' perceptual "holes" are easily seen in this diagram, which shows the orientation angles that triggered nerve impulses from feature detectors. SOURCE: Adapted from Blakemore & Cooper, 1970.

Restored Sensory Capacity

Scientists have studied the experiences of visually impaired people who acquired the ability to see later in life. For example, people born with cataracts grow up in a visual world without form. The clouded lenses of their eyes permit them to perceive light but not patterns or shapes. One such person was Virgil, who had been almost totally blind since childhood. He read Braille, enjoyed listening to sports on the radio and conversing with other people, and had adjusted quite well to his disability. At the urging of his fiancee, Virgil agreed to undergo surgery to remove his thick cataracts. The day after the surgery, his bandages were removed. Neurologist Oliver Sacks (1999) recounts what happened next.

> There was light, there was color, all mixed up, meaningless, a blur. Then out of the blur came a voice that said, "Well?" Then, and only then . . . did he finally realize that this chaos of light and shadow was a face—and, indeed, the face of his surgeon. . . . His retina and optic nerve were active, transmitting impulses, but his brain could make no sense of them. (p. 132)

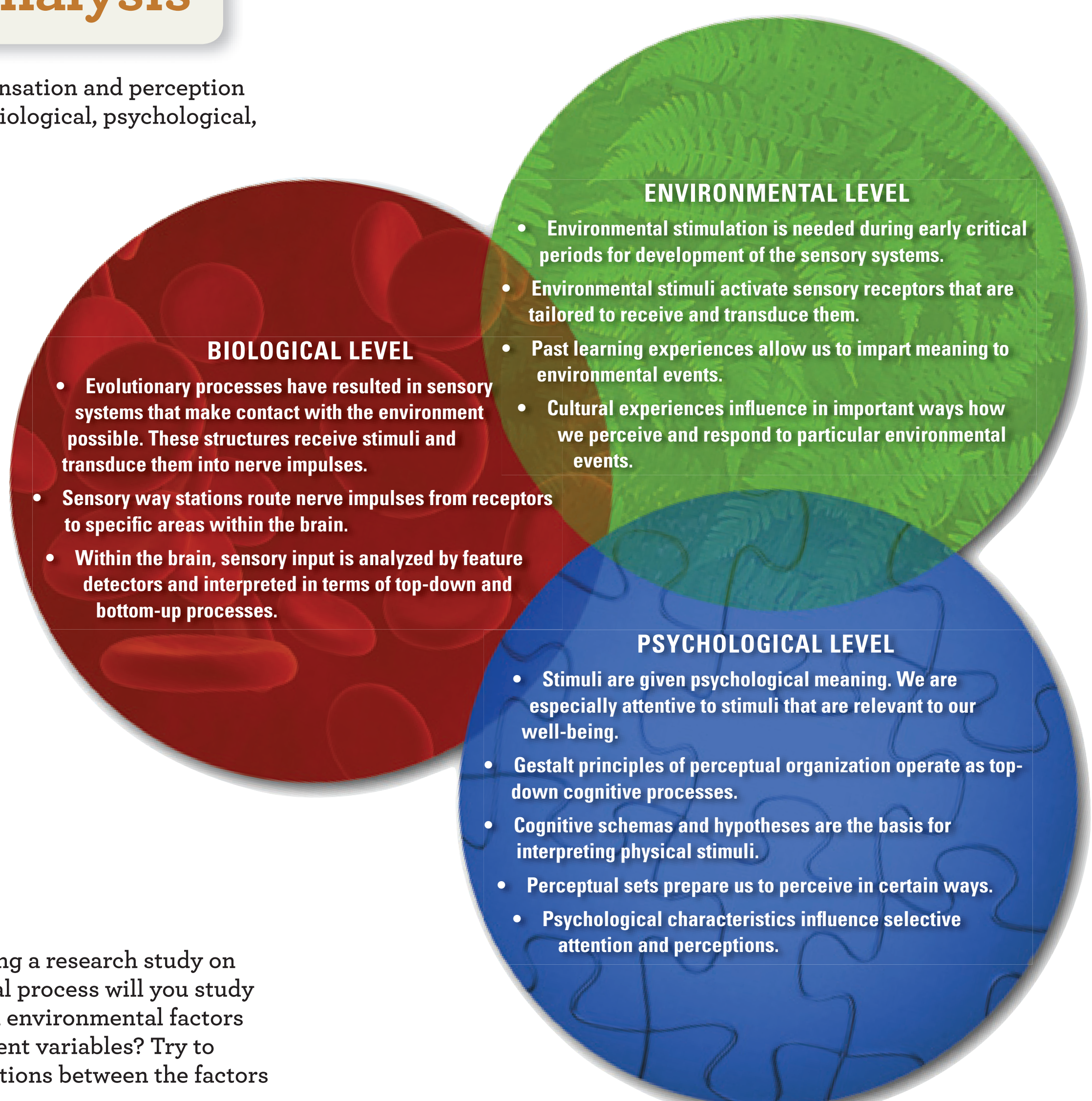
Virgil was never able to adjust to his new visual world. He had to touch objects in order to identify them. He had to be led through his own house and would quickly become disoriented if he deviated from his path. Eventually, Virgil lost his sight once again. This time, however, he regarded his blindness as a gift, a release from a sighted world that was bewildering to him.

Virgil's experiences are characteristic of people who have their vision restored later in life. A German physician, Marius von Senden (1960), compiled data on patients born with cataracts who were tested soon after their cataracts were

Levels of Analysis

Sensation and Perception

The processes involved in sensation and perception illustrate the interaction of biological, psychological, and environmental factors.



Imagine you are designing a research study on perception. Which perceptual process will you study and which psychological and environmental factors will you include as independent variables? Try to describe the possible interactions between the factors you've selected.

surgically removed in adulthood. These people were immediately able to perceive figure-ground relations, to scan objects visually, and to follow moving targets with their eyes, indicating that such abilities are innate. However, they could not visually identify objects, such as eating utensils, that they were familiar with through touch; nor were they able to distinguish simple geometric figures without counting the corners or tracing the figures with their fingers.

After several weeks of training, the patients were able to identify simple objects by sight, but their perceptual constancies were very poor. Often they were unable to recognize the same shape in another color, even though they could discriminate between colors. Years later, some patients could identify only a few of the faces of people they knew well. Many also had great difficulty judging distances. Apparently, no amount of subsequent experience could make up for their lack of visual experience during the critical period of childhood.

More recently, a woman in India was studied 20 years after she had cataracts removed at age 12 (Ostrovsky et al., 2007). Although the patient's visual acuity was below par, she did surprisingly well on complex visual tasks. This suggests that the human brain retains an impressive capacity for visual learning, even for children who are blind until early adolescence.

All of these lines of evidence—cross-cultural perceptual differences, animal studies involving visual deprivation, and observations of congenitally impaired people whose vision has been restored—suggest that biological and experiential factors interact in complex ways. Some of our perceptual abilities are at least partially present at birth, but experience plays an important role in their normal development. How innate and experiential factors interact promises to be a continued focus of perception research. Thus perception is very much a biopsychological process whose mysteries are best explored by examining them from biological, psychological, and environmental levels of analysis.

test yourself

Perception, Illusions, and Perceptual Development

True or false?

1. People show faster reaction times to threat-related stimuli.
2. Fraser's spiral illustrates the Gestalt law of continuity.
3. Visual illusions can be attributed to perceptual constancies.
4. Movies utilize the principle of stroboscopic movement.
5. Motion parallax is a binocular depth cue.
6. The Ames Room is designed to distort size constancy.
7. Animals will venture onto the "visual cliff," but human babies won't.

ANSWERS: 1-true, 2-true, 3-true, 4-true, 5-false, 6-true, 7-false

Chapter Summary

SENSORY PROCESSES

- Sensation is the process by which our sense organs receive and transmit information, whereas perception involves the brain's processing and interpretation of the information.
- The absolute threshold is the lowest intensity at which a stimulus is detected 50 percent of the time. Signal-detection theory is concerned with factors that influence decisions about whether or not a stimulus is present.
- The difference threshold, or just noticeable difference (jnd), is the amount by which two stimuli must differ for them to be perceived as different 50 percent of the time. Weber's law states that the jnd is proportional to the intensity of the original stimulus and is constant within a given sense modality.
- Sensory systems are particularly responsive to changes in stimulation, and adaptation occurs in response to unchanging stimuli.

VISION

- Light-sensitive visual receptor cells are located in the retina. The rods are brightness receptors, and the less numerous cones are color receptors. Light energy striking the retina is converted into nerve impulses by chemical reactions in the photopigments of the rods and cones. Dark adaptation involves the gradual regeneration of photopigments that have been depleted by brighter illumination.
- Color vision is a two-stage process having both trichromatic and opponent-process components.
- Visual stimuli are analyzed by feature detectors in the primary visual cortex, and the stimulus elements are reconstructed and interpreted in light of input from the visual association cortex.

AUDITION

- Sound waves, the stimuli for audition, have two characteristics: frequency, measured in terms of cycles per second, or hertz (Hz); and amplitude, measured in terms of decibels (dB). Frequency is related to pitch, amplitude to loudness.
- Loudness is coded in terms of the number and types of auditory nerve fibers that fire. Pitch is coded in two ways, explained by frequency and place theories.
- Hearing loss may result from conduction deafness, produced by problems involving the structures of the ear that transmit vibrations to the cochlea, or from nerve deafness, in which the receptors in the cochlea or the auditory nerve are damaged.

TASTE AND SMELL: THE CHEMICAL SENSES

- The receptors for taste and smell respond to chemical molecules. Taste buds are responsive to four basic qualities: sweet, sour, salty, and bitter. The receptors for smell (olfaction) are long cells in the upper nasal cavity.

THE SKIN AND BODY SENSES

- The skin and body senses include touch, kinesthesis, and equilibrium. Receptors in the skin and body tissues are sensitive to pressure, pain, warmth, and cold. Kinesthesis functions by means of nerve endings in the muscles, tendons, and joints. The sense organs for equilibrium are in the vestibular apparatus of the inner ear.
- Pain receptors are free nerve endings. Gate control theory takes account of downward influences from the brain. Endorphins decrease pain.
- Principles derived from the study of sensory processes have been applied in developing sensory prosthetics for people who are blind, hearing impaired, or have lost their hands.

PERCEPTION: THE CREATION OF EXPERIENCE

- Perception involves both bottom-up processing, in which individual stimulus fragments are combined into a perception, and top-down processing, in which existing knowledge and perceptual schemas are applied to interpret stimuli.
- We cannot attend completely to more than one thing at a time, but we are capable of rapid attentional shifts. Inattentional blindness refers to a failure to perceive certain stimuli when attending to other stimulus elements. The perceptual system appears to be especially vigilant to stimuli that denote threat or danger.
- Gestalt psychologists identified a number of principles of perceptual organization, including figure-ground relations and the laws of similarity, proximity, closure, and continuity. Gregory suggested that perception is essentially a hypothesis about what a stimulus is, based on previous experience and the nature of the stimulus.
- Perceptual sets involve a readiness to perceive stimuli in certain ways, based on our expectations, assumptions, motivations, and current emotional state.
- Perceptual constancies allow us to recognize familiar stimuli under changing conditions. In the visual realm, there are three constancies: shape, brightness, and size.

PERCEPTION OF DEPTH, DISTANCE, AND MOVEMENT

- Monocular cues to judge distance and depth include patterns of light and shadow, linear perspective, interposition, height in the horizontal plane, texture, clarity, relative size, and motion parallax.
- Binocular disparity occurs as slightly different images are viewed by each eye and acted on by feature detectors for depth. Convergence of the eyes provides a second binocular cue.
- The basis for perception of movement is absolute movement of a stimulus across the retina or relative movement of an object in relation to its background. Stroboscopic movement is illusory.

ILLUSIONS: FALSE PERCEPTUAL HYPOTHESES

- Illusions are erroneous perceptions, or incorrect perceptual hypotheses. Perceptual constancies help produce many illusions.

EXPERIENCE, CRITICAL PERIODS, AND PERCEPTUAL DEVELOPMENT

- Perceptual development involves both physical maturation and learning. Some perceptual abilities are innate or develop shortly after birth, whereas others require particular experiences early in life in order to develop.
- Cultural factors can influence certain aspects of perception, including picture perception and susceptibility to illusions. However, many aspects of perception seem constant across cultures.
- Visual-deprivation studies, manipulation of visual input, and studies of restored vision have shown that the normal biological development of the perceptual system depends on certain sensory experiences at early periods of development.

KEY TERMS AND CONCEPTS

Each term has been boldfaced and defined in the chapter on the page indicated in parentheses.

absolute threshold (p. 132)
amplitude (p. 144)
basilar membrane (p. 144)
binocular depth cues (p. 160)
binocular disparity (p. 161)
bottom-up processing (p. 154)
cochlea (p. 144)
conduction deafness (p. 146)
cones (p. 136)
convergence (p. 161)
critical periods (p. 168)
dark adaptation (p. 138)
decibel (dB) (p. 144)
decision criterion (p. 132)
difference threshold (p. 133)
dual-process theory (p. 140)
endorphins (p. 150)
feature detectors (p. 142)
figure-ground relations (p. 156)
fovea (p. 137)
frequency (p. 143)
frequency theory of pitch perception (p. 145)
gate control theory (p. 150)
Gestalt laws of perceptual organization (p. 157)
gustation (p. 147)
Hering's opponent-process theory (p. 140)
hertz (Hz) (p. 143)
illusions (p. 162)
inattentional blindness (p. 155)
kinesthesis (p. 151)
lens (p. 136)
menstrual synchrony (p. 148)
monocular depth cues (p. 160)
nerve deafness (p. 146)
olfaction (p. 147)
olfactory bulb (p. 148)
optic nerve (p. 137)
organ of Corti (p. 144)
perception (p. 131)
perceptual constancies (p. 159)
perceptual schema (p. 158)
perceptual set (p. 159)
pheromones (p. 148)
photopigments (p. 138)
place theory of pitch perception (p. 146)
psychophysics (p. 132)
retina (p. 136)
rods (p. 136)
sensation (p. 131)
sensory adaptation (p. 135)
sensory prosthetic devices (p. 151)
signal-detection theory (p. 132)
stroboscopic movement (p. 162)
subliminal stimulus (p. 133)
synesthesia (p. 130)
taste buds (p. 147)
top-down processing (p. 154)
transduction (p. 131)
vestibular sense (p. 151)
visual acuity (p. 138)
Weber's law (p. 133)
Young-Helmholtz trichromatic theory (p. 139)

thinking **critically**

NAVIGATING IN FOG: PROFESSOR MAYER'S TOPOPHONE (Page 146)

The device shown in Figure 5.18 made use of two principles of sound localization. First, because the two ear receptors were much larger than human ears, they could capture more sound waves and funnel them to the sailor's ears. Second, the wide spacing between the two receptors increased the time difference between the sound's arrival at the two human ears, thus increasing directional sensitivity.

WHY DOES THAT RISING MOON LOOK SO BIG? (Page 159)

To begin with, let's emphasize the obvious: the moon is not actually larger when it's on the horizon. Photographs show that the size of the image cast on the retina is exactly the same in both cases. So what psychologists call the moon illusion must be created by our perceptual system. Though not completely understood, the illusion seems to be a false perception caused by cues that ordinarily contribute to maintaining size constancy. The chief suspect is apparent distance, which figures importantly in our size judgments. One theory holds that the moon looks bigger as it's rising over the horizon because we use objects in our field of vision, such as trees, buildings, and landscape features, to estimate its distance. Experiments have shown that objects look farther away when viewed through filled spaces than they do when viewed through empty spaces (such as the sky overhead). Filled space can make objects look as much as 2.5 to 4 times farther away. According to the theory, the perceptual system basically says, "If the size of the retinal image is the same but it's farther away, then it must be bigger."

This explanation can't be the whole story, however, because some people perceive the moon on the horizon as being closer, rather than farther away. If something the same size seems closer, it will look larger even though it isn't. It may be that there are individual differences in the size-judgment processes that cause the illusion, so that no single explanation applies to everybody.

EXPLAIN THIS STRIKING ILLUSION (Page 163)

To analyze your experience, it is important to understand that both the "tent" and the "corner" cast identical images on your retina. After perceiving the tent for a while, your brain shifted to the second perceptual hypothesis, as it did in response to the Necker cube shown in Figure 5.34. When the object looked like a tent, all the depth information was consistent with that perception. But when you began to see it as a corner and then moved your head slowly back and forth, the object seemed to twist and turn as if it were made of rubber. This occurred because, when you moved, the image of the near point of the fold moved across your retina faster than the image of the far point. This is the normal pattern of stimulation for points at different depths and is known as motion parallax. Thus, when you were seeing a tent, the monocular cue of motion parallax was consistent with the shape of the object. But when the object was later seen as standing upright, all the points along the fold appeared to be the same distance away, yet they were moving at different rates of speed! The only way your brain could maintain its "corner" perception in the face of the motion parallax cues was to see the object as twisting and turning. Again, as in other illusions, forcing all of the sensory data to fit the perceptual hypothesis produced an unusual experience.