





Psychophysics: Basic Concepts and Issues

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Recap

Practice Test

ake a look at the adjacent photo. What do you see? You probably answered, "a rose" or "a flower." But is that what you really see? No, this isn't a trick question. Let's examine the odd case of "Dr. P." It shows that there's more to seeing than meets the eye.

Dr. P was an intelligent and distinguished music professor who began to exhibit some worrisome behaviors that seemed to be related to his vision. Sometimes he failed to recognize familiar students by sight, although he knew them instantly by the sound of their voices. Sometimes he acted as if he saw faces in inanimate objects, cordially greeting fire hydrants and parking meters as if they were children. On one occasion, reaching for what he thought was his hat, he took hold of his wife's head and tried to put it on! Except for these kinds of visual mistakes, Dr. P was a normal, talented man.

Ultimately Dr. P was referred to Oliver Sacks, a neurologist, for an examination. During one visit, Sacks handed Dr. P a fresh red rose to see whether he would recognize it. Dr. P took the rose as if he were being given a model of a geometric solid rather than a flower. "About six inches in length," Dr. P ob-

served, "a convoluted red form with a linear green attachment."

"Yes," Sacks persisted, "and what do you think it is, Dr. P?"

"Not easy to say," the patient replied. "It lacks the simple symmetry of the Platonic solids \dots "

"Smell it," the neurologist suggested. Dr. P looked perplexed, as if being asked to smell symmetry, but he complied and brought the flower to his nose. Suddenly, his confusion cleared up. "Beautiful. An early rose. What a heavenly smell" (Sacks, 1987, pp. 13–14).

What accounted for Dr. P's strange inability to recognize faces and familiar objects by sight? There was nothing wrong with his eyes. He could readily spot a pin on the floor. If you're thinking that he must have had something wrong with his vision, look again at the photo of the rose. What you see is "a convoluted red form with a linear green attachment." It doesn't occur to you to describe it that way only because, without thinking about it, you instantly perceive that combination of form and color as a flower. This is precisely what Dr. P was unable to do. He could see perfectly well, but he was losing the ability to assemble what he saw into a meaningful



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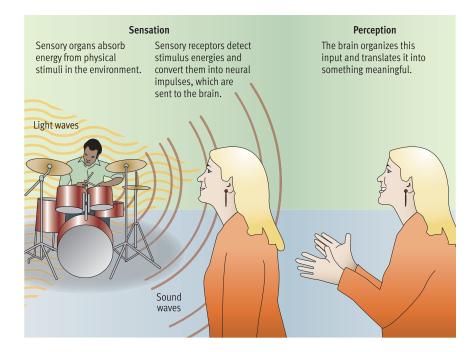


Figure 4.1
The distinction between sensation and perception. Sensation involves the stimulation of sensory organs, whereas perception involves the interpretation of sensory input. The two processes merge at the point where sensory receptors convert physical energy into neural impulses.

picture of the world. Technically, he suffered from a condition called *visual agnosia*, an inability to recognize objects through sight. As Sacks (1987) put it, "Visually, he was lost in a world of lifeless abstractions" (p. 15).

As Dr. P's case illustrates, without effective processing of sensory input, our familiar world can become a chaos of bewildering sensations. To acknowledge the need to both take in and process sensory information, psychologists distinguish between sensation and perception. *Sensation* is the stimulation of sense organs. *Perception* is the selection, organization, and interpretation of sensory input.

Sensation involves the absorption of energy, such as light or sound waves, by sensory organs, such as the eyes and ears. Perception involves organizing and translating sensory input into something meaningful (see Figure 4.1). For example, when you look at the photo of the rose, your eyes are *sensing* the light reflected from the page, including areas of low reflectance where ink has been deposited in an irregular shape. What you *perceive*, however, is a picture of a rose.

The distinction between sensation and perception stands out in Dr. P's case of visual agnosia. His eyes were doing their job of registering sensory input and transmitting signals to the brain. However, damage in his brain interfered with his ability to put these signals together into organized wholes. Thus, Dr. P's process of visual *sensation* was intact, but his process of visual *perception* was severely impaired.

Dr. P's case is unusual, of course. Normally, the processes of sensation and perception are difficult to separate because people automatically start organizing incoming sensory stimulation the moment it arrives. Although the distinction between sensation and perception has been useful in organizing theory and research, in operation the two processes merge.

We'll begin our discussion of sensation and perception by examining some general concepts that are relevant to all the senses. Next, we'll examine individual senses, in each case beginning with the sensory aspects and working our way through to the perceptual aspects. The chapter's Personal Application explores how principles of visual perception come into play in art and illusion. The Critical Thinking Application discusses how perceptual contrasts can be used in efforts to persuade us.



Key Learning Goals

- **4.1** Explain how stimulus intensity is related to absolute thresholds and JNDs.
- **4.2** Articulate the basic thrust of signal-detection theory.
- **4.3** Summarize evidence on perception without awareness, and discuss its practical implications.
- **4.4** Clarify the meaning and significance of sensory adaptation.

Psychophysics: Basic Concepts and Issues

As you may recall from Chapter 1, the first experimental psychologists were interested mainly in sensation and perception. They called their area of interest *psychophysics*—the study of how physical stimuli are translated into psychological experience. A particularly important contributor to psychophysics was Gustav Fechner, who published pioneering work on the subject in 1860. Fechner was a German scientist working at the University of Leipzig, where Wilhelm Wundt later founded the first formal laboratory and journal devoted to psychological research. Unlike Wundt, Fechner was not a "campaigner" interested in establishing psy-

chology as an independent discipline. However, his groundbreaking research laid the foundation that Wundt built upon.

Thresholds: Looking for Limits

Sensation begins with a *stimulus*, any detectable input from the environment. What counts as detectable, though, depends on who or what is doing the detecting. For instance, you might not be able to detect a weak odor that is readily apparent to your dog. Thus, Fechner wanted to know: For any given sense, what is the weakest detectable stimulus? For exam-



ple, what is the minimum amount of light needed for a person to see that there is light?

Implicit in Fechner's question is a concept central to psychophysics: the threshold. A *threshold* is a dividing point between energy levels that do and do not have a detectable effect. For example, hardware stores sell a gadget with a photocell that automatically turns a lamp on when a room gets dark. The level of light intensity at which the gadget clicks on is its threshold.

An absolute threshold for a specific type of sensory input is the minimum stimulus intensity that an organism can detect. Absolute thresholds define the boundaries of an organism's sensory capabilities. Fechner and his contemporaries used a variety of methods to determine humans' absolute threshold for detecting light. They discovered that absolute thresholds are anything but absolute. When lights of varying intensity are flashed at a subject, there is no single stimulus intensity at which the subject jumps from no detection to completely accurate detection. Instead, as stimulus intensity increases, subjects' probability of responding to stimuli gradually increases, as shown in red in Figure 4.2. Thus, researchers had to arbitrarily define the absolute threshold as the stimulus intensity detected 50% of the time.

Using this definition, investigators found that under ideal conditions, human abilities to detect weak stimuli are greater than appreciated. Some concrete examples of the absolute thresholds for various senses can be seen in **Table 4.1**. For example, on a clear, dark night, in the absence of other distracting lights, you could see the light of a candle burning

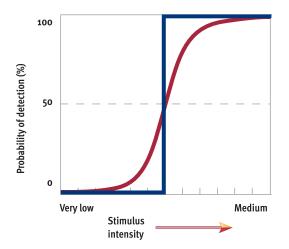


Figure 4.2

The absolute threshold. If absolute thresholds were truly absolute, then at threshold intensity the probability of detecting a stimulus would jump from 0 to 100%, as graphed here in blue. In reality, the chances of detecting a stimulus increase gradually with stimulus intensity, as shown in red. Accordingly, an "absolute" threshold is defined as the intensity level at which the probability of detection is 50%.

Table 4.1 Examples of Absolute Thresholds

| Sense | Absolute Threshold | |
|---------|---|--|
| Vision | A candle flame seen at 30 miles on a dark clear night | |
| Hearing | The tick of a watch under quiet conditions at 20 feet | |
| Taste | One teaspoon of sugar in two gallons of water | |
| Smell | One drop of perfume diffused into entire volume of a six-room apartment | |
| Touch | The wing of a fly falling on your cheek from a distance of 1 centimeter | |

Source: Galanter, E. (1962). Contemporary psychophysics. In R. Brown (Ed.), New directions in psychology. New York: Holt, Rinehart & Winston. © 1962 Eugene Galanter. Reprinted by permission.

30 miles in the distance! Of course, we're talking about ideal conditions—you would have to go out to the middle of nowhere to find the darkness required to put this assertion to a suitable test.

Fechner was also interested in people's sensitivity to differences between stimuli. A *just noticeable difference (JND)* is the smallest difference in stimulus intensity that a specific sense can detect. JNDs are close cousins of absolute thresholds. In fact, an absolute threshold is simply the just noticeable difference from nothing (no stimulus input) to something. In general, as stimuli increase in magnitude, the JND between them becomes larger. However, the size of a just noticeable difference in a specific sense tends to be a constant proportion of the size of the initial stimulus.

Signal-Detection Theory

Modern psychophysics has a more complicated view of how stimuli are detected. *Signal-detection theory* proposes that the detection of stimuli involves decision processes as well as sensory processes, which are both influenced by a variety of factors besides stimulus intensity (Egan, 1975; Swets, Tanner, & Birdsall, 1961).

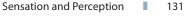
Imagine that you are monitoring a radar screen, looking for signs of possible enemy aircraft. Your mission is to detect signals that represent approaching airplanes as quickly and as accurately as possible. In this situation, there are four possible outcomes, which are outlined in **Figure 4.3** (on the next page): hits (detecting signals when they are present), misses (failing to detect signals when they are present), false alarms (detecting signals when they are not present), and correct rejections (not detecting signals when they are absent). Given these possibilities, signal-detection theory attempts to account for the influence of decision-making processes on stimulus detection.



Gustav Fechner

"The method of just noticeable differences consists in determining how much the weights have to differ so that they can just be discriminated."







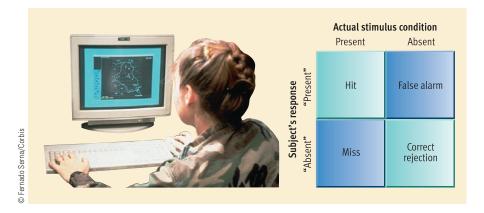


Figure 4.3
Signal-detection theory.

Signal-detection theory emerged from pragmatic efforts to improve the monitoring of modern equipment, such as the radar screen shown in the photo on the left. This diagram shows the four outcomes that are possible in attempting to detect the presence of weak signals. The criterion you set for how confident you want to feel before reporting a signal will affect your responding. For example, if you require high confidence before reporting a signal, you will minimize false alarms, but you'll be more likely to miss some signals.

In detecting weak signals on the radar screen, you will often have to decide whether a faint signal represents an airplane or you're just imagining that it does. Your responses will depend in part on the *criterion* you set for how sure you must feel before you react. Setting this criterion involves higher mental processes rather than raw sensation and depends on your expectations and on the consequences of missing a signal or of reporting a false alarm.

A major innovation of signal-detection theory was its assertion that your performance will also depend on the level of "noise" in the system (Kubovy, Epstein, & Gepshtein, 2003). Noise comes from all the irrelevant stimuli in the environment and the neural activity they elicit. Noise is analogous to the background static on a radio station. The more noise in the system, the harder it will be for you to pick up a weak signal. Variations in noise provide another reason that sensory thresholds depend on more than just the intensity of stimuli.

The key point is that signal-detection theory replaces Fechner's sharp threshold with the concept of "detectability." Detectability is measured in terms of probability and depends on decision-making processes as well as sensory processes. In comparison to classical models of psychophysics, signal-detection theory is better equipped to explain some of the complexities of perceived experience in the real world.

Perception Without Awareness

The concepts of thresholds and detectability lie at the core of an interesting debate: Can sensory stimuli that fall beneath the threshold of awareness still influence behavior? This issue centers on the concept of *subliminal perception*—the registration of sensory input without conscious awareness (*limen* is another term for threshold, so *subliminal* means below threshold). This question might be just another technical issue in the normally staid world of psychophysics, except that subliminal perception

has become tied up in highly charged controversies relating to money, sex, religion, and rock music.

The controversy began in 1957 when an executive named James Vicary placed hidden messages such as "Eat popcorn" in a film showing at a theater in New Jersey. The messages were superimposed on only a few frames of the film, so that they flashed by quickly and imperceptibly. Nonetheless, Vicary claimed in the press that popcorn sales increased by 58%, and a public outcry ensued (McConnell, Cutler, & McNeil, 1958; Merikle, 2000). Since then, Wilson Brian Key, a former advertising executive, has written several books claiming that sexual words and drawings are embedded subliminally in magazine advertisements to elicit favorable unconscious reactions from consumers (Key, 1973, 1976, 1980, 1992). Taking the sexual manipulation theme a step further, entrepreneurs are now marketing music audiotapes containing subliminal messages that are supposed to help seduce unsuspecting listeners. Furthermore, subliminal self-help tapes intended to facilitate weight loss, sleep, memory, self-esteem, and the like have become a \$50 million industry. Religious overtones were added to this controversy in the 1980s when subliminal messages encouraging devil worship were allegedly found in rock music played backward (Vokey & Read, 1985).

Can listening to Led Zeppelin's "Stairway to Heaven" promote Satanic rituals? Can your sexual urges be manipulated by messages hidden under music? Can advertisers influence your product preferences with subliminal stimuli? Those who are concerned about subliminal messages assert that such messages are likely to be persuasive because people supposedly are defenseless against appeals operating below their threshold of awareness. How justified are these fears? Research on subliminal perception was sporadic in the 1960s and 1970s because scientists initially dismissed the entire idea as preposterous. However, empirical studies have begun to accumulate since the 1980s.

Quite a number of studies have found support for the existence of subliminal perception (De Houwer, 2001; Greenwald, 1992; Snodgrass, Bernat, & Shevrin, 2004). Using diverse methodological and conceptual approaches, researchers have examined a variety of phenomena, such as unconscious semantic priming (Abrams, Klinger, & Greenwald, 2002), subliminal affective conditioning (Dijksterhuis, 2004), subliminal mere exposure effects (Monahan, Murphy, & Zajonc, 2000), subliminal visual priming (Haneda et al., 2003), and subliminal psychodynamic activation (Sohlberg & Birgegard, 2003), and they have found evidence that perception without awareness *can* take place.







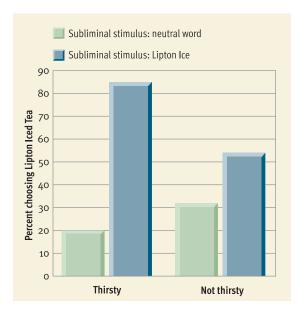






For example, in one recent study, Karremans, Stroebe, and Claus (2006) set out to determine whether participants' inclination to consume a particular drink (Lipton iced tea) could be influenced without their awareness. Subjects were asked to work on a visual detection task that was supposedly designed to determine whether people could spot small deviations in visual stimuli. Specifically, they were asked to view brief presentations of letter strings containing mostly capital letters (BBBBBBBBBB) and identify any that included a lower-case letter (such as BBBBBBBBBB). For half of the participants, subliminal presentations ($^{23}/_{1000}$ of a second) of the words LIPTON ICE were interspersed among these visual stimuli. Control subjects were given subliminal presentations of neutral words. After the visual detection task, subjects participated in a study of "consumer behavior" and their inclination to drink Lipton iced tea was assessed with a variety of comparative ratings. As predicted, participants exposed subliminally to LIPTON ICE were significantly more interested in consuming Lipton iced tea, especially among those who indicated that they were thirsty (see Figure 4.4). In a somewhat similar study, Cooper and Cooper (2002) demonstrated that subliminal presentations of pictures of Coca Cola cans and the word THIRSTY increased participants' ratings of their thirst. Thus, subliminal inputs can produce measurable, although small, effects in subjects who subsequently report that they did not consciously register the stimuli. As a result, the dominant view today is that subliminal perception is a genuine phenomenon worthy of experimental investigation. Indeed, researchers have recently begun to use brain imaging technology to study how the brain processes subliminal stimuli (Dehaene et al., 2006; Ortigue et al., 2007)

So, should we be worried about the threat of subliminal persuasion? The research to date suggests that there is little reason for concern. The effects of subliminal stimuli turn out to be nearly as subliminal as the stimuli themselves. Subliminal stimula-



tion generally produces weak effects (De Houwer, Hendrickx, & Baeyens, 1997; Kihlstrom, Barnhardt, & Tataryn, 1992). These effects can be detected only by very precise measurement, under carefully controlled laboratory conditions, in which subjects are asked to focus their undivided attention on visual or auditory materials that contain the subliminal stimuli. Although these effects are theoretically interesting, they appear unlikely to have much practical importance (Merikle, 2000). More research on the manipulative potential of subliminal persuasion is needed, but so far there is no cause for alarm.

Sensory Adaptation

The process of sensory adaptation is yet another factor that influences the registration of sensory input. Sensory adaptation is a gradual decline in sensitivity to prolonged stimulation. For example, suppose the garbage in your kitchen has started to smell. If you stay in the kitchen without removing the garbage, the stench will soon start to fade. In reality, the stimulus intensity of the odor is stable, but with

Figure 4.4 **Results of Karremans** et al. (2006) study of subliminal perception.

One measure of whether the subliminal presentation of LIPTON ICE affected particpants' drink preferences was to ask them to choose between Lipton Iced Tea and another popular drink. As you can see, the experimental group subjects showed a decided preference for Lipton Iced Tea in comparison to the control group subjects, especially among subjects who indicated that they were thirsty.

SOURCE: Adapted from Karremans, J. C., Stroebe, W., & Claus, J. (2006). Beyond Vicary's fantasies: The impact of subliminal priming and brand choice. Journal of Experimental Psychology, 42, 792–798 (Figure 2 from Study 2). Reprinted by permis-







Because of sensory adaptation, people who live near foul-smelling industrial plants tend to grow accustomed to the stench in the air, whereas visitors may initially be overwhelmed by the same odors.

continued exposure, your *sensitivity* to it decreases. Meanwhile, someone new walking into the room is likely to remark on the foul odor. Sensory adaptation is a pervasive aspect of everyday life. When you put on your clothes in the morning, you feel them initially, but the sensation quickly fades. Similarly, if you jump reluctantly into a pool of cold water, you'll probably find that the water temperature feels fine in a few moments after you *adapt* to it.

Sensory adaptation is an automatic, built-in process that keeps people tuned in to the *changes* rather than the *constants* in their sensory input. It allows people to ignore the obvious. After all, you don't need constant confirmation that your clothes are still on. But, like most organisms, people are interested in changes in their environment that may signal threats to safety. Thus, as its name suggests, sensory adaptation probably is a behavioral adaptation that has been sculpted by natural selection. Sensory adaptation also shows once again that there is no one-to-one correspondence between sensory input and sensory experience.

The general points we've reviewed so far begin to suggest the complexity of the relationships between the world outside and people's perceived experience of it. As we review each of the principal sensory systems in detail, we'll see repeatedly that people's experience of the world depends on both the physical stimuli they encounter and their active processing of stimulus inputs. We begin our exploration of the senses with vision—the sense that most people think of as nearly synonymous with a direct perception of reality. The case is actually quite different, as you'll see.

REVIEW of Key Learning Goals

- **4.1** Psychophysicists use a variety of methods to relate sensory inputs to subjective perception. They have found that absolute thresholds are not really absolute. The size of a just noticeable difference tends to be a constant proportion of the size of the initial stimulus.
- **4.2** According to signal-detection theory, the detection of sensory inputs is influenced by noise in the system and by decision-making strategies. Signal-detection theory replaces Fechner's sharp threshold with the concept of detectability and emphasizes that factors besides stimulus intensity influence detectability.
- **4.3** In recent years, a number of researchers, using very different conceptual approaches, have demonstrated that perception can occur without awareness. However, research indicates that the effects of subliminal perception are relatively weak and of little or no practical concern.
- **4.4** Prolonged stimulation may lead to sensory adaptation, which involves a reduction in sensitivity to constant stimulation. Sensory adaptation keeps people tuned in to the changes rather than the constants in their sensory input.



Key Learning Goals

- **4.5** List the three properties of light and the aspects of visual perception that they influence.
- **4.6** Describe the role of the lens and pupil in the functioning of the eye.
- **4.7** Explain how the retina contributes to visual information processing.
- **4.8** Trace the routing of signals from the eye to the brain, and explain the brain's role in visual information processing.
- **4.9** Distinguish two types of color mixing, and compare the trichromatic and opponent process theories of color vision

The Visual System: Essentials of Sight

"Seeing is believing." Good ideas are "bright," and a good explanation is "illuminating." This section is an "overview." Do you see the point? As these common expressions show, humans are visual animals. People rely heavily on their sense of sight, and they virtually equate it with what is trustworthy (seeing is believing). Although it is taken for granted, you'll see (there it is again) that the human visual system is amazingly complex. Furthermore, as in all sensory domains, what people "sense" and what they "perceive" may be quite different. In this section, we will focus on basic sensory processes in the visual system; in the following section we will look at higher-level perceptual processes in vision.

The Stimulus: Light

For people to see, there must be light. *Light* is a form of electromagnetic radiation that travels as a wave,

moving, naturally enough, at the speed of light. As **Figure 4.5(a)** shows, light waves vary in *amplitude* (height) and in *wavelength* (the distance between peaks). Amplitude affects mainly the perception of brightness, while wavelength affects mainly the perception of color. The lights humans normally see are mixtures of several wavelengths. Thus, light can also vary in its *purity* (how varied the mix is). Purity influences perception of the saturation, or richness, of colors. *Saturation* refers to the relative amount of whiteness in a color. The less whiteness seen in a color, the more saturated it is (see **Figure 4.6**). Of course, most objects do not emit light, they reflect it (the sun, lamps, and fireflies being some exceptions).

What most people call light includes only the wavelengths that humans can see. But as **Figure 4.5(c)** shows, the visible spectrum is only a slim portion of the total range of wavelengths. Vision is a filter that permits people to sense but a fraction of the



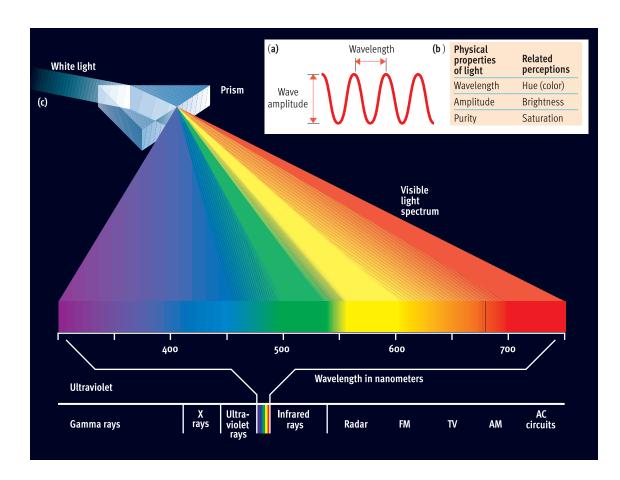


Figure 4.5 Light, the physical stimulus for vision. (a) Light waves vary in amplitude and wavelength. (b) Within the spectrum of visible light, amplitude (corresponding to physical intensity) affects mainly the experience of brightness. Wavelength affects mainly the experience of color, and purity is the key determinant of saturation. (c) If white light (such as sunlight) passes through a prism, the prism separates the light into its component wavelengths, creating a rainbow of colors. However, visible light is only the narrow band of wavelengths to which human eyes happen to be sensitive.

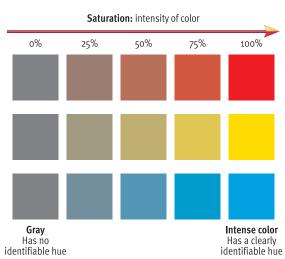


Figure 4.6

Saturation. Saturation refers to the amount of whiteness in a color. As you can see in these examples, as the amount of whiteness declines (moving to the right), the saturation or richness of a color increases.

real world. Other animals have different capabilities and so live in a quite different visual world. For example, many insects can see shorter wavelengths than humans, in the *ultraviolet* spectrum, whereas many fish and reptiles can see longer wavelengths,

in the *infrared* spectrum. Although the sense of sight depends on light waves, for people to *see*, incoming visual input must be converted into neural impulses that are sent to the brain. Let's investigate how this transformation is accomplished.

The Eye: A Living Optical Instrument



The eyes serve two main purposes: They channel light to the neural tissue that receives it, called the *retina*, and they house that tissue. The structure of the eye is shown in **Figure 4.7** (on the next page). Each eye is a living optical instrument that creates an image of the visual world on the light-sensitive retina lining its inside back surface.

Light enters the eye through a transparent "window" at the front, the *cornea*. The cornea and the crystalline *lens*, located behind it, form an upsidedown image of objects on the retina. It might seem disturbing that the image is upside down, but the brain knows the rule for relating positions on the retina to the corresponding positions in the world.

The *lens* is the transparent eye structure that focuses the light rays falling on the retina. The lens is made up of relatively soft tissue, capable of adjustments that facilitate a process called accommodation.

web link 4.1



Vision Science: An Internet Resource for Research in Human and Animal Vision

Numerous online sites are devoted to the sense of sight and visual processes. Vision Science provides a convenient guide to the best of these sites, especially for online demonstrations and tutorials.



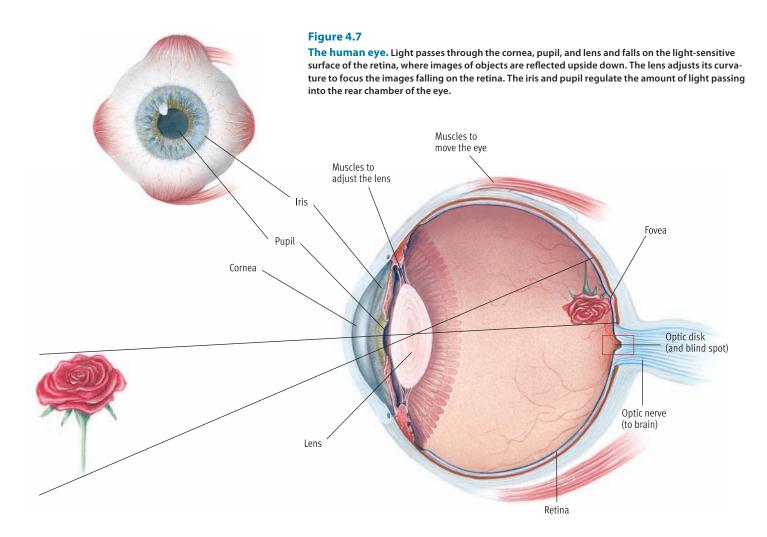
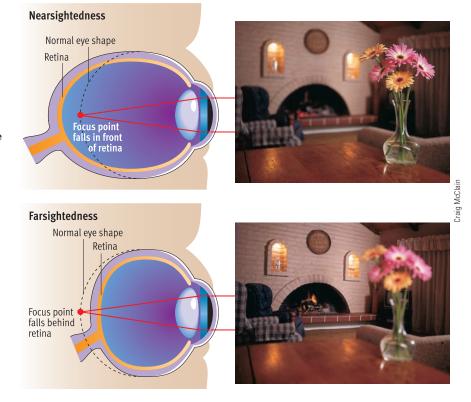


Figure 4.8

Nearsightedness and farsightedness. The pictures shown here simulate how a scene might look to nearsighted and farsighted people. Nearsightedness occurs because light from distant objects focuses in front of the retina. Farsightedness is due to the opposite situation—light from close objects focuses behind the retina.



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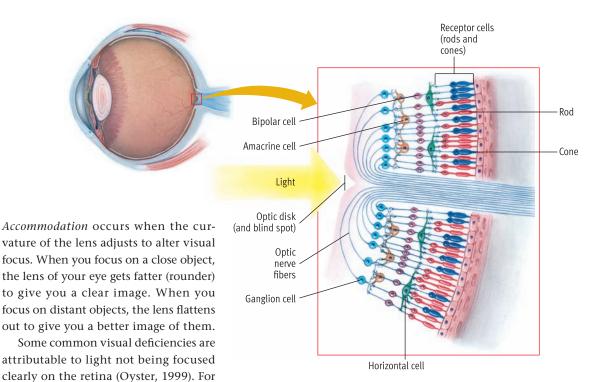


Figure 4.9

The retina. The closeup shows the several layers of cells in the retina. The cells closest to the back of the eye (the rods and cones) are the receptor cells that actually detect light. The intervening layers of cells receive signals from the rods and cones and form circuits that begin the process of analyzing incoming information. The visual signals eventually converge into aanalion cells. whose axons form the optic fibers that make up the optic nerve. These optic fibers all head toward the "hole" in the retina where the optic nerve leaves the eve-the point known as the optic disk (which corresponds to the blind spot).

images, and sends visual information to the brain.

You may be surprised to learn that the retina processes images. But it's a piece of the central nervous system that happens to be located in the eyeball. Much as the spinal cord is a complicated extension of the brain, the retina is the brain's envoy in the eye. About half as thick as a credit card, this thin sheet of neural tissue contains a complex network of specialized cells arranged in layers (Rodieck, 1998), as shown in Figure 4.9.

The axons that run from the retina to the brain converge at the optic disk, a hole in the retina where the optic nerve fibers exit the eye. Because the optic disk is a hole in the retina, you cannot see the part of an image that falls on it. It is therefore known as the blind spot. You may not be aware that you have a blind spot in each eye, as each normally compensates for the blind spot of the other.

Visual Receptors: Rods and Cones

The retina contains millions of receptor cells that





are sensitive to light. Surprisingly, these receptors are located in the innermost layer of the retina. Hence, light must pass through several layers of cells before it gets to the receptors that actually detect it. Interestingly, only about 10% of the light arriving at the cornea reaches these receptors (Leibovic, 1990). The retina contains two types of receptors, rods and cones. Their names are based on their shapes, as rods are elongated and cones are stubbier. Rods outnumber cones by a huge margin, as humans have

The Retina: The Brain's **Envoy in the Eye**

that more remains visible.

example, in nearsightedness, close ob-

eveball is too short.

jects are seen clearly but distant objects appear

blurry because the focus of light from distant ob-

jects falls a little short of the retina (see Figure 4.8).

This problem occurs when the cornea or lens bends

light too much, or when the eyeball is too long. In

farsightedness, distant objects are seen clearly but close objects appear blurry because the focus of

light from close objects falls behind the retina (see

Figure 4.8). This problem typically occurs when the

of light reaching the retina. The iris is the colored

ring of muscle surrounding the pupil, or black cen-

ter of the eye. The iris regulates the amount of light

entering the eye because it controls the size of the

pupil. The pupil is the opening in the center of the

iris that permits light to pass into the rear cham-

ber of the eye. When the pupils are constricted,

they let less light into the eye, but they sharpen the image falling on the retina. When the pupils are di-

lated (opened more), they let more light in, but the

image is less sharp. In bright light, the pupils constrict to take advantage of the sharpened image. But

in dim light, the pupils dilate; image sharpness is sacrificed to allow more light to fall on the retina so

The eye can make adjustments to alter the amount

The retina is the neural tissue lining the inside back surface of the eye; it absorbs light, processes



100-125 million rods, but only 5-6.4 million cones (Frishman, 2001).

Cones are specialized visual receptors that play a key role in daylight vision and color vision. The cones handle most of people's daytime vision, because bright lights dazzle the rods. The special sensitivities of cones also allow them to play a major role in the perception of color. However, cones do not respond well to dim light, which is why you don't see color very well in low illumination. Nonetheless, cones provide better visual acuity—that is, sharpness and precise detail—than rods. Cones are concentrated most heavily in the center of the retina and quickly fall off in density toward its periphery. The fovea is a tiny spot in the center of the retina that contains only cones; visual acuity is greatest at this spot. When you want to see something sharply, you usually move your eyes so the object is centered in the fovea.

Rods are specialized visual receptors that play a key role in night vision and peripheral vision. Rods handle night vision because they are more sensitive than cones to dim light. They handle the lion's share of peripheral vision because they greatly outnumber cones in the periphery of the retina. The density of the rods is greatest just outside the fovea and gradually decreases toward the periphery of the retina. Because of the distribution of rods, when you want to see a faintly illuminated object in the dark, it's best to look slightly above or below the place it should be. Averting your gaze this way moves the image from the cone-filled fovea, which requires more light, to the rod-dominated area just outside the fovea, which requires less light. This trick of averted vision is well known to astronomers, who use it to study dim objects viewed through the eyepiece of a telescope.

NKTRE **Dark and Light Adaptation**

You've probably noticed that when you enter a dark theater on a bright day, you stumble around almost blindly. But within minutes you can make your way about quite well in the dim light. This adjustment is called dark adaptation—the process in which the eyes become more sensitive to light in low illumination. Figure 4.10 maps out the course of this process. The declining absolute thresholds over time indicate that you require less and less light to see. Dark adaptation is virtually complete in about 30 minutes, with considerable progress occurring in the first 10 minutes. The curve (in Figure 4.10) that charts this progress consists of two segments because cones adapt more rapidly than rods (Walraven et al., 1990).

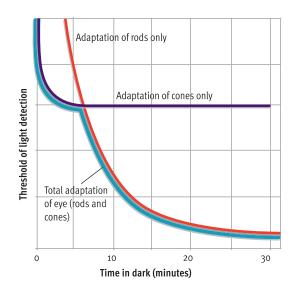


Figure 4.10 The process of dark adaptation. The declining thresholds over time indicate that your visual sensitivity is improving, as less and less light is required to see. Visual sensitivity improves markedly during the first 5 to 10 minutes after entering a dark room, as the eye's bright-light receptors (the cones) rapidly adapt to low light levels. However, the cones' adaptation, which is plotted in purple, soon reaches its limit, and further improvement comes from the rods' adaptation, which is plotted in red. The rods adapt more slowly than the cones, but they are capable of far greater visual sensitivity in low levels of light.

When you emerge from a dark theater on a sunny day, you need to squint to ward off the overwhelming brightness, and the reverse of dark adaptation occurs. Light adaptation is the process whereby the eyes become less sensitive to light in high illumination. As with dark adaptation, light adaptation improves your visual acuity under the prevailing circumstances. Both types of adaptation are due in large part to chemical changes in the rods and cones, but neural changes in the receptors and elsewhere in the retina also contribute (Frumkes, 1990).

Information Processing in the Retina



In processing visual input, the retina transforms a pattern of light falling onto it into a very different representation of the visual scene. Light striking the retina's receptors (rods and cones) triggers the firing of neural signals that pass into the intricate network of cells in the retina, which in turn send impulses along the optic nerve—a collection of axons from ganglion cells that connect the eye with the brain (see Figure 4.9). These axons, which depart from the eye through the optic disk, carry visual information, encoded as a stream of neural impulses, to the brain.

A great deal of complex information processing goes on in the retina itself before visual signals are sent

web link 4.2



Perception: A Web Book

This site shows the Internet at its best. Peter Kaiser of York University has crafted a comprehensive guide to human color vision, supplying plenty of graphics and demonstrations to help visitors understand what laboratory research in psychology has learned about visual perception.

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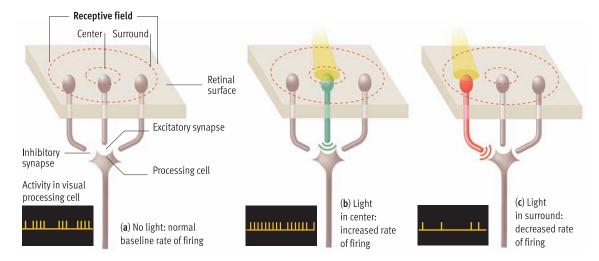


Figure 4.11

Receptive fields in the retina. Visual cells' receptive fields—made up of rods and cones in the retina—are often circular with a center-surround arrangement (a), so that light striking the center of the field produces the opposite result of light striking the surround. In the receptive field depicted here, light in the center produces excitatory effects (symbolized by green at the synapse) and increased firing in the visual cell (b), whereas light in the surround produces inhibitory effects (symbolized by red at the synapse) and decreased firing (c). Interestingly, no light in the receptive field and light in both center and surround produce similar baseline rates of firing. This arrangement makes the visual cell particularly sensitive to contrast, which facilitates the extremely important task of recognizing the edges of objects.

to the brain. Ultimately, the information from over 100 million rods and cones converges to travel along "only" 1 million axons in the optic nerve (Slaughter, 1990). The collection of rod and cone receptors that funnel signals to a particular visual cell in the retina (or ultimately in the brain) make up that cell's receptive field. Thus, the receptive field of a visual cell is the retinal area that, when stimulated, affects the firing of that cell.

Receptive fields in the retina come in a variety of shapes and sizes. Particularly common are circular fields with a center-surround arrangement (Tessier-Lavigne, 2000). In these receptive fields, light falling in the center has the opposite effect of light falling in the surrounding area (see Figure 4.11). For example, the rate of firing of a visual cell might be *increased* by light in the *center* of its receptive field and *decreased* by light in the *surrounding area*, as Figure 4.11 shows. Other visual cells may work in just the opposite way. Either way, when receptive fields are stimulated, retinal cells send signals both toward the brain and *laterally* (sideways) toward nearby visual cells. These lateral signals allow visual cells in the retina to have interactive effects on each other.

Lateral antagonism (also known as lateral inhibition) is the most basic of these interactive effects. *Lateral antagonism* occurs when neural activity in a cell opposes activity in surrounding cells. Lateral antagonism is responsible for the opposite effects that occur when light falls on the inner versus outer portions of center-surround receptive fields.

Lateral antagonism allows the retina to compare the light falling in a specific area against general lighting. This means that the visual system can compute the *relative* amount of light at a point instead of reacting to *absolute* levels of light. This attention to *contrast* is exactly what is needed, because most of the crucial information required to recognize objects in a visual scene is contained in the pattern of contrasts, which reveal the *edges* of the objects (Tessier-Lavigne, 2000). If you look at **Figure 4.12**, you will experience a perplexing illusion attributable to lateral antagonism in the ganglion cells of the retina.

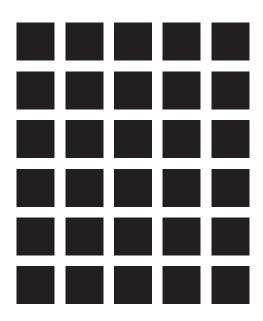


Figure 4.12

The Hermann grid. If you look at this grid, you will see dark spots at the intersections of the white bars, except in the intersection you're staring at directly. This illusion is due to lateral antagonism.







concept check 4.1

Understanding Sensory Processes in the Retina

Check your understanding of sensory receptors in the retina by completing the following exercises. Consult Appendix A for the answers.

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The receptors for vision are rods and cones in the retina. These two types of receptors have many important differences, which are compared systematically in the chart below. Fill in the missing information to finish the chart.

| Dimension | Rods | Cones |
|--|-----------|---------------|
| Physical shape | Elongated | |
| Number in the retina | | 5-6.4 million |
| Area of the retina in which they are dominant receptor | | |
| Critical to color vision | | |
| Critical to peripheral vision | | <i>No</i> |
| Sensitivity to dim light | Strong | |
| Speed of dark adaptation | | Rapid |

Vision and the Brain

Light falls on the eye, but you see with your brain. Although the retina does an unusual amount of information processing for a sensory organ, visual input is meaningless until it is processed in the brain.

Visual Pathways to the Brain

How does visual information get to the brain? Axons from ganglion cells leaving the back of each eye form the optic nerves, which travel to the *optic chiasm*—the point at which the optic nerves from the inside half of each eye cross over and then project to the opposite half of the brain. This arrangement ensures that signals from both eyes go to both hemispheres of the brain. Thus, as Figure 4.13 shows, axons from the left half of each retina carry signals to the left side of the brain, and axons from the right half of each retina carry information to the right side of the brain.

After reaching the optic chiasm, the optic nerve fibers diverge along two pathways. The main pathway projects into the thalamus, the brain's major relay station. Here, about 90% of the axons from the retinas synapse in the *lateral geniculate nucleus* (LGN) (Pasternak, Bisley, & Calkins, 2003). Visual signals are processed in the LGN and then distributed to areas in the occipital lobe that make up the *primary visual cortex* (see **Figure 4.13**). The second visual pathway leaving the optic chiasm branches off to an area in the midbrain called the *superior col-*

liculus before traveling through the thalamus and on to the occipital lobe. The principal function of the second pathway appears to be the perception of motion and the coordination of visual input with other sensory input (Casanova et al., 2001; Stein & Meredith, 1993).

The main visual pathway is subdivided into two more specialized pathways called the *magnocellular* and *parvocellular* channels (based on the layers of the LGN they synapse in). These channels engage in *parallel processing*, which involves simultaneously extracting different kinds of information from the same input. For example, the parvocellular channel handles the perception of color, while the magnocellular channel processes information regarding brightness (Wurtz & Kandel, 2000). Of course, this brief description hardly does justice to the immense complexity of visual processing in the brain.

Information Processing in the Visual Cortex

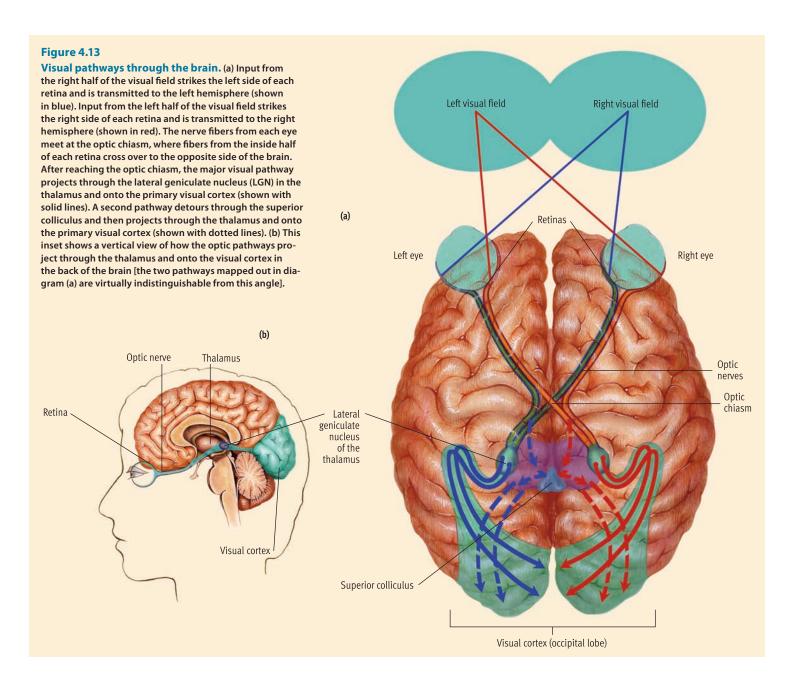
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Most visual input eventually arrives in the primary visual cortex, located in the occipital lobe. Explaining how the cortical cells in this area respond to light used to pose a perplexing problem. Researchers investigating the question placed microelectrodes in the primary visual cortex of animals to record action potentials from individual cells. They would flash spots of light in the retinal receptive fields that the cells were thought to monitor, but there was rarely any response.









According to David Hubel and Torsten Wiesel (1962, 1963), they discovered the solution to this mystery quite by accident. One of the projector slides they used to present a spot to a cat had a crack in it. The spot elicited no response, but when they removed the slide, the crack moved through the cell's receptive field, and the cell fired like crazy in response to the moving dark line. It turns out that individual cells in the primary visual cortex don't really respond much to little spots—they are much more sensitive to lines, edges, and other more complicated stimuli. Armed with new slides, Hubel and Wiesel embarked on years of painstaking study of the visual cortex (see Figure 4.14 on the next page). Their work eventually earned them a Nobel prize in 1981.

Hubel and Wiesel (1979, 1998) identified various types of specialized cells in the primary visual cortex that respond to different stimuli. For example, *simple cells* respond best to a line of the correct width, oriented at the correct angle, and located in the correct position in its receptive field. *Complex cells* also care about width and orientation, but they respond to any position in their receptive fields. Some complex cells are most responsive if a line sweeps across their receptive field—but only if it's moving in the "right" direction. The key point of all this is that the cells in the visual cortex seem to be highly specialized. They have been characterized as *feature detectors*, neurons that respond selectively to very specific features of more complex stimuli. According to

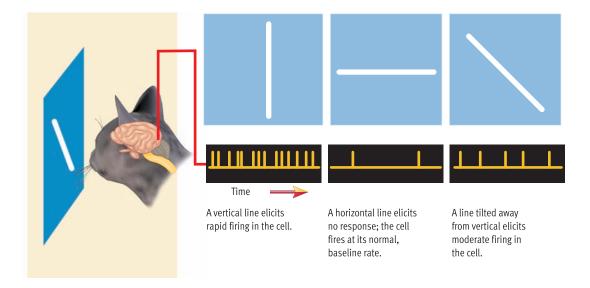


David Hubel

"One can now begin to grasp the significance of the great number of cells in the visual cortex. Each cell seems to have its own specific duties."



Figure 4.14
Hubel and Wiesel's
procedure for studying
the activity of neurons
in the visual cortex. As
the cat is shown various
stimuli, a microelectrode
records the firing of a neuron
in the cat's visual cortex. The
figure shows the electrical
responses of a visual cell
apparently "programmed"
to respond to lines oriented
vertically.



some theorists, most visual stimuli could ultimately be represented by combinations of lines such as those registered by these feature detectors (Maguire, Weisstein, & Klymenko, 1990).

After visual input is processed in the primary visual cortex, it is often routed to other cortical areas for additional processing. These signals travel through two streams that have sometimes been characterized as the *what* and *where pathways* (see Figure 4.15). The *ventral stream* processes the details of *what* objects are out there (the perception of form and color), while the *dorsal stream* processes *where* the objects are (the perception of motion and depth) (Pasternak et al., 2003; Ungerleider & Haxby, 1994).

As signals move farther along in the visual processing system, neurons become even more specialized or fussy about what turns them on, and the stimuli that activate them become more and more complex. For example, researchers have identified

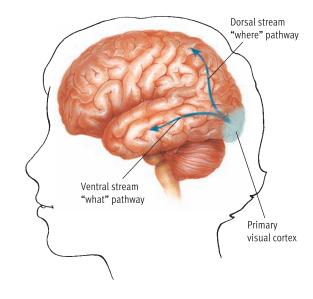
cells in the temporal lobe (along the *what* pathway) of monkeys and humans that are especially sensitive to pictures of faces (Levine, 2001; Rolls & Tovee, 1995). These neurons respond even to pictures that merely *suggest* the form of a face (Cox, Meyers, & Sinha, 2004). Scientists have also found neurons in a nearby region that respond to body parts and another group of neurons that respond to indoor and outdoor scenes (Downing et al., 2006).

This incredible specificity led researchers to joke that they might eventually find a neuron that only recognizes one's grandmother (Cowey, 1994). Although the concept of a "grandmother cell" was meant to be humorous, researchers recently have discovered the equivalent, albeit in areas of the brain that handle memory rather than vision (Gaschler, 2006). Using pictures of famous people as stimuli, Quiroga et al. (2005) found individual neurons in the hippocampal area that would respond only to Bill Clinton, others that would respond only to Halle Berry, and still others that were activated only by Jennifer Aniston. Interestingly, these cells would also respond to the words BILL CLINTON or HALLE BERRY (see Figure 4.16), so it appears that they are activated by concepts rather than visual forms. Hence, these ultraspecific cells probably have more to do with memory than vision. Nonetheless, it is fascinating that the frequently mocked concept of a "grandmother cell" is not as preposterous as once assumed.

Another dramatic finding in this area of research is that the neurons in the what pathway that are involved in perceiving faces can learn from experience (Gauthier & Curby, 2005; Palmeri & Gauthier, 2004). In one eye-opening study, participants were given extensive training in discriminating among similar artificial objects called Greebles (see Figure 4.17). After this training, neurons that

Figure 4.15
The what and where pathways from the primary visual cortex.

Cortical processing of visual input is begun in the primary visual cortex. From there. signals are shuttled onward to a variety of other areas in the cortex along a number of pathways. Two prominent pathways are highlighted here. The dorsal stream. or where pathway, which processes information about motion and depth, moves on to areas of the parietal lobe. The ventral stream, or what pathway, which processes information about color and form, moves on to areas of the temporal lobe.



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are normally sensitive to faces were found to be almost as sensitive to Greebles as to faces (Gauthier et al., 1999). In other words, neurons that usually serve as face detectors were "retooled" to be responsive to other visual forms. Like many findings discussed in Chapter 3 (see pp. 104–105), these results demonstrate that the functional organization of the brain is somewhat "plastic" and that the brain can be rewired by experience.

Viewing the World in Color



So far, we've considered only how the visual system deals with light and dark. Let's journey now into the world of color. On the one hand, you can see perfectly well without seeing in color. Many animals get by with little or no color vision, and no one seemed to suffer back when all photographs, movies, or TV shows were in black and white. On the other hand, color clearly adds rich information to our perception of the world. The ability to identify objects is enhanced by the addition of color (Tanaka, Weiskopf, & Williams, 2001). Thus, some theorists have suggested that color vision evolved in humans and monkeys because it improved their abilities to find food through foraging, to spot prey, and to quickly recognize predators (Spence et al., 2006). Although the purpose of color vision remains elusive, scientists have learned a great deal about the mechanisms underlying the perception of color.

The Stimulus for Color



As noted earlier, the lights people see are mixtures of various wavelengths. Perceived color is primarily a function of the dominant wavelength in these mixtures. In the visible spectrum, lights with the longest wavelengths appear red, whereas those with the shortest appear violet. Notice the word *appear*. Color is a psychological interpretation. It's not a physical property of light itself.

Although wavelength wields the greatest influence, perception of color depends on complex blends of all three properties of light. *Wavelength* is most closely related to hue, *amplitude* to brightness, and *purity* to saturation. These three dimensions of color are illustrated in the *color solid* shown in Figure 4.18 on the next page.

As a color solid demonstrates systematically, people can perceive many different colors. Indeed, experts estimate that humans can discriminate among roughly a million colors (Boynton, 1990). Most of these diverse variations are the result of mixing a few basic colors. There are two kinds of color mixture:







Examples of stimuli used by Quiroga et al. (2005). Quiroga and colleagues exposed participants to varied views of specific objects, buildings, animals, faces, and random photos while monitoring activity in selected brain cells. They discovered neurons in the hippocampal area that were uniquely responsive to certain famous people, such as Halle Berry. These cells apparently were responding to the *concept* of Halle Berry rather than to her *face* because they responded not only to facial photos but also to pictures of the actress in a Catwoman costume and to the words HALLE BERRY. Similar results were observed for diverse stimuli related to other famous people.

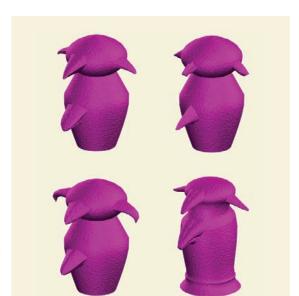


Figure 4.17
Distinguishing Greebles.

Gauthier et al. (1999) gave subjects seven hours of training in the recognition of novel stimuli called Greebles, four of which are shown here. As the text explains, this training was conducted to explore whether neurons that normally respond to faces could be retuned by experience.

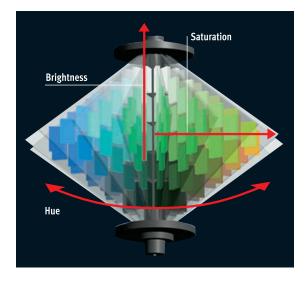
SOURCE: Reproduced by permission of Gauthier, I., (2008). Copyright © by Isabel Gauthier.

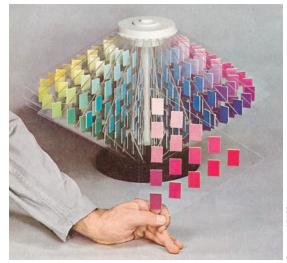
works by removing some wavelengths of light, leaving less light than was originally there. You probably became familiar with subtractive mixing as a child when you mixed yellow and blue paints to make green. Paints yield subtractive mixing because pigments *absorb* most wavelengths, selectively reflecting specific wavelengths that give rise to particular colors. Subtractive color mixing can also be demonstrated by stacking color filters. If you look through a sandwich of yellow and blue cellophane filters, they will block out certain wavelengths. The middle wavelengths that are left will look green.

Additive color mixing works by superimposing lights, putting more light in the mixture than exists in any one light by itself. If you shine red, green, and blue spotlights on a white surface, you'll



Figure 4.18
The color solid. The color solid shows how color varies along three perceptual dimensions: brightness (increasing from the bottom to the top of the solid), hue (changing around the solid's perimeter), and saturation (increasing toward the periphery of the solid).





have an additive mixture. As **Figure 4.19** shows, additive and subtractive mixtures of the same colors produce different results. Human processes of color perception parallel additive color mixing much more closely than subtractive mixing, as you'll see in the

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Trichromatic Theory of Color Vision

three types of receptors.

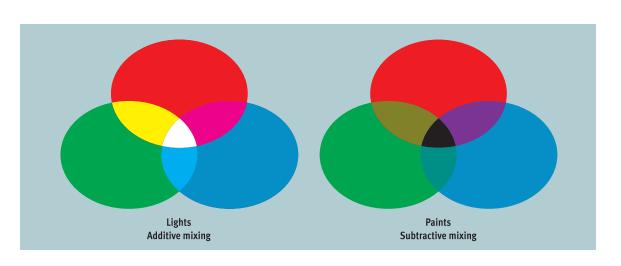
The *trichromatic theory* of color vision (*tri* for "three," *chroma* for "color") was first stated by Thomas Young and modified later by Hermann von Helmholtz (1852). The *trichromatic theory* of color vision holds that the human eye has three types of receptors with differing sensitivities to different light wavelengths. Helmholtz theorized that the eye contains specialized receptors sensitive to the specific wavelengths associated with red, green, and blue. According to this model, people can see all the colors of the rainbow because the eye does its own "color mixing" by varying the ratio of neural activity among these

following discussion of theories of color vision.

The impetus for the trichromatic theory was the demonstration that a light of any color can be matched by the additive mixture of three *primary colors*. Any three colors that are appropriately spaced out in the visible spectrum can serve as primary colors, although red, green, and blue are usually used. Does it sound implausible that three colors should be adequate for creating all other colors? If so, consider that this is exactly what happens on your color TV screen. Additive mixtures of red, green, and blue fool you into seeing all the colors of a natural scene.

Most of the known facts about color blindness also meshed well with trichromatic theory. *Color blindness* encompasses a variety of deficiencies in the ability to distinguish among colors. Color blindness occurs much more frequently in males than in females. Actually, the term color *blindness* is somewhat misleading, since complete blindness to differences in colors is quite rare. Most people who are color blind are *dichromats*; that is, they make do with only two types of color receptors. There are

Figure 4.19 Additive versus subtractive color mixing. Lights mix additively because all the wavelengths contained in each light reach the eye. If red, blue, and green lights are projected onto a white screen, they produce the colors shown on the left. with white at the intersection of all three lights. If paints of the same three colors were combined in the same way, the subtractive mixture would produce the colors shown on the right, with black at the intersection of all three colors. As you can see, additive and subtractive color mixing produce differ-



ent results.



three types of dichromats, and each type is insensitive to a different color (red, green, or blue, although the latter is rare) (Gouras, 1991). The three deficiencies seen among dichromats support the notion that there are three sets of receptors for color vision, as proposed by trichromatic theory.

Opponent Process Theory of Color Vision



Although trichromatic theory explained some facets of color vision well, it ran aground in other areas. Consider complementary afterimages, for instance. Complementary colors are pairs of colors that produce gray tones when mixed together. The various pairs of complementary colors can be arranged in a color circle, such as the one in Figure 4.20. If you stare at a strong color and then look at a white background, you'll see an afterimage—a visual image that persists after a stimulus is removed. The color of the afterimage will be the complement of the color you originally stared at. Trichromatic theory cannot account for the appearance of complementary afterimages.

Here's another peculiarity to consider. If you ask people to describe colors but restrict them to using three names, they run into difficulty. For example, using only red, green, and blue, they simply don't feel comfortable describing yellow as "reddish green." However, if you let them have just one more name, they usually choose yellow; they can then describe any color quite well (Gordon & Abramov, 2001). If colors can be reduced to three primaries, why are four color names required to describe the full range of possible colors?

In an effort to answer questions such as these, Ewald Hering proposed the *opponent process theory* in 1878. The *opponent process theory* of color vision holds that color perception depends on receptors that make antagonistic responses to three pairs of colors. The three pairs of opponent colors he posited were red versus green, yellow versus blue, and black versus white. The antagonistic processes in this theory provide plausible explanations for complementary afterimages and the need for four names (red, green, blue, and yellow) to describe colors. Opponent process theory also explains some aspects of color blindness. For instance, it can explain why dichromats typically find it hard to distinguish either green from red or yellow from blue.

Reconciling Theories of Color Vision



Advocates of trichromatic theory and opponent process theory argued about the relative merits of their models for almost a century. Most researchers assumed that one theory must be wrong and the other

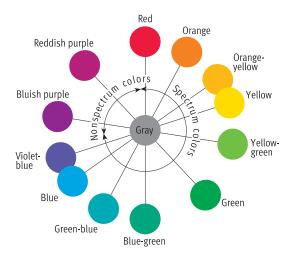


Figure 4.20
The color circle and complementary colors.

Colors opposite each other on this color circle are complements, or "opposites." Additively mixing complementary colors produces gray. Opponent process principles help explain this effect as well as the other peculiarities of complementary colors noted in the text.

must be right. In recent decades, however, it has become clear that *it takes both theories to explain color vision*. Eventually a physiological basis for both theories was found. Research that earned George Wald a Nobel prize demonstrated that *the eye has three types of cones*, with each type being most sensitive to a different band of wavelengths, as shown in **Figure 4.21** (Lennie, 2000; Wald, 1964). The three types of cones represent the three different color receptors predicted by trichromatic theory. Interestingly, the three types of cones are distributed in a seemingly random fashion in the central area of the retina where cones predominate (Solomon & Lennie, 2007).

Researchers also discovered a biological basis for opponent processes. They found cells in the retina,

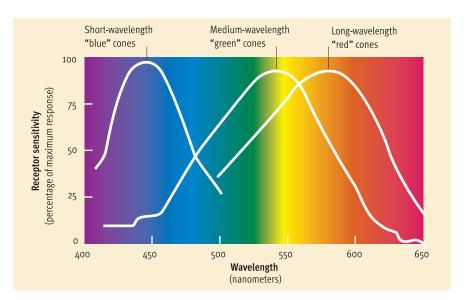


Figure 4.21

Three types of cones. Research has identified three types of cones that show varied sensitivity to different wavelengths of light. As the graph shows, these three types of cones correspond only roughly to the red, green, and blue receptors predicted by trichromatic theory, so it is more accurate to refer to them as cones sensitive to short, medium, and long wavelengths.

SOURCE: Wald, G., & Brown, P. K. (1965). Human color vision and color blindness. *Symposium Cold Spring Harbor Laboratory of Quantitative Biology*, *30*, 345–359 (p. 351). Copyright © 1965. Reprinted by permission of the author.





LGN, and visual cortex that respond in opposite ways to red versus green and blue versus yellow (DeValois & Jacobs, 1984; Zrenner et al., 1990). For example, specific ganglion cells in the retina are excited by green and inhibited by red. Other retinal ganglion cells work in just the opposite way, as predicted in opponent process theory.

In summary, the perception of color appears to involve sequential stages of information processing

(Hurvich, 1981). The receptors that do the first stage of processing (the cones) seem to follow the principles outlined in trichromatic theory. In later stages of processing, at least some cells in the retina, the LGN, and the visual cortex seem to follow the principles outlined in opponent process theory. As you can see, vigorous theoretical debate about color vision produced a solution that went beyond the contributions of either theory alone.

REVIEW of Key Learning Goals

- **4.5** Light varies in terms of wavelength, amplitude, and purity. Perceptions of color (hue) are primarily a function of light wavelength, while amplitude mainly affects brightness and purity mainly affects saturation.
- **4.6** Light enters the eye through the cornea and pupil and is focused upside down on the retina by the lens. Distant objects appear blurry to nearsighted people and close objects appear blurry to farsighted people. The pupils control the amount of light entering the eye.
- **4.7** The retina is the neural tissue in the eye that absorbs light, processes images, and sends visual signals to the brain. Cones, which are concentrated in the fovea, play a key role in daylight vision and color perception. Rods, which have their greatest density just outside the fovea, are critical to night vision and peripheral vision. Dark adaptation and light adaptation both involve changes in the retina's sensitivity to light. Receptive fields are areas in the retina that affect the firing of visual cells.
- **4.8** The optic nerves from the inside half of each eye cross at the optic chiasm and then project to the opposite half of the brain. Two visual pathways engage in parallel processing and send signals to different areas of the primary visual cortex. The main pathway is routed through the LGN in the thalamus. After processing in the primary visual cortex, visual information is shuttled along the *what* and *where* pathways to other cortical areas. Research suggests that the visual cortex contains cells that function as feature detectors. The *what pathway* has neurons inside it that are especially sensitive to faces and other highly specific stimuli.
- **4.9** There are two types of color mixing: additive and subtractive. Human color perception depends on processes that resemble additive color mixing. The trichromatic theory holds that people have three types of receptors that are sensitive to wavelengths associated with red, green, and blue. The opponent process theory holds that color perception depends on receptors that make antagonistic responses to red versus green, blue versus yellow, and black versus white. The evidence now suggests that both theories are necessary to account for color vision.



Key Learning Goals

- **4.10** Discuss the subjectivity of form perception, the phenomenon of inattentional blindness, and the concept of feature analysis.
- **4.11** State the basic premise of Gestalt psychology, and describe Gestalt principles of visual perception.
- **4.12** Clarify how form perception can be a matter of formulating perceptual hypotheses.
- **4.13** Describe the monocular and binocular cues used in depth perception, and discuss cultural variations in depth perception.
- **4.14** Summarize the Featured Study on the perception of geographical slant.
- **4.15** Describe perceptual constancies and illusions in vision, and discuss cultural variations in susceptibility to certain illusions.

The Visual System: Perceptual Processes

We have seen how sensory receptors in the eye transform light into neural impulses that are sent to the brain. We focus next on how the brain makes sense of it all—how does it convert streams of neural impulses into perceptions of chairs, doors, friends, automobiles, and buildings? In this section we explore perceptual processes in vision, such as the perception of forms, objects, depth, and so forth.

Perceiving Forms, Patterns, and Objects

3c, 3e



The drawing in **Figure 4.22** is a poster for a circus act involving a trained seal. Take a good look at it. What do you see?

No doubt you see a seal balancing a ball on its nose and a trainer holding a fish and a whip. But suppose you had been told that the drawing is actually a poster for a costume ball. Would you have perceived it differently?

If you focus on the idea of a costume ball (stay with it a minute if you still see the seal and trainer), you will probably see a costumed man and woman in Figure 4.22. She's handing him a hat, and he has a sword in his right hand. This tricky little sketch was made ambiguous quite intentionally. It's a reversible figure, a drawing that is compatible with two interpretations that can shift back and forth. Another classic reversible figure is shown in Figure 4.23. What do you see? A rabbit or a duck? It all depends on how you look at the drawing.

The key point is simply this: The same visual input can result in radically different perceptions. No one-to-one correspondence exists between sensory input and what you perceive. This is a principal reason that people's experience of the world is subjective. Perception involves much more than passively receiving signals from the outside world. It involves the interpretation of sensory input. To some extent, this interpretive process can be influenced by manipulating people's



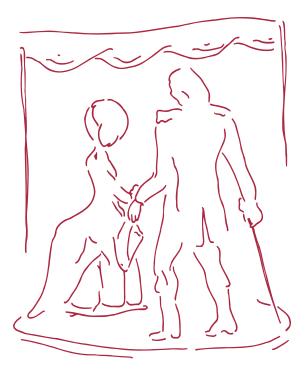


Figure 4.22

A poster for a trained seal act. Or is it? The picture is an ambiguous figure, which can be interpreted as either of two scenes, as explained in the text.

expectations. For example, information given to you about the drawing of the "circus act involving a trained seal" created a perceptual set—a readiness to perceive a stimulus in a particular way. A perceptual set creates a certain slant in how someone interprets sensory input.

Like expectations, motivational forces can foster perceptual sets, as demonstrated in one recent study (Balcetis & Dunning, 2006) using reversible figures as stimuli. Participants were told that a computer would flash a number or a letter to indicate whether they were assigned to a pleasant or unpleasant experimental task (trying some orange juice or a nasty looking health food drink). Each of the subjects briefly saw the same ambiguous stimulus (see Figure 4.24), which could be viewed as either a number (13) or a letter (B), and then the computer appeared to crash. Participants were then asked what they had seen before the computer crashed. Subjects hoping for a letter were much more likely to interpret the stimulus as a B, and those hoping for a number were much more likely to view the stimulus as a 13. Thus, we see once again, that people have a tendency to see what they want to see.

Form perception also depends on the *selection* of sensory input—that is, what people focus their attention on (Chun & Wolfe, 2001). A visual scene

may include many objects and forms. Some of them may capture viewers' attention, while others may not. This fact has been demonstrated in dramatic fashion in studies of inattentional blindness, which involves the failure to see visible objects or events because one's attention is focused elsewhere. In one such study (Simons & Chabris, 1999), participants watched a video of a group of people in white shirts passing a basketball that was laid over another video of people in black shirts passing a basketball (the two videos were partially transparent). The observers were instructed to focus on one of the two teams and press a key whenever that team passed the ball. Thirty seconds into the task, a woman carrying an umbrella clearly walked through the scene for four seconds. You might guess that this bizarre development would be noticed by virtually all the observers, but 44% of the participants failed to see the woman. Moreover, when someone in a gorilla suit strolled through the same scene, even more subjects (73%) missed the unexpected event!

Additional studies using other types of stimulus materials have demonstrated that people routinely overlook obvious forms that are unexpected (Most et al., 2005). Inattentional blindness has been attributed to a perceptual set that leads people to focus most of their attention on a specific feature in a scene (such as the basketball passes) while neglecting other facets of the scene (Most et al., 2001). Consistent with this analysis, recent research has shown that the likelihood of inattentional blindness increases when people work on tasks that require a lot of attention or create a heavy perceptual load (Cartwright-Finch & Lavie, 2007). Inattentional blindness may account for many automobile accidents, as accident reports frequently include the statement "I looked right there, but I never saw them" (Shermer, 2004). Although this phenomenon can happen to an attentive and unimpaired driver, research shows that inattentional blindness increases when people talk on a cell phone or are even slightly intoxicated (Clifasefi, Takarangi, & Bergman, 2006; Strayer & Drews, 2007).

The idea that we see much less of the world than we think we do surprises many people, but an auditory parallel exists that people take for granted (Mack, 2003). Think of how often you have had someone clearly say something to you, but you did not hear a word of what was said because you were "not listening." Inattentional blindness is essentially the same thing in the visual domain.

An understanding of how people perceive forms and objects also requires knowledge of how people *organize* their visual inputs. Several influential approaches to this issue emphasize *feature analysis*.



Figure 4.23
Another ambiguous
figure. What animal do
you see here? As the text
explains, two very different
perceptions are possible.
This ambiguous figure was
devised around 1900 by
Joseph Jastrow, a prominent
psychologist at the turn of
the 20th century (Block &
Yuker. 1992).

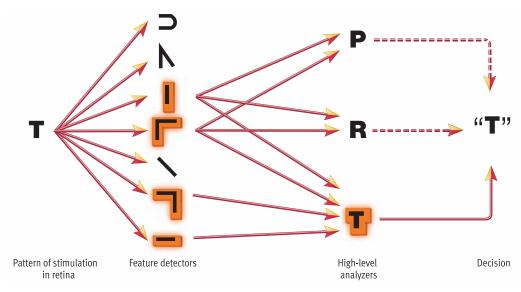


Figure 4.24
Ambiguous stimulus
used by Balcetis and
Dunning (2006). Participants saw brief presentations
of this stimulus, which could
be viewed as a letter (B) or
as a number (13). The study
demonstrated that motivational factors influence what
people tend to see.



Figure 4.25 Feature analysis in form perception. One vigorously debated theory of form perception is that the brain has cells that respond to specific aspects or features of stimuli, such as lines and angles. Neurons functioning as higher-level analyzers then respond to input from these "feature detectors." The more input each analyzer receives, the more active it becomes. Finally, other neurons weigh signals from these analyzers and make a "decision" about the stimulus. In this way perception of a form is arrived at by assembling elements

from the bottom up.



Feature Analysis: Assembling Forms



The information received by your eyes would do you little good if you couldn't recognize objects and forms—ranging from words on a page to mice in your cellar and friends in the distance. According to some theories, perceptions of form and pattern entail *feature analysis* (Lindsay & Norman, 1977; Maguire et al., 1990). *Feature analysis* is the process of detecting specific elements in visual input and assembling them into a more complex form. In other words, you start with the components of a form, such as lines, edges, and corners, and build them into perceptions of squares, triangles, stop signs, bicycles, ice cream cones, and telephones. An application of this model of form perception is diagrammed in Figure 4.25.

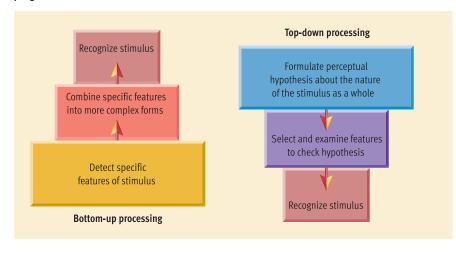
Feature analysis assumes that form perception involves *bottom-up processing*, a progression from individual elements to the whole (see Figure 4.26). The plausibility of this model was bolstered greatly when Hubel and Wiesel showed that cells in the visual cortex operate as highly specialized feature detectors. Indeed, their findings strongly suggested that at least some aspects of form perception involve feature analysis.

Can feature analysis provide a complete account of how people perceive forms? Clearly not. A crucial problem for the theory is that form perception often does not involve bottom-up processing. In fact, there is ample evidence that perceptions of form frequently involve top-down processing, a progression from the whole to the elements (see Figure 4.26). For example, there is evidence that people can perceive a word before its individual letters, a phenomenon that has to reflect top-down processing (Johnston & McClelland, 1974). If readers depended exclusively on bottom-up processing, they would have to analyze the features of letters in words to recognize them and then assemble the letters into words. This task would be terribly time-consuming and would slow down reading speed to a snail's pace.

Subjective contours is another phenomenon traditionally attributed to top-down processing, although that view is changing (Gunn et al., 2000; Murray et al., 2004). Subjective contours involves the perception of contours where none actually exist. Consider, for instance, the triangle shown in Figure 4.27. We see the contours of the triangle easily, even though no physical edges or lines are present. It is hard to envision how feature detectors could detect edges that are not really there, so most theorists have argued that bottom-up models of form perception are unlikely to account for subjec-

Figure 4.26

Bottom-up versus top-down processing. As explained in these diagrams, bottom-up processing progresses from individual elements to whole elements, whereas top-down processing progresses from the whole to the individual elements.





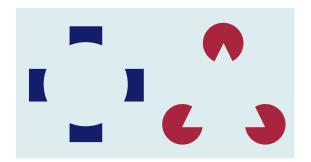


Figure 4.27

Subjective contours. Your perception of the triangle on the right and the circle on the left results from subjective contours that are not really there. The effect is so powerful, the triangle and circle appear lighter than the background, which they are not. To demonstrate the illusory nature of these contours for yourself, cover the red circles that mark off the triangle. You'll see that the triangle disappears.

tive contours. In any event, it appears that both topdown and bottom-up processing have their niches in form perception.

Looking at the Whole Picture: Gestalt Principles

Top-down processing is clearly at work in the principles of form perception described by the Gestalt psychologists. As mentioned in Chapter 1, *Gestalt psychology* was an influential school of thought that emerged out of Germany during the first half of the 20th century. (*Gestalt* is a German word for "form" or "shape.") Gestalt psychologists repeatedly demonstrated that *the whole can be greater than the sum of its parts*.

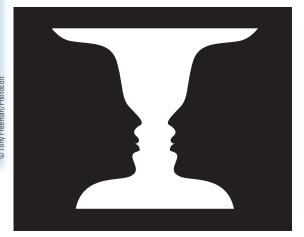
A simple example of this principle is the *phi phenomenon,* first described by Max Wertheimer in 1912. The *phi phenomenon* is the illusion of movement created by presenting visual stimuli in rapid

The illusion of movement in a highway construction sign is an instance of the phi phenomenon, which is also at work in motion pictures and television. The phenomenon illustrates the Gestalt principle that the whole can have properties that are not found in any of its parts.

succession. You encounter examples of the phi phenomenon nearly every day. For example, movies and TV consist of separate still pictures projected rapidly one after the other. You see smooth motion, but in reality the "moving" objects merely take slightly different positions in successive frames. Viewed as a whole, a movie has a property (motion) that isn't evident in any of its parts (the individual frames). The Gestalt psychologists formulated a series of principles that describe how the visual system organizes a scene into discrete forms. Let's examine some of these principles.

Figure and Ground. Take a look at Figure 4.28. Do you see the figure as two silhouetted faces against a white background, or as a white vase against a black background? This reversible figure illustrates the Gestalt principle of figure and ground. Dividing visual displays into figure and ground is a fundamental way in which people organize visual perceptions (Baylis & Driver, 1995). The figure is the thing being looked at, and the ground is the background against which it stands. Figures seem to have more substance and shape, appear to be closer to the viewer, and seem to stand out in front of the ground. Other things being equal, an object is more likely to be viewed as a figure when it is smaller in size, higher in contrast, or greater in symmetry (Palmer, 2003), and especially when it is lower in one's frame of view (Vecera & Palmer, 2006). More often than not, your visual field may contain many figures sharing a background. The following Gestalt principles relate to how these elements are grouped into higher-order figures (Palmer, 2003).

Proximity. Things that are near one another seem to belong together. The black dots in the upper left panel of **Figure 4.29(a)** on the next page could be grouped into vertical columns or horizontal rows.



Archives of the History of American Psychology.

Max Wertheimer

"The fundamental 'formula' of Gestalt theory might be expressed in this way: There are wholes, the behaviour of which is not determined by that of their individual elements."

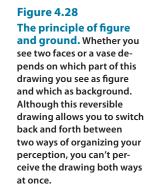
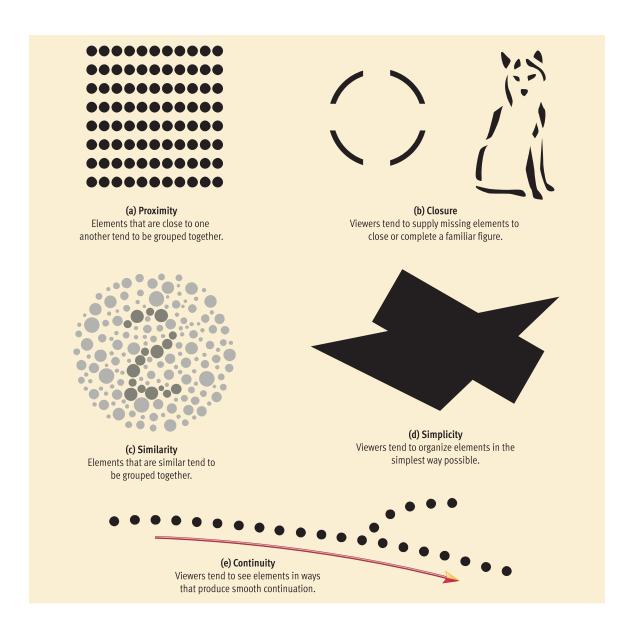




Figure 4.29 Gestalt principles of perceptual organization.

Gestalt principles help explain some of the factors that influence form perception. (a) Proximity: These dots might well be organized in vertical columns rather than horizontal rows. but because of proximity (the dots are closer together horizontally), they tend to be perceived in rows. (b) Closure: Even though the figures are incomplete, you fill in the blanks and see a circle and a dog. (c) Similarity: Because of similarity of color, you see dots organized into the number 2 instead of a random array. If you did not group similar elements, you wouldn't see the number 2 here. (d) Simplicity: You could view this as a complicated 11-sided figure, but given the preference for simplicity, you are more likely to see it as an overlapping rectangle and triangle. (e) Continuity: You tend to group these dots in a way that produces a smooth path rather than an abrupt shift in direction.



However, people tend to perceive rows because of the effect of proximity (the dots are closer together horizontally).

Closure. People often group elements to create a sense of *closure,* or completeness. Thus, you may "complete" figures that actually have gaps in them. This principle is demonstrated in the upper right panel of **Figure 4.29(b)**.

Similarity. People also tend to group stimuli that are similar. This principle is apparent in **Figure 4.29**(c), where viewers group elements of similar lightness into the number two.

Simplicity. The Gestaltists' most general principle was the law of *Pragnanz*, which translates from German as "good form." The idea is that people tend to group elements that combine to form a good figure.

This principle is somewhat vague in that it's often difficult to spell out what makes a figure "good" (Biederman, Hilton, & Hummel, 1991). Some theorists maintain that goodness is largely a matter of simplicity, asserting that people tend to organize forms in the simplest way possible (see Figure 4.29d).

Continuity. The principle of continuity reflects people's tendency to follow in whatever direction they've been led. Thus, people tend to connect points that result in straight or gently curved lines that create "smooth" paths, as shown in the bottom panel of **Figure 4.29(e)**.

Although Gestalt psychology is no longer an active theoretical orientation in modern psychology, its influence is still felt in the study of perception (Banks & Krajicek, 1991). The Gestalt psychologists raised many important questions that still occupy

web link 4.3

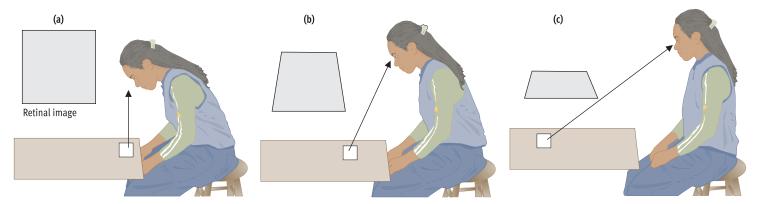


Sensation and Perception Tutorials

John Krantz of Hanover College has assembled a collection of quality tutorials on sensation and perception. Topics covered include receptive fields, depth perception, Gestalt laws, and the use of perceptual principles in art.

150 CHAPTER 4





Distal and proximal stimuli. Proximal stimuli are often distorted, shifting representations of distal stimuli in the real world. If you look directly down at a small, square piece of paper on a desk (a), the distal stimulus (the paper) and the proximal stimulus (the image projected on your retina) will both be square. But as you move the paper away on the desktop, as shown in (b) and (c), the square distal stimulus projects an increasingly trapezoidal image on your retina, making the proximal stimulus more and more distorted. Nevertheless, you continue to perceive a square.

researchers, and they left a legacy of many useful insights about form perception that have stood the test of time (Sharps & Wertheimer, 2000).

Formulating Perceptual Hypotheses

The Gestalt principles provide some indications of how people organize visual input. However, scientists are still one step away from understanding how these organized perceptions result in a representation of the real world. Understanding the problem requires distinguishing between two kinds of stimuli: distal and proximal (Hochberg, 1988). Distal stimuli are stimuli that lie in the distance (that is, in the world outside the body). In vision, these are the objects that you're looking at. They are "distant" in that your eyes don't touch them. What your eyes do "touch" are the images formed by patterns of light falling on your retinas. These images are the proximal stimuli, the stimulus energies that impinge directly on sensory receptors. The distinction is important, because there are great differences between the objects you perceive and the stimulus energies that represent them.

In visual perception, the proximal stimuli are distorted, two-dimensional versions of their actual, three-dimensional counterparts. For example, consider the distal stimulus of a square such as the one in **Figure 4.30**. If the square is lying on a desk in front of you, it is actually projecting a trapezoid (the proximal stimulus) onto your retinas, because the top of the square is farther from your eyes than the bottom. Obviously, the trapezoid is a distorted representation of the square. If what people have to work with is so distorted a picture, how do they get an accurate view of the world out there?

One explanation is that people bridge the gap

between distal and proximal stimuli by constantly making and testing *hypotheses* about what's out there in the real world (Gregory, 1973). Thus, a *perceptual hypothesis* is an inference about which distal stimuli could be responsible for the proximal stimuli sensed. In effect, people make educated guesses about what form could be responsible for a pattern of sensory stimulation. The square in Figure 4.30 may project a trapezoidal image on your retinas, but your perceptual system "guesses" correctly that it's a square—and that's what you see.

Let's look at another ambiguous drawing to further demonstrate the process of making a perceptual hypothesis. Figure 4.31 is a famous reversible figure, first published as a cartoon in a humor magazine. Perhaps you see a drawing of a young woman looking back over her right shoulder. Alternatively, you might see an old woman with her chin down on her chest.



Figure 4.31
A famous reversible
figure. What do you see?
Consult the text to learn the
two possible interpretations
of this figure.





The ambiguity exists because there isn't enough information to force your perceptual system to accept only one of these hypotheses. Incidentally, studies show that people who are led to *expect* the young woman or the old woman generally see the one they expect (Leeper, 1935). This is another example of how perceptual sets influence what people see.

Psychologists have used a variety of reversible figures to study how people formulate perceptual hypotheses. Another example can be seen in Figure 4.32, which shows the *Necker cube*. The shaded surface can appear as either the front or the rear of the transparent cube. When people stare at the cube continuously, their perception tends to involuntarily alternate between these possibilities (Leopold et al., 2002).

The *context* in which something appears often guides people's perceptual hypotheses. To illustrate, take a look at **Figure 4.33**. What do you see? You probably saw the words "THE CAT." But look again; the middle characters in both words are identical. You identified an "H" in the first word and an "A" in the second because of the surrounding letters, which created an expectation—another example of top-down processing in visual perception. The power of expectations explains why typographocal errors like those in this sentance often pass unoberved (Lachman, 1996).

Our perceptual hypotheses clearly are guided by our experience-based expectations. For example, subjects recognize everyday objects more quickly when they are presented from familiar viewpoints as opposed to unfamiliar viewpoints (Enns, 2004;

Figure 4.32
The Necker cube.
The tinted surface of this reversible figure can become either the front or the back of the cube.

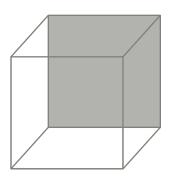


Figure 4.33
Context effects. You probably read these letters as "THE CAT" even though the middle letter of each word is the same. This simple demonstration shows that the context in which a stimulus is seen can affect your perceptual hypotheses.



see **Figure 4.34**). We also realize that certain objects and settings generally go together. We expect to see a sofa sitting in a living room, but not on a beach. When subjects are given brief glimpses of objects in typical versus unusual settings, the objects that appear in typical settings are identified more accurately (Davenport & Potter, 2004; see **Figure 4.35**). This finding illustrates the importance of both context and experience.

Perceiving Depth or Distance 3f

More often than not, forms and figures are objects in space. Spatial considerations add a third dimension to visual perception. *Depth perception* involves interpretation of visual cues that indicate how near or far away objects are. To make judgments of distance, people rely on a variety of cues, which can be classified into two types: binocular and monocular (Hochberg, 1988; Proffitt & Caudek, 2003).

Binocular Cues

Because they are set apart, the eyes each have a slightly different view of the world. *Binocular depth cues* are clues about distance based on the differing views of the two eyes. "Stereo" viewers like the Viewmaster toy you may have had as a child make use of this principle by presenting slightly different flat images of the same scene to each eye. The brain



Figure 4.34

Effect of viewpoint on form perception. Research on object recognition shows that the time needed to recognize an object depends on the perspective from which it is viewed (Enns, 2004). Subjects recognize familiar, prototypical views of everyday objects (such as the tricycle on the left) more quickly than atypical views of the same objects (such as the tricycle on the right) (Palmer, Rosch, & Chase, 1981). This finding shows that our perceptual hypotheses are guided by our experience.

SOURCE: Enns, J. T. (2004). The thinking eye, the seeing brain: Explorations in visual cognition. New York: W. W. Norton, p. 204. Copyright © 2004 by W. W. Norton & Company. Used by permission of W. W. Norton & Company.









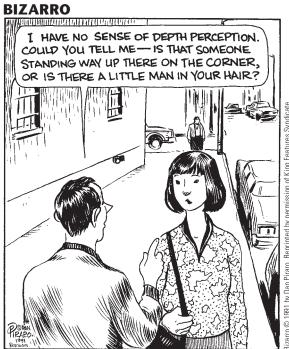


Figure 4.35 Effect of object and background consistency on object recognition. In a study by Davenport and Potter (2004), participants were given brief glimpses of objects that were presented in a typical setting consistent with expectations, such as a football player on a football field or a priest in a church (top), or in an unusual, unexpected setting, as seen in the bottom photos, where the priest is on a football field and the football player is in a church. The findings showed that when objects are consistent with their background, they are recognized more accurately. Thus, context and experience affect form perception.

SOURCE: Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception, Psychological Science, 15, 559-564, Reprinted by permission of Blackwell Publishers and the author

then supplies the "depth," and you perceive a threedimensional scene.

The principal binocular depth cue is retinal disparity, which refers to the fact that objects within 25 feet project images to slightly different locations on the right and left retinas, so the right and left eyes see slightly different views of the object. The closer an object gets, the greater the disparity between the images seen by each eye. Thus, retinal disparity increases as objects come closer, providing information about distance. Another binocular cue is convergence, which involves sensing the eyes converging toward each other as they focus on closer objects.



Monocular Cues

Monocular depth cues are clues about distance based on the image in either eye alone. There are two kinds of monocular cues to depth. One kind is the result of active use of the eye in viewing the world. For example, as an object comes closer, you may sense the accommodation (the change in the curvature of the lens) that must occur for the eye to adjust its focus. Furthermore, if you cover one eye and move your head from side to side, closer objects appear to move more than distant objects. In a similar vein, you may notice when driving along a highway that nearby objects (such as fenceposts along the road) appear to move by more rapidly than objects that are farther away (such as trees in the distance). Thus, you get cues about depth from motion parallax, which involves images of objects at different distances moving across the retina at different rates.

The other kind of monocular cues are pictorial depth cues—clues about distance that can be given in a flat picture. There are many pictorial cues to depth, which is why some paintings and photographs seem so realistic that you feel you can climb right into them. Six prominent pictorial depth cues are described and illustrated in Figure 4.36 on the next page. Linear perspective is a depth cue reflecting the fact that lines converge in the distance. Because details are too small to see when they are far away, texture gradients can provide information about depth. If an object comes between you and another object, it must be closer to you, a cue called interposition. Relative size is a cue because closer objects appear larger. Height in plane reflects the fact that distant objects appear higher in a picture. Finally, the familiar effects of shadowing make light and shadow useful in judging distance.



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Linear perspective Parallel lines that run away from the viewer seem to get closer together.



Texture gradient As distance increases, a texture gradually becomes denser and less distinct.



Interposition The shapes of near objects overlap or mask those of more distant ones.



Relative size If separate objects are expected to be of the same size, the larger ones are seen as closer.



Height in plane Near objects are low in the visual field; more distant ones are higher up.



Light and shadow Patterns of light and dark suggest shadows that can create an impression of three-dimensional forms.

Figure 4.36 Pictorial cues to depth. Six pictorial depth cues are explained and illustrated here. Although one cue stands out in each photo, in most visual scenes several pictorial cues are present. Try looking at the light-and-shadow picture upside down. The change

in shadowing reverses what

you see.

There appear to be some cultural differences in the ability to take advantage of pictorial depth cues in two-dimensional drawings. These differences were first investigated by Hudson (1960, 1967), who presented pictures like that shown in Figure 4.37 to various cultural groups in South Africa. Hudson's approach was based on the assumption that subjects who indicate that the hunter is trying to spear the elephant instead of the antelope don't understand the depth cues (interposition, relative size, height in plane) in the picture, which place the elephant in the distance. Hudson found that subjects from a rural South African tribe (the Bantu), who had little exposure at that time to pictures and photos, frequently misinterpreted the depth cues in his pictures. Similar difficulties with depth cues in pictures have been documented for other cultural groups who have little experience with two-dimensional representations of three-dimensional space (Berry et al., 1992). Thus, the application of pictorial depth cues to pictures varies to some degree across cultures.

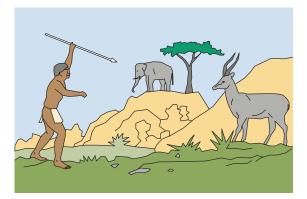


Figure 4.37
Testing understanding of pictorial depth cues. In his cross-cultural research, Hudson (1960) asked subjects to indicate whether the hunter is trying to spear the antelope or the elephant. He found cultural disparities in subjects' ability to

elephant. He found cultural disparities in subjects' ability to make effective use of the pictorial depth cues, which place the elephant in the distance and make it an unlikely target.

SOURCE: Adapted by permission from an illustration by Ilil Arbel, in Dere-

SOURCE: Adapted by permission from an illustration by liil Arbel, in Deregowski, J. B. (1972, November). Pictorial perception and culture. *Scientific American*, 227 (5), p. 83. Copyright © 1972 by Scientific American, Inc. All rights reserved.



concept check 4.2

Recognizing Pictorial Depth Cues

_ **3.** Texture gradient

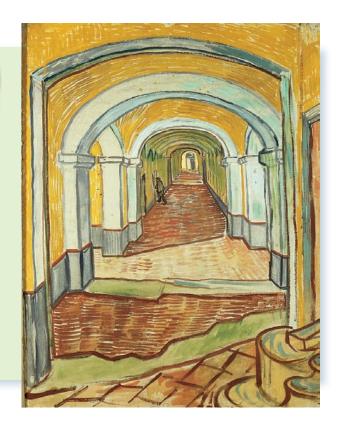
Painters routinely attempt to create the perception of depth on a flat canvas by using pictorial depth cues. **Figure 4.36** describes and illustrates six pictorial depth cues, most of which are apparent in van Gogh's colorful piece *Corridor in the Asylum* (1889). Check your understanding of depth perception by trying to spot the depth cues in the painting.

In the list below, check off the depth cues used by van Gogh. The answers can be found in the back of the book in Appendix A. You can learn more about how artists use the principles of visual perception in the Personal Application at the end of this chapter.

Interposition
 Relative size
 Height in plane
 Light and shadow

Vincent van Gogh, A *Corridor in the Asylum* (1889), Black chalk and gouache on pink Ingres paper. H. 25-5/8 in. W. 19-5/16/2 in. (65.1 x 49.1 cm.). The Metropolitan Museum of Art, Bequest of Abby Aldrich Rockefeller, 1948. (48.190.2) Photograph © 1998 The Metropolitan Museum of Art.

_ 6. Linear perspective



Recent studies have shown that estimates of distance can be skewed by transient changes in people's goals and their physical and emotional states (Proffitt, 2006a). For example, the effort required to walk to a target destination influences how far away the target appears to be. Participants wearing a heavy backpack estimate that target destinations are farther away than do subjects not burdened with the backpack (Proffitt et al., 2003). Similarly, when participants are asked to throw a ball at targets, subjects throwing a heavy ball estimate that the targets are farther away than do subjects throwing a light ball (Witt, Proffitt, & Epstein, 2004). And when they are standing on a high balcony, the more anxious subjects are about heights, the more they tend to overestimate the distance to the ground (Proffitt, 2006b). Thus, like other perceptual experiences, judgments of distance can be highly

subjective. We will draw similar conclusions in our discussion of the perception of geographical slant.

Perceiving Geographical Slant

The perception of *geographical slant* involves making judgments about how steep hills and other inclines are in relation to the norm of a flat, horizontal surface. As with depth perception, the perception of geographical slant involves juggling spatial considerations. However, unlike with depth perception, which has a rich tradition of empirical inquiry, the perception of geographical slant has largely been neglected by researchers. Nevertheless, a clever series of studies have turned up some thought-provoking findings and raised some interesting questions. We will look at this work in our Featured Study for Chapter 4.

Why Hills Look Steeper Than They Are

Accurate perceptions of geographical slant have obvious practical significance for people walking up hills, skiing down mountain slopes, working on pitched roofs, and so forth. Yet anecdotal accounts suggest that people tend to overestimate geographical slant. Thus, Proffitt and his colleagues set out to collect the first systematic data on everyday geographical pitch perception. They ended up conducting a series of five studies. We'll focus on their first study.

Method

Participants. Three hundred students at the University of Virginia agreed to participate in the study when asked by an experimenter stationed near the bottom of various hills around campus. Each participant made estimates for only one hill.

Stimuli. Nine hills on the University of Virginia campus were used as stimuli. The experimenters chose hills with



SOURCE: Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin and Review, 2*, 409–428.







A participant works with the tilt board to provide a haptic estimate of the pitch of a hill.

Figure 4.38

Apparatus used to measure visual and haptic

estimates of geographi-

cal slant. (a) Visual esti-

mates of pitch were made

of pitch were made by ad-

justing a tilt board by hand

without looking at it.

by adjusting the incline on a disk to match the incline of the hill. (b) Haptic estimates lots of foot traffic, unobstructed views, and wide variation in geographical slant. The inclinations of the nine hills were 2, 4, 5, 6, 10, 21, 31, 33, and 34 degrees. To put these figures in perspective, the authors note that 9 degrees is the steepest incline allowed for roads in Virginia and that a 30-degree hill is about the limit of what most people can walk up (the very steep hills on campus had stairs nearby).

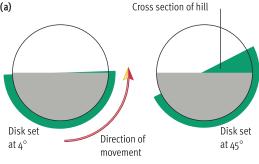
Measures and apparatus. The participants were asked to estimate geographical slant in three ways. They provided a verbal measure by estimating the slope of the hill they were viewing in degrees. They provided a visual measure by adjusting the incline on the disk shown in Figure 4.38(a) to match the slope of the hill they were viewing. Finally, they provided a haptic measure (one based on touch) by adjusting the tilt board shown in Figure 4.38(b) to match the slope of the stimulus hill. To keep the latter measure exclusively haptic and not visual, participants were not allowed to look at their hand while they adjusted the tilt board.

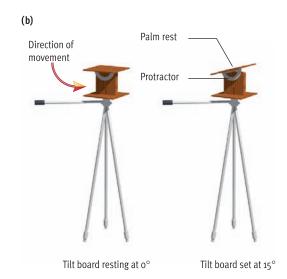
Results

The mean slant estimates for all three measures and all nine hills are summarized graphically in Figure 4.39. As you can see, the participants' verbal and visual judgments resulted in large overestimates of all nine hills' geographic slant. For example, participants' verbal estimates for the 5-degree hill in the study averaged 20 degrees. Similarly, their visual estimates for the 10-degree hill averaged 25 degrees. In contrast, the subjects' haptic judgments were much more accurate.

(a) at 4°

SOURCE: Adapted from Proffitt. D. R., Bhalla, M., Gossweiler, R., & Midaett, J. (1995). Perceiving geographical slant, Psychonomic Bulletin & Review, 214, 409-428, Copyright © 1995 by Psychonomic Society Publications. Reprinted by permission





Discussion

Why do hills appear substantially steeper than they are? Why are haptic judgments relatively immune to this peculiar perceptual bias? The authors argue that the data for all three measures make sense from an adaptive point of view. Subjects' verbal and visual estimates reflect their conscious awareness of how challenging hills will be to climb. Overestimates of slant are functional in that they should prevent people from undertaking climbs they are not equipped to handle, and they should lead people to pace themselves and conserve energy on the steep hills they do attempt to traverse. Although overestimates of slant may be functional when people make conscious decisions about climbing hills, they would be dysfunctional if they distorted people's locomotion on hills. If people walking up a 5-degree hill raised their feet to accommodate a 20-degree slope, they would stumble. Accurate tactile perceptions are thus crucial to people's motor responses when they walk up a hill, so it is functional for haptic perceptions to be largely unaffected by the misperception of slant. Thus, learning, or evolution, or some combination has equipped people with perceptual responses that are adaptive.

Comment

The study of sensation and perception is one of the oldest areas of scientific research in psychology. Yet this study shows that there are still fascinating areas of inquiry that remain unexplored. It just takes some creativity and insight to recognize them. This research also illustrates the importance of using more than a single measure of the

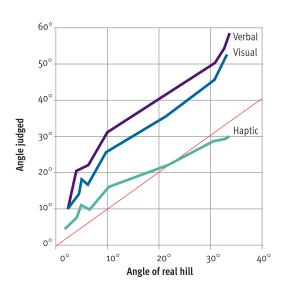


Figure 4.39 Mean slant estimates. The average pitch estimates for all three types of measures are plotted here. The red line shows where accurate estimates would fall. As you can see, verbal and visual measures yielded substantial overestimates, but haptic measures were reasonably accurate.

SOURCE: Adapted from Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. Psychonomic Bulletin & Review, 214, 409-428. Copyright © 1995 by Psychonomic Society Publications. Reprinted by permission







phenomenon that one is interested in. The investigators chose to assess the dependent variable of slant perception in several ways, leading to a much richer understanding of slant perception than if only one of the three measures had been used. Finally, the highly exaggerated estimates of slant show once again that human perceptions are not simple reflections of reality, although most people tend to

assume that they are. The authors note that many of their subjects were "incredulous" during their postexperimental briefings: "To look at a 10-degree hill—typically judged to be about 30 degrees by verbal reports and visual matching—and to be told that it is actually 10 degrees is an astonishing experience for anyone unfamiliar with the facts of geographical slant overestimation" (p. 425).

Perceptual Constancies in Vision

When a person approaches you from a distance, his or her image on your retinas gradually changes in size. Do you perceive that the person is growing right before your eyes? Of course not. Your perceptual system constantly makes allowances for this variation in visual input. The task of the perceptual system is to provide an accurate rendition of distal stimuli based on distorted, ever-changing proximal stimuli. In doing so, it relies in part on perceptual constancies. A perceptual constancy is a tendency to experience a stable perception in the face of continually changing sensory input. Among other things, people tend to view objects as having a stable size, shape, brightness, hue, and location in space.

The Power of Misleading **Cues: Visual Illusions** SIM3, 3g



In general, perceptual constancies, depth cues, and principles of visual organization (such as the Gestalt laws) help people perceive the world accurately. Sometimes, however, perceptions are based on inappropriate assumptions, and visual illusions can result. A visual illusion involves an apparently inexplicable discrepancy between the appearance of a visual stimulus and its physical reality.

One famous visual illusion is the Müller-Lyer illusion, shown in Figure 4.40. The two vertical lines in this figure are equally long, but they certainly don't look that way. Why not? Several mechanisms probably play a role (Day, 1965; Gregory, 1978). The figure

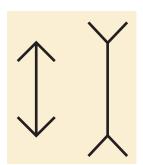
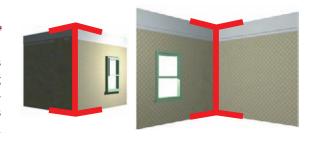


Figure 4.40 The Müller-Lyer illusion. The vertical lines in this classic illusion are very deceptive. Although they do not appear to be the same length, they are. Go ahead, measure them.



on the left looks like the outside of a building, thrust toward the viewer, while the one on the right looks like an inside corner, thrust away (see Figure 4.41). The vertical line in the left figure therefore seems closer. If two lines cast equally long retinal images but one seems closer, the closer one is assumed to be shorter. Thus, the Müller-Lyer illusion may result from a combination of size constancy processes and misperception of depth.

The geometric illusions shown in Figure 4.42 also demonstrate that visual stimuli can be highly

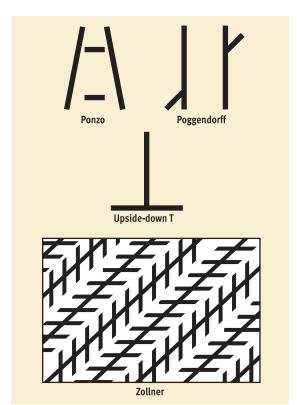


Figure 4.41 **Explaining the Müller-**Lyer illusion. The figure on the left seems to be closer, since it looks like an outside corner thrust toward you, whereas the figure on the right looks like an inside corner thrust away from you. Given retinal images of the same length, you assume that the "closer" line is shorter.

Figure 4.42 Four geometric illulines are the same length. The vertical and horizontal lines are the same length. Zollner: The long diagonals are all parallel (try covering up some of the short diagonal lines if you don't

sions. Ponzo: The horizontal Poggendorff: The two diagonal segments lie on the same straight line. Upside-down T: believe it).



web link 4.4



Eyetricks

Eyetricks houses a comprehensive collection of optical and sensory illusions. The illusions are not accompanied by explanations, but they are entertaining.

web link 4.5



Visual Illusions Gallery

This site contains a smaller collection of illusions than the Eyetricks site, but here the illusions are accompanied by brief explanations that elucidate key principles of perception. The site is maintained by psychology professor David Landrigan of the University of Massachusetts (Lowell).

deceptive. The *Ponzo illusion*, which is shown at the top of **Figure 4.42**, appears to result from the same factors at work in the Müller-Lyer illusion (Coren & Girgus, 1978). The upper and lower horizontal lines are the same length, but the upper one appears longer. This illusion probably occurs because the converging lines convey linear perspective, a key depth cue suggesting that the upper line lies farther away. **Figure 4.43** shows a drawing by Stanford University psychologist Roger Shepard (1990) that creates a similar illusion. The second monster appears much larger than the first, even though they are really identical in size.

Adelbert Ames designed a striking illusion that makes use of misperception of distance. It's called, appropriately enough, the Ames room. It's a specially contrived room built with a trapezoidal rear wall and a sloping floor and ceiling. When viewed from the correct point, as in the picture, it looks like an ordinary rectangular room (see Figure 4.44). But in reality, the left corner is much taller and much farther from the viewer than the right corner. Hence, bizarre illusions unfold in the Ames room. People standing in the right corner appear to be giants, while those standing in the left corner appear to be midgets. Even more disconcerting, a person who walks across the room from right to left appears to shrink before your eyes! The Ames room creates these misperceptions by toying with the perfectly reasonable assumption that the room is vertically and horizontally rectangular.

Impossible figures create another form of illusion. Impossible figures are objects that can be represented in two-dimensional pictures but cannot exist in three-dimensional space. These figures may look fine at first glance, but a closer look reveals

that they are geometrically inconsistent or impossible. Three widely studied impossible figures are shown in **Figure 4.45**, and a more recent impossible figure created by Roger Shepard (1990) can be seen



Figure 4.43

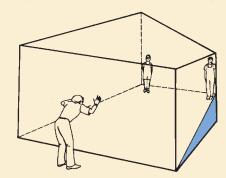
A monster of an illusion. The principles underlying the Ponzo illusion also explain the striking illusion seen here, in which two identical monsters appear to be quite different in size, although they really are equal in size.

SOURCE: Shepard, R. N. (1990). *Mind sights*. New York: W. H. Freeman. Copyright © 1990 by Roger N. Shepard. Used by permission of Henry Holt & Company, LLC.



Figure 4.44

The Ames room. The diagram on the right shows the room as it is actually constructed. However, the viewer assumes that the room is rectangular, and the image cast on the retina is consistent with this hypothesis. Because of this reasonable perceptual hypothesis, the normal perceptual adjustments made to preserve size constancy lead to the illusions described in the text. For example, naive viewers "conclude" that the boy on the right is much larger than the other, when in fact he is merely closer.





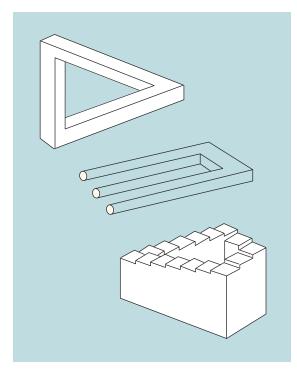
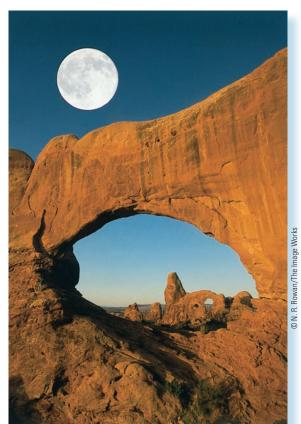
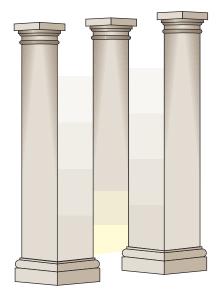


Figure 4.45
Three classic impossible figures. These figures are impossible, yet they clearly exist—on the page. What makes them impossible is that they appear to be three-dimensional representations yet are drawn in a way that frustrates mental attempts to "assemble" their features into possible objects. It's difficult to see the drawings simply as lines lying in a plane—even though this perceptual hypothesis is the only one that

resolves the contradiction.

A puzzling perceptual illusion common in everyday life is the moon illusion: the moon looks larger when at the horizon than when overhead.

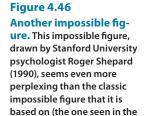




in Figure 4.46. Notice that specific portions of these figures are reasonable, but they don't add up to a sensible whole. The parts don't interface properly. The initial illusion that the figures make sense is probably a result of bottom-up processing. You perceive specific features of the figure as acceptable but are baffled as they are built into a whole.

Obviously, illusions such as impossible figures and their real-life relative, the Ames room, involve a conspiracy of cues intended to deceive the viewer. Many visual illusions, however, occur quite naturally. A well-known example is the moon illusion. The full moon appears to be much smaller when overhead than when looming on the horizon (see the adjacent photo). As with many of the other illusions we have discussed, the moon illusion appears to be due mainly to size constancy effects coupled with the misperception of distance (Coren & Aks, 1990; Kaufman & Rock, 1962), although other factors may also play a role (Suzuki, 2007). The moon illusion shows that optical illusions are part of everyday life. Indeed, many people are virtually addicted to an optical illusion called television (an illusion of movement created by a series of still images presented in quick succession).

Cross-cultural studies have uncovered some interesting differences among cultural groups in their propensity to see certain illusions. For example, Segall, Campbell, and Herskovits (1966) found that people from a variety of non-Western cultures are less susceptible to the Müller-Lyer illusion than Western samples. What could account for this difference? The most plausible explanation is that in the West, we live in a "carpentered world" dominated by straight lines, right angles, and rectangular rooms, buildings, and furniture. Thus, our experience prepares us to readily view the Müller-Lyer figures as



SOURCE: Shepard, R. N. (1990). *Mind sights*. New York: W. H. Freeman. Copyright © 1990 by Roger N. Shepard. Used by permission of Henry Holt & Company, LLC.

middle of Figure 4.45).

weblink 4.6



The Moon Illusion Explained

Don McCready, professor emeritus at the University of Wisconsin (Whitewater), addresses the age-old puzzle of why the moon appears much larger at the horizon than overhead. He uses a helpful collection of illustrations in a comprehensive review of alternative theories.







Unlike people in Western nations, the Zulus live in a culture where straight lines and right angles are scarce. Thus, they are not affected by such phenomena as the Müller-Lyer illusion nearly as much as people raised in environments that abound with rectangular structures.

inside and outside corners of buildings—inferences that help foster the illusion (Segall et al., 1990). In contrast, people in many non-Western cultures, such as the Zulu (see the above photo) who were tested by Segall and associates (1966), live in a less carpentered world, making them less prone to see the Müller-Lyer figures as building corners.

What do illusions reveal about visual perception? They drive home the point that people go through life formulating perceptual hypotheses about what lies out there in the real world. The fact that these are only hypotheses becomes especially striking when the hypotheses are wrong, as they are with illusions. Finally, like ambiguous figures, illusions clearly demonstrate that human perceptions are not simple reflections of objective reality. Once again, we see that perception of the world is subjective. These insights do not apply to visual perception only. We will encounter these lessons again as we examine other sensory systems, such as hearing, which we turn to next.

REVIEW of Key Learning Goals

4.10 Reversible figures and perceptual sets demonstrate that the same visual input can result in very different perceptions. Form perception depends on both the selection and interpretation of sensory inputs. Inattentional blindness involves the failure to see readily visible objects. According to feature analysis theories, people detect specific elements in stimuli and build them into recognizable forms through bottom-up processing, but form perception also involves top-down processing.

4.11 Gestalt psychology emphasized that the whole may be greater than the sum of its parts (features), as illustrated by the phi phenomenon. Objects are more likely to be viewed as figure rather than ground when they are smaller, higher in contrast or symmetry, and lower in one's frame of view. Gestalt principles of form perception include proximity, similarity, continuity, closure, and simplicity.

4.12 Other approaches to form perception emphasize that people develop perceptual hypotheses about the distal stimuli that could be responsible for the proximal stimuli that are sensed. These perceptual hypotheses are influenced by context and guided by experience-based expectations.

4.13 Binocular cues such as retinal disparity and convergence can contribute to depth perception. Depth perception depends primarily on monocular cues, including pictorial cues such as texture gradient, linear perspective, light and shadow, interposition, relative size, and height in plane. People from pictureless societies have some difficulty in applying pictorial depth cues to two-dimensional pictures.

4.14 The Featured Study showed that conscious perceptions of geographical slant, as reflected by visual and verbal estimates of pitch angles, tend to be greatly exaggerated, but haptic (tactile) judgments seem largely immune to this perceptual bias. Overestimates of slant can be adaptive and may reflect the influence of evolution.

4.15 Perceptual constancies in vision help viewers deal with the ever-shifting nature of proximal stimuli. Visual illusions demonstrate that perceptual hypotheses can be inaccurate and that perceptions are not simple reflections of objective reality. Researchers have found some interesting cultural differences in susceptibility to the Müller-Lyer and Ponzo illusions.



Key Learning Goals

4.16 List the three properties of sound and the aspects of auditory perception that they influence.

4.17 Summarize information on human hearing capacities, and describe how sensory processing occurs in the ear.

4.18 Compare the place and frequency theories of pitch perception, and discuss the resolution of the debate.

4.19 Identify the cues used in auditory localization.

The Auditory System: Hearing

Stop reading for a moment, close your eyes, and listen carefully. What do you hear?

Chances are, you'll discover that you're immersed in sounds: street noises, a high-pitched laugh from the next room, the buzzing of a fluorescent lamp, perhaps some background music you put on a while ago but forgot about. As this little demonstration shows, physical stimuli producing sound are present almost constantly, but you're not necessarily aware of these sounds.

Like vision, the auditory (hearing) system provides input about the world "out there," but not until incoming information is processed by the

brain. A distal stimulus—a screech of tires, someone laughing, the hum of the refrigerator—produces a proximal stimulus in the form of sound waves reaching the ears. The perceptual system must somehow transform this stimulation into the psychological experience of hearing. We'll begin our discussion of hearing by looking at the stimulus for auditory experience: sound.

The Stimulus: Sound

Sound waves are vibrations of molecules, which means that they must travel through some physical

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medium, such as air. They move at a fraction of the speed of light. Sound waves are usually generated by vibrating objects, such as a guitar string, a loud-speaker cone, or your vocal cords. However, sound waves can also be generated by forcing air past a chamber (as in a pipe organ), or by suddenly releasing a burst of air (as when you clap).

Like light waves, sound waves are characterized by their *amplitude*, their *wavelength*, and their *purity* (see Figure 4.47). The physical properties of amplitude, wavelength, and purity affect mainly the perceived (psychological) qualities of *loudness*, *pitch*, and *timbre*, respectively. However, the physical properties of sound interact in complex ways to produce perceptions of these sound qualities (Hirsh & Watson, 1996).

3h

Human Hearing Capacities

Wavelengths of sound are described in terms of their *frequency*, which is measured in cycles per second, or *hertz* (*Hz*). For the most part, higher frequencies are perceived as having higher pitch. That is, if you strike the key for high C on a piano, it will produce higher-frequency sound waves than the key for low C. Although the perception of pitch depends mainly on frequency, the amplitude of the sound waves also influences it.

Just as the visible spectrum is only a portion of the total spectrum of light, so, too, what people can hear is only a portion of the available range of sounds. Humans can hear sounds ranging from a low of 20 Hz up to a high of about 20,000 Hz. Sounds at either end of this range are harder to hear, and sensitivity to high-frequency tones declines as adults grow older. Other organisms have different capabilities. Low-frequency sounds under 10 Hz are audible to homing pigeons, for example. At the other extreme, bats and porpoises can hear frequencies well above 20,000 Hz.

In general, the greater the amplitude of sound waves, the louder the sound perceived. Whereas frequency is measured in hertz, amplitude is measured in *decibels* (*dB*). The relationship between decibels (which measure a physical property of sound) and loudness (a psychological quality) is complex. A rough rule of thumb is that perceived loudness doubles about every 10 decibels (Stevens, 1955). Very loud sounds can jeopardize the quality of your hearing. Even brief exposure to sounds over 120 decibels can be painful and may cause damage to your auditory system (Henry, 1984).

As shown in **Figure 4.48**, the absolute thresholds for the weakest sounds people can hear differ for sounds of various frequencies. The human ear is

most sensitive to sounds at frequencies near 2000 Hz. That is, these frequencies yield the lowest absolute thresholds. To summarize, amplitude is the principal determinant of loudness, but loudness ultimately depends on an interaction between amplitude and frequency.

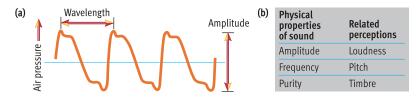


Figure 4.47

Sound, the physical stimulus for hearing. (a) Like light, sound travels in waves—in this case, waves of air pressure. A smooth curve would represent a pure tone, such as that produced by a tuning fork. Most sounds, however, are complex. For example, the wave shown here is for middle C played on a piano. The sound wave for the same note played on a violin would have the same wavelength (or frequency) as this one, but the "wrinkles" in the wave would be different, corresponding to the differences in timbre between the two sounds. (b) The table shows the main relations between objective aspects of sound and subjective perceptions.

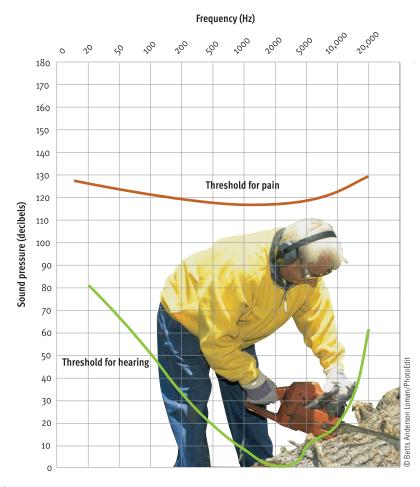


Figure 4.48

Sound pressure and auditory experience. The threshold for human hearing (graphed in green) is a function of both sound pressure (decibel level) and frequency. Human hearing is keenest for sounds at a frequency of about 2000 Hz; at other frequencies, higher decibel levels are needed to produce sounds people can detect. On the other hand, the human threshold for pain (graphed in red) is almost purely a function of decibel level.





web link 4.7



American Speech-Language-Hearing Association

The site for this national organization of audiologists and speech pathologists has a useful section intended for the public that provides information on the dangerous effects of loud noise, ways to detect hearing loss, the utility of hearing aids, and other topics related to hearing.

People are also sensitive to variations in the purity of sounds. The purest sound is one that has only a single frequency of vibration, such as that produced by a tuning fork. Most everyday sounds are complex mixtures of many frequencies. The purity or complexity of a sound influences how *timbre* is perceived. To understand timbre, think of a note with precisely the same loudness and pitch played on a French horn and then on a violin. The difference you perceive in the sounds is a difference in timbre.

Sensory Processing in the Ear



Like your eyes, your ears channel energy to the neural tissue that receives it. **Figure 4.49** shows that the human ear can be divided into three sections: the external ear, the middle ear, and the inner ear. Sound is conducted differently in each section. The external ear depends on the *vibration of air molecules*. The middle ear depends on the *vibration of movable bones*. And the inner ear depends on *waves in a fluid,* which are finally converted into a stream of neural signals sent to the brain (Moore, 2001).

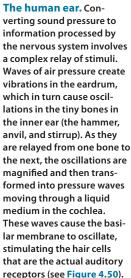
The *external ear* consists mainly of the *pinna*, a sound-collecting cone. When you cup your hand behind your ear to try to hear better, you are augmenting

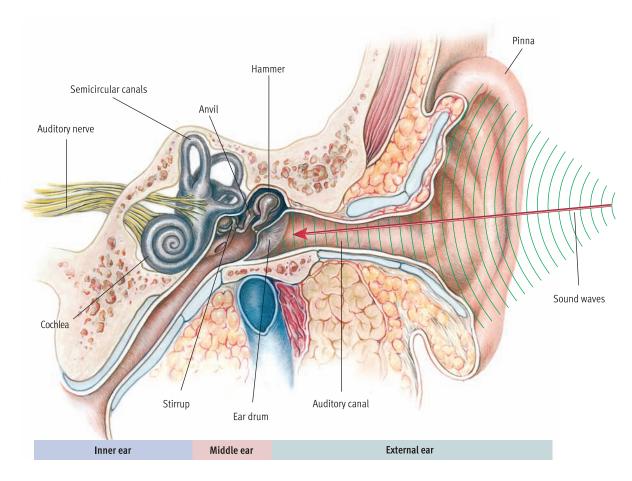
that cone. Many animals have large external ears that they can aim directly toward a sound source. However, humans can adjust their aim only crudely, by turning their heads. Sound waves collected by the pinna are funneled along the auditory canal toward the *eardrum*, a taut membrane that vibrates in response.

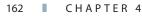
In the *middle ear*, the vibrations of the eardrum are transmitted inward by a mechanical chain made up of the three tiniest bones in your body (the hammer, anvil, and stirrup), known collectively as the *ossicles*. The ossicles form a three-stage lever system that converts relatively large movements with little force into smaller motions with greater force. The ossicles serve to amplify tiny changes in air pressure.

The *inner ear* consists largely of the *cochlea*, a fluid-filled, coiled tunnel that contains the receptors for hearing. The term *cochlea* comes from the Greek word for a spiral-shelled snail, which this chamber resembles (see Figure 4.49). Sound enters the cochlea through the *oval window*, which is vibrated by the ossicles. The ear's neural tissue, analogous to the retina in the eye, lies within the cochlea. This tissue sits on the basilar membrane that divides the cochlea into upper and lower chambers. The *basilar membrane*, which runs the length of the spiraled cochlea, holds the auditory receptors. The auditory receptors are called *hair cells* because of











the tiny bundles of hairs that protrude from them. Waves in the fluid of the inner ear stimulate the hair cells. Like the rods and cones in the eye, the hair cells convert this physical stimulation into neural impulses that are sent to the brain (Hudspeth, 2000).

These signals are routed through the thalamus to the auditory cortex, which is located mostly in the temporal lobes of the brain. Studies demonstrate that the auditory cortex has specialized cells—similar to the feature detectors found in the visual cortex—that have special sensitivity to certain features of sound (Pickles, 1988). Evidence also suggests that the parallel processing of input seen in the visual system also occurs in the auditory pathways (Rouiller, 1997).

Auditory Perception: Theories of Hearing

Theories of hearing need to account for how sound waves are physiologically translated into the perceptions of pitch, loudness, and timbre. To date, most of the theorizing about hearing has focused on the perception of pitch, which is reasonably well understood. Researchers' understanding of loudness and timbre perception is primitive by comparison. Consequently, we'll limit our coverage to theories of pitch perception.

Two theories have dominated the debate on pitch perception: *place theory* and *frequency theory*. You'll be able to follow the development of these theories more easily if you can imagine the spiraled cochlea unraveled, so that the basilar membrane becomes a long, thin sheet, lined with about 25,000 individual hair cells (see **Figure 4.50**).

Place Theory

Long ago, Hermann von Helmholtz (1863) proposed that specific sound frequencies vibrate specific portions of the basilar membrane, producing distinct pitches, just as plucking specific strings on a harp produces sounds of varied pitch. This model, called *place theory*, holds that perception of pitch corresponds to the vibration of different portions, or places, along the basilar membrane. Place theory assumes that hair cells at various locations respond independently and that different sets of hair cells are vibrated by different sound frequencies. The brain then detects the frequency of a tone according to which area along the basilar membrane is most active.

Frequency Theory

Other theorists in the 19th century proposed an alternative theory of pitch perception, called frequency theory (Rutherford, 1886). *Frequency theory* holds that perception of pitch corresponds to the rate, or

frequency, at which the entire basilar membrane vibrates. This theory views the basilar membrane as more like a drumhead than a harp. According to frequency theory, the whole membrane vibrates in unison in response to sounds. However, a particular sound frequency, say 3000 Hz, causes the basilar membrane to vibrate at a corresponding rate of 3000 times per second. The brain detects the frequency of a tone by the rate at which the auditory nerve fibers fire.

Reconciling Place and Frequency Theories

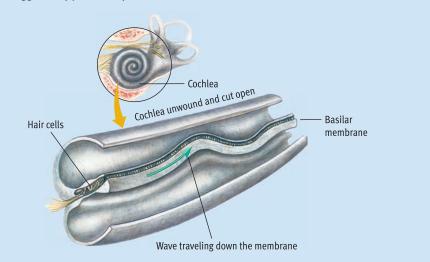
The competition between these two theories is reminiscent of the dispute between the trichromatic and opponent process theories of color vision. As with that argument, the debate between place and frequency theories generated roughly a century of research. Although both theories proved to have some flaws, both turned out to be valid in part.

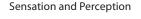
Helmholtz's place theory was basically on the mark except for one detail. The hair cells along the basilar membrane are not independent. They vibrate together, as suggested by frequency theory. The actual pattern of vibration, described in Nobel prizewinning research by Georg von Békésy (1947), is a traveling wave that moves along the basilar membrane. Place theory is correct, however, in that the wave peaks at a particular place, depending on the frequency of the sound wave.

Frequency theory was also found to be flawed when investigators learned that neurons fire at a maximum

Figure 4.50

The basilar membrane. This graphic shows how the cochlea might look if it were unwound and cut open to reveal the basilar membrane, which is covered with thousands of hair cells (the auditory receptors). Pressure waves in the fluid filling the cochlea cause oscillations to travel in waves down the basilar membrane, stimulating the hair cells to fire. Although the entire membrane vibrates, as predicted by frequency theory, the point along the membrane where the wave peaks depends on the frequency of the sound stimulus, as suggested by place theory.









Hermann von Helmholtz

"The psychic activities, by which we arrive at the judgment that a certain object of a certain character exists before us at a certain place, are generally not conscious activities but unconscious ones...! It may be permissible to designate the psychic acts of ordinary perception as unconscious inferences."

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rate of about 1000 impulses per second. How, then, can frequency theory account for the translation of 4000 Hz sound waves, which would require 4000 impulses per second? The answer, suggested by Wever and Bray (1937), is that groups of hair cells operate according to the volley principle. The *volley principle* holds that groups of auditory nerve fibers fire neural impulses in rapid succession, creating volleys of impulses. These volleys exceed the 1000-per-second limit. Studies suggest that auditory nerves can team up like this to generate volleys of up to 5000 impulses per second (Zwislocki, 1981).

Although the original theories had to be revised, the current thinking is that pitch perception depends on both place and frequency coding of vibrations along the basilar membrane (Goldstein, 1996). Sounds under 1000 Hz appear to be translated into pitch through frequency coding. For sounds between 1000 and 5000 Hz, pitch perception seems to depend on a combination of frequency and place coding. Sounds over 5000 Hz seem to be handled through place coding only. Again we find that theories that were pitted against each other for decades are complementary rather than contradictory.

Auditory Localization: Perceiving Sources of Sound

You're driving down a street when suddenly you hear a siren wailing in the distance. As the wail grows

louder, you glance around, cocking your ear to the sound. Where is it coming from? Behind you? In front of you? From one side? This example illustrates a common perceptual task called *auditory localization*—locating the source of a sound in space. The process of recognizing where a sound is coming from is analogous to recognizing depth or distance in vision. Both processes involve spatial aspects of sensory input. The fact that human ears are set *apart* contributes to auditory localization, just as the separation of the eyes contributes to depth perception.

Many features of sounds can contribute to auditory localization, but two cues are particularly important: the intensity (loudness) and the timing of sounds arriving at each ear (Yost, 2001). For example, a sound source to one side of the head produces a greater intensity at the ear nearer to the sound. This difference is due partly to the loss of sound intensity with distance. Another factor at work is the "shadow," or partial sound barrier, cast by the head itself (see Figure 4.51). The intensity difference between the two ears is greatest when the sound source is well to one side. The human perceptual system uses this difference as a clue in localizing sounds. Because the path to the farther ear is longer, a sound takes longer to reach that ear. This fact means that sounds can be localized by comparing the timing of their arrival at each ear. Such comparison of the timing of sounds is remarkably sensitive. People can detect timing differences as small as 1/100,000 of a second

concept check 4.3

Comparing Vision and Hearing

Check your understanding of both vision and hearing by comparing key aspects of sensation and perception in these senses. The dimensions of comparison are listed in the first column below. The second column lists the answers for the sense of vision. Fill in the answers for the sense of hearing in the third column. The answers can be found in Appendix A in the back of the book.

| Dimension | Vision | Hearing |
|---|-----------------------------|---------|
| 1. Stimulus | Light waves | |
| 2. Elements of stimulus and related perceptions | <u> Wavelength/hue</u> | |
| | <u>Amplitude/brightness</u> | |
| | Purity/saturation | |
| 3. Receptors | Rods and cones | |
| 4. Location of receptors | Retina | |
| 5. Main location of | Occipital lobe | |
| processing in brain | Visual Cortex | |
| 6. Spatial aspect of perception | Depth perception | |







(Durlach & Colburn, 1978). Evidence suggests that people depend primarily on timing differences to localize low-frequency sounds and intensity differences to localize high-frequency sounds (Yost, 2003).

REVIEW of Key Learning Goals

- **4.16** Sound varies in terms of wavelength (frequency), amplitude, and purity. Wavelength mainly affects perceptions of pitch, amplitude mainly influences perceptions of loudness, and purity is the key determinant of timbre.
- **4.17** The human ear can detect sounds between 20 and 20,000 Hz, but it is most sensitive to sounds around 2000 Hz. Even brief exposure to sounds over 120 decibels can be painful and damaging. Sound is transmitted through the external ear via air conduction to the middle ear, where sound waves are translated into the vibration of tiny bones called ossicles. In the inner ear, fluid conduction vibrates hair cells along the basilar membrane in the cochlea. These hair cells are the receptors for hearing.
- **4.18** Place theory proposed that pitch perception depends on where vibrations occur along the basilar membrane. Frequency theory countered with the idea that pitch perception depends on the rate at which the basilar membrane vibrates. Modern evidence suggests that these theories are complementary rather than incompatible.
- **4.19** Auditory localization involves locating the source of a sound in space. People pinpoint where sounds have come from by comparing interear differences in the intensity and timing of sounds.

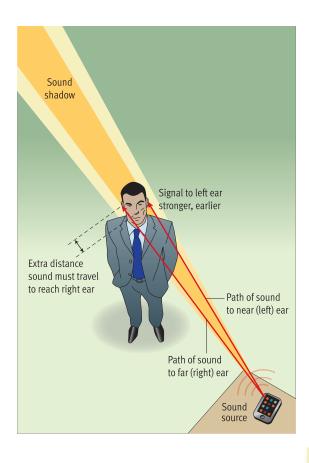


Figure 4.51
Cues in auditory localization. A sound coming from the left reaches the left ear sooner than the right. When the sound reaches the right ear, it is also less intense because it has traveled a greater distance and because it is in the sound shadow produced by the listener's head. These cues are used to localize the sources of sound in space.

The Chemical Senses: Taste and Smell

Psychologists have devoted most of their attention to the visual and auditory systems. Although less is known about the chemical senses, taste and smell also play a critical role in people's experience of the world. Let's take a brief look at what psychologists have learned about the *gustatory system*—the sensory system for taste—and its close cousin, the *olfactory system*—the sensory system for smell.

The Gustatory System: Taste

 \bigoplus

True wine lovers go through an elaborate series of steps when they are served a good bottle of wine. Typically, they begin by drinking a little water to cleanse their palate. Then they sniff the cork from the wine bottle, swirl a small amount of the wine around in a glass, and sniff the odor emerging from the glass. Finally, they take a sip of the wine, rolling it around in their mouth for a short time before swallowing it. At last they are ready to confer their approval or disapproval. Is all this activity really a meaningful way to put the wine to a sensitive test?

Or is it just a harmless ritual passed on through tradition? You'll find out in this section.

The physical stimuli for the sense of taste are chemical substances that are soluble (dissolvable in



Key Learning Goals

- **4.20** Describe the stimulus and receptors for taste, and discuss some determinants of taste preferences.
- **4.21** Review research on individual differences in taste sensitivity, and explain what is meant by the perception of flavor.
- **4.22** Describe the stimulus and receptors for smell, discuss odor identification, and explain how odors can influence behavior.

Are the elaborate wine-tasting rituals of wine lovers just a pretentious tradition, or do they make sense in light of what science has revealed about the gustatory system? Your text answers this question in this section.

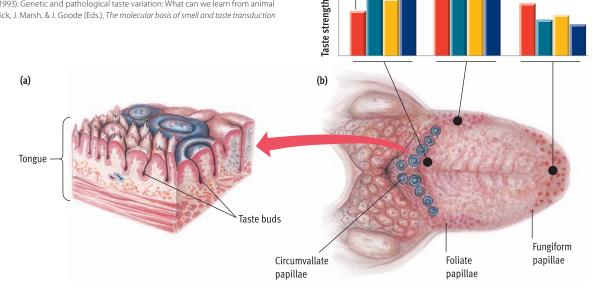
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Figure 4.52

The tongue and taste. Taste buds are clustered around tiny bumps on the tongue called papillae. The three types of papillae are distributed on the tongue as shown here. The taste buds found in each type of papillae show slightly different sensitivities to the four basic tastes, as mapped out in the graph at the top. Thus, sensitivity to the primary tastes varies across the tongue, but these variations are small, and all four primary tastes can be detected wherever there are taste receptors.

SOURCE: Adapted from Bartoshuk, L. M. (1993). Genetic and pathological taste variation: What can we learn from animal models and human disease? In D. Chadwick, J. Marsh, & J. Goode (Eds.), The molecular basis of smell and taste transduction (pp. 251-267). New York: Wiley



Salty

Sweet

water). The gustatory receptors are clusters of taste cells found in the taste buds that line the trenches around tiny bumps on the tongue (see Figure 4.52). When these cells absorb chemicals dissolved in saliva, they trigger neural impulses that are routed through the thalamus to the cortex. Interestingly, taste cells have a short life, spanning only about ten days, and they are constantly being replaced (Cowart, 2005). New cells are born at the edge of the taste bud and migrate inward to die at the center.

It's generally (but not universally) agreed that there are four primary tastes: sweet, sour, bitter, and salty (Buck, 2000). Sensitivity to these tastes is distributed somewhat unevenly across the tongue, but the variations in sensitivity are quite small and highly complicated (Bartoshuk, 1993b; see Figure 4.52). Although taste cells respond to more than one of the primary tastes, they typically respond best to a specific taste (Di Lorenzo & Youngentob, 2003). Perceptions of taste quality appear to depend on complex patterns of neural activity initiated by taste receptors (Erickson, DiLorenzo, & Woodbury, 1994). Taste signals are routed through the thalamus and onto the insular cortex in the frontal lobe, where the initial cortical processing takes place.

Some basic taste preferences appear to be inborn and to be automatically regulated by physiological mechanisms. In humans, for instance, newborn infants react positively to sweet tastes and negatively to strong concentrations of bitter or sour tastes (Cowart, 2005). To some extent, these innate taste preferences are flexible, changing to accommodate the body's nutritional needs (Scott, 1990).

Although some basic aspects of taste perception may be innate, taste preferences are largely learned and heavily influenced by social processes (Rozin, 1990). Most parents are aware of this fact and intentionally try-with varied success-to mold their children's taste preferences early in life (Patrick et al., 2005). This extensive social influence contributes greatly to the striking ethnic and cultural disparities found in taste preferences (Kittler & Sucher, 2008). Foods that are a source of disgust in Western cultures—such as worms, fish eyes, and blood—may be delicacies in other cultures (see Figure 4.53). Indeed, Rozin (1990) asserts that feces may be the only universal source of taste-related disgust in humans. To a large degree, variations in taste preferences depend on what one has been exposed to (Capaldi & VandenBos, 1991; Zellner, 1991). Exposure to particular foods varies along ethnic lines because different cultures have different traditions in food preparation, different agricultural resources, different climates to work with, and so forth.

Research by Linda Bartoshuk and others reveals that people vary considerably in their sensitivity to certain tastes. These individual differences depend in part on the density of taste buds on the tongue, which appears to be a matter of genetic inheritance (Bartoshuk, 1993a). People characterized as non-

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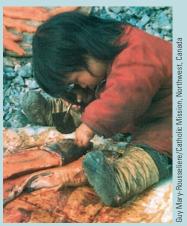
The ChemoReception Web

This site is devoted to the sensory and biological aspects of the chemical senses of taste and smell. It includes abstracts of relevant research. book reviews, and links to many other useful websites.

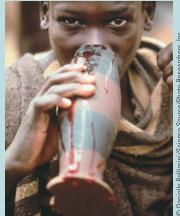




Grubs. For most North Americans, the thought of eating a worm would be totally unthinkable. For the Asmat of New Guinea, however, a favorite delicacy is the plump, white, 2-inch larva or beetle grub.



Fish eyes. For some Eskimo children, raw fish eyes are like candy. Here you see a young girl using the Eskimo's all-purpose knife to gouge out the eye of an already-filleted Artic fish.



Blood. Several tribes in East Africa supplement their diet with fresh blood that is sometimes mixed with milk. They obtain the blood by puncturing a cow's jugular vein with a sharp arrow. The blood-milk drink provides a rich source of protein and iron.

Figure 4.53
Culture and taste preferences. Taste preferences are heavily influenced by learning and vary dramatically from one society to the next, as these examples demonstrate.

tasters, as determined by their insensitivity to PTC (phenythiocarbamide), or its close relative, PROP (propylthiouracil), tend to have about one-quarter as many taste buds per square centimeter as people at the other end of the spectrum, who are called supertasters (Miller & Reedy, 1990). Supertasters also have specialized taste receptors that are not found in nontasters (Bufe et al., 2005). In the United States, roughly 25% of people are nontasters, another 25% are supertasters, and the remaining 50% fall between these extremes and are characterized as medium tasters (Di Lorenzo & Youngentob, 2003). Supertasters and nontasters respond similarly to many foods, but supertasters are much more sensitive to certain sweet and bitter substances. For example, supertasters react far more strongly to the chemical (capsaicin) in hot peppers (Tepper & Nurse, 1997). Supertasters also respond more intensely to many fatty substances (Bartoshuk, 2000).

These differences in taste sensitivity influence people's eating habits in ways that can have important repercussions for their physical health. For example, supertasters are less likely to be fond of sweets (Yeomans et al., 2007) and tend to consume fewer high-fat foods, both of which are likely to reduce their risk for cardiovascular disease (Duffy, Lucchina, & Bartoshuk, 2004). Supertasters also tend to react more negatively to alcohol and smoking, thereby reducing their likelihood of developing drinking problems or nicotine addiction (Duffy, Peterson, & Bartoshuk, 2004; Snedecor et al., 2006). The only health disadvantage identified for supertasters thus

far is that they respond more negatively to many vegetables, which seems to hold down their vegetable intake (Basson et al., 2005; Dinehart et al., 2006). Overall, however, supertasters tend to have better health habits than nontasters, thanks to their strong reactions to certain tastes (Duffy, 2004).

Women are somewhat more likely to be supertasters than men (Bartoshuk, Duffy, & Miller, 1994). Some psychologists speculate that the gender gap in this trait may have evolutionary significance. Over the course of evolution, women have generally been more involved than men in feeding children. Increased reactivity to sweet and bitter tastes would have been adaptive in that it would have made women more sensitive to the relatively scarce high-caloric foods (which often taste sweet) needed for survival and to the toxic substances (which often taste bitter) that hunters and gatherers needed to avoid.

So far, we've been discussing taste, but what we are really interested in is the *perception of flavor*. Flavor is a combination of taste, smell, and the tactile sensation of food in one's mouth (Smith & Margolskee, 2006). Odors make a surprisingly great contribution to the perception of flavor (Lawless, 2001). Although taste and smell are distinct sensory systems, they interact extensively. The ability to identify flavors declines noticeably when odor cues are absent. You might have noticed this interaction when you ate a favorite meal while enduring a severe head cold. The food probably tasted bland, because your stuffy nose impaired your sense of smell.



Linda Bartoshuk

"Good and bad are so intimately associated with taste and smell that we have special words for the experiences (e.g., repugnant, foul). The immediacy of the pleasure makes it seem absolute and thus inborn. This turns out to be true for taste but not for smell."





web link 4.9



Seeing, Hearing, and Smelling the World

Hosted by the Howard Hughes Medical Institute, this site provides a graphically attractive review of what scientific research has discovered about human sensory systems, with suggestions about where research will be moving in the future. the wine-tasting ritual. This elaborate ritual is indeed an authentic way to put wine to a sensitive test. The aftereffects associated with sensory adaptation make it wise to cleanse one's palate before tasting the wine. Sniffing the cork, and the wine in the glass, is important because odor is a major determinant of flavor. Swirling the wine in the glass helps release the wine's odor. And rolling the wine around in your mouth is especially critical, because it distributes the wine over the full diversity of taste cells. It also forces the wine's odor up into the nasal passages. Thus, each action in this age-old ritual makes a meaningful contribution to the tasting.

Now that we've explored the dynamics of taste,

we can return to our question about the value of

The Olfactory System: Smell

In many ways, the sense of smell is much like the sense of taste. The physical stimuli are chemical substances—volatile ones that can evaporate and be carried in the air. These chemical stimuli are dissolved in fluid—specifically, the mucus in the nose. The receptors for smell are olfactory cilia, hairlike structures in the upper portion of the nasal passages (see Figure 4.54). They resemble taste cells in that they have a short life (30-60 days) and are constantly being replaced (Buck, 2000). Olfactory receptors have axons that synapse with cells in the olfactory bulb and then are routed directly to the olfactory cortex in the temporal lobe and other areas in the cortex. This arrangement is unique. Smell is the only sensory system in which incoming information is not routed through the thalamus before it projects to the cortex.

Odors cannot be classified as neatly as tastes, since efforts to identify primary odors have proven unsatisfactory (Doty, 1991). If primary odors exist, there must be a fairly large number of them. Perhaps that is why humans have about 350 different types of olfactory receptors (Buck, 2004). Most olfactory receptors respond to a wide range of odors (Doty, 2001). Specific odors trigger responses in different *combinations* of receptors (Malnic et al., 1999). Like the other senses, the sense of smell shows sensory adaptation. The perceived strength of an odor usually fades to less than half its original strength within about 4 minutes (Cain, 1988).

Humans can distinguish a great many odors, with estimates of the number of distinct odors ranging from 10,000 (Axel, 1995) to 100,000 (Firestein, 2001). However, when people are asked to identify the sources of specific odors (such as smoke or soap), their performance is rather mediocre. For some un-

known reason, people have a hard time attaching names to odors (Cowart & Rawson, 2001). Gender differences have been found in the ability to identify odors, as females tend to be somewhat more accurate than males on odor-recognition tasks (de Wijk, Schab, & Cain, 1995).

Although smell is often viewed as an unimportant sense in humans, ample evidence demonstrates that odors can have profound effects on people's mood and cognition (Herz & Schooler, 2002; Jacob et al., 2002). The \$4 billion spent on perfumes annually in the United States shows how motivated people are to enjoy pleasant fragrances. Interestingly, recent research indicates that subtle background odors that people are unaware of can influence their behavior. In one study, subliminal exposure to a citrus-scented cleaning solution led participants to keep their immediate environment cleaner (Holland, Hendriks, & Aarts, 2005). In another study, subjects' ratings of the likability of a series of faces were swayed by the subliminal introduction of pleasant versus unpleasant odors (Li et al., 2007). Small wonder, given these results, that "environmental fragrancing" is a growing industry (Gilbert & Firestein, 2002; Peltier, 1999).

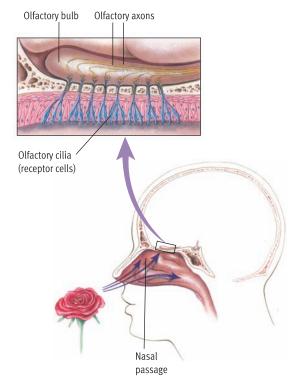


Figure 4.54 The olfactory system. Odor molecules travel through the nasal passages and stimulate olfactory cilia. An enlargement of these hairlike olfactory receptors is shown in the inset. The olfactory nerves transmit neural impulses through the olfactory bulb to the brain.

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CHAPTER 4

Sense of Smell Institute

The Sense of Smell Institute maintains a site that monitors and profiles interesting research on the olfactory system. It provides access to current and back issues of the Aroma-Chology Review, which provides brief, easy-to-understand articles on developments in olfactory research, mostly written by prominent researchers in the area.

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REVIEW of Key Learning Goals

4.20 The taste buds are sensitive to four basic tastes: sweet, sour, bitter, and salty. Sensitivity to these tastes is distributed unevenly across the tongue, but the variations are small. Some basic taste preferences appear to be innate, but taste preferences are largely learned as a function of what one is exposed to. Taste preferences are also heavily influenced by cultural background.

4.21 Supertasters are much more sensitive to some tastes than nontasters, with medium tasters falling in between these extremes. Nontasters tend to be more susceptible to the lure of sweets, high-fat foods, alcohol, and smoking, which means their consumption habits tend to be less healthy than those of supertasters. The perception of flavor involves a mixture of taste, smell, and the tactile sensation of food in one's mouth.

4.22 Like taste, smell is a chemical sense. Chemical stimuli activate receptors, called olfactory cilia, that line the nasal passages. Most of these receptors respond to more than one odor. Smell is the only sense that is not routed through the thalamus. Humans can distinguish many odors, but their performance on odor identification tasks tends to be surprisingly mediocre. Ambient odors can influence mood and cognition—even when they are subliminal.

The Sense of Touch

If there is any sense that people trust almost as much as sight, it is the sense of touch. Yet, like all the senses, touch involves converting the sensation of physical stimuli into a psychological experience—and it can

The physical stimuli for touch are mechanical, thermal, and chemical energy that impinges on the skin. These stimuli can produce perceptions of tactile stimulation (the pressure of touch against the skin), warmth, cold, and pain. The human skin is saturated with at least six types of sensory receptors,

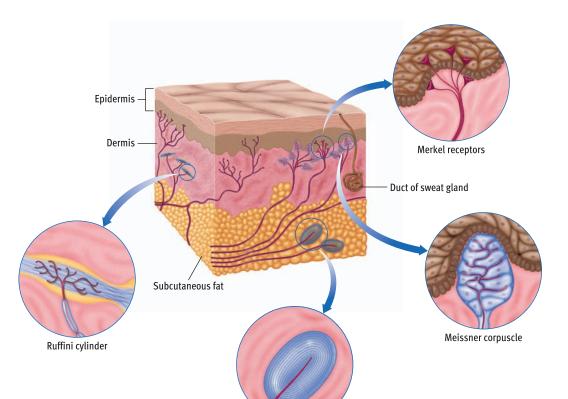
four of which are depicted in Figure 4.55. To some degree, these different types of receptors are specialized for different functions, such as the registration of pressure, heat, cold, and so forth. However, these distinctions are not as clear as researchers had originally expected (Sinclair, 1981).

Feeling Pressure

If you've been to a mosquito-infested picnic lately, you'll appreciate the need to quickly know where

Key Learning Goals

- **4.23** Describe the processes involved in the perception of pressure on the skin.
- 4.24 Trace the two pathways along which pain signals travel, and discuss evidence that the perception of pain is subjective.
- 4.25 Explain the gatecontrol theory of pain perception and recent findings related to it.



Pacinian corpuscle

Figure 4.55 Receptors in the skin.

Human skin houses quite a variety of receptors in a series of layers. The four types of receptors shown in this diagram all respond to various aspects of pressure, stretching, and vibration. In addition to these receptors, free nerve endings in the skin respond to pain, warmth, and cold, and hairfollicle receptors register the movement of hairs.

Source: Goldstein, E. B. (2007). Sensation and perception. Belmont, CA: Wadsworth



tactile stimulation is coming from. The sense of touch is set up to meet this need for tactile localization with admirable precision and efficiency. Cells in the nervous system that respond to touch are sensitive to specific patches of skin. These skin patches, which vary considerably in size, are the functional equivalents of *receptive fields* in vision. Like visual receptive fields, they often involve a center-surround arrangement. Thus, stimuli falling in the center produce the opposite effect of stimuli falling in the surrounding area (Kandel & Jessell, 1991).

If a stimulus, such as a finger or the top of a pen, is applied continuously to a specific spot on the skin, the perception of pressure gradually fades. Thus, sensory adaptation occurs in the perception of touch, as it does in other sensory systems.

The nerve fibers that carry incoming information about tactile stimulation are routed through the spinal cord to the brainstem. There, the fibers from each side of the body cross over mostly to the opposite side of the brain. The tactile pathway then projects through the thalamus and onto the *somatosensory cortex* in the brain's parietal lobe. Some cells in the somatosensory cortex function like the *feature detectors* discovered in vision (Gardner & Kandel, 2000). They respond to specific features of touch, such as a movement across the skin in a particular direction.

Feeling Pain

As unpleasant as it is, the sensation of pain is crucial to survival. Pain is a marvelous warning system. It tells people when they should stop shoveling snow or remove their hand from a hot oven. Although a life without pain may sound appealing, people born with a rare, congenital insensitivity to pain would testify otherwise, as they routinely harm themselves (Coderre, Mogil, & Bushnell, 2003). However, chronic pain is a frustrating, demoralizing affliction that affects roughly 75 million people in American society (Gallagher & Rosenthal, 2007). Although scientists have learned a great deal about the neural bases for the experience of pain, clinical treatment of pain remains only moderately effective (Scholz & Woolf, 2002). Thus, there are pressing practical reasons for psychologists' keen interest in the perception of pain.

Pathways to the Brain

The receptors for pain are mostly free nerve endings in the skin. Pain messages are transmitted to the brain via two types of pathways that pass through different areas in the thalamus (Willis, 1985). One is a *fast pathway* that registers localized pain and relays it to the cortex in a fraction of a second. This is the system that hits you with sharp pain when you first

cut your finger. The second system uses a *slow pathway* that lags a second or two behind the fast system. This pathway (which also carries information about temperature) conveys the less localized, longerlasting, aching or burning pain that comes after the initial injury. The slow pathway depends on thin, unmyelinated neurons called *C fibers*, whereas the fast pathway is mediated by thicker, myelinated neurons called *A-delta fibers* (see **Figure 4.56**). Pain signals may be sent to many areas in the cortex, as well as to subcortical centers associated with emotion (such as the hypothalamus and amygdala), depending in part on the nature of the pain (Hunt & Mantyh, 2001).

Puzzles in Pain Perception

As with other perceptions, pain is not an automatic result of certain types of stimulation. Some people with severe injuries report little pain, whereas other people with much more modest injuries report agonizing pain (Coderre et al., 2003). The perception of pain can be influenced greatly by beliefs, expectations, personality, mood, and other factors involving higher mental processes (Turk & Okifuji, 2003). The subjective nature of pain is illustrated by placebo effects. As we saw in Chapter 2, many people suffering from pain report relief when given a placebo—such as an inert "sugar pill" that is presented to them as if it were a painkilling drug (Stewart-Williams, 2004; Vase, Riley, & Price, 2002).

Further evidence regarding the subjective quality of pain has come from studies that have found ethnic and cultural differences in pain tolerance (Ondeck, 2003). According to Melzack and Wall (1982), culture does not affect the process of pain perception so much as the willingness to tolerate certain types of pain, a conclusion echoed by Zatzick and Dimsdale (1990).

The psychological element in pain perception becomes clear when something distracts your attention from pain and the hurting temporarily disappears. For example, imagine that you've just hit your thumb with a hammer and it's throbbing with pain. Suddenly, your child cries out that there's a fire in the laundry room. As you race to deal with this emergency, you forget all about the pain in your thumb.

As you can see, then, tissue damage that sends pain impulses on their way to the brain doesn't necessarily result in the experience of pain. Cognitive and emotional processes that unfold in higher brain centers can somehow block pain signals coming from peripheral receptors. Thus, any useful explantion of pain perception must be able to answer a critical question: How does the central nervous system block incoming pain signals?





Figure 4.56 Somatosensory cortex Pathways for pain signals. Pain signals are sent inward from receptors to the brain along the two ascending pathways depicted here in red and black. The fast pathway (red) and the slow pathway (black) depend on different types of nerve fibers and are routed through different parts of the thalamus. The gate-Thalamus control mechanism hypothesized by Melzack and Wall Midline nucleus (1965) apparently depends of the thalamus on signals in a descending pathway (shown in green) Midbrain that originates in an area of the midbrain. Ventrobasal nucleus Spinal cord of the thalamus C fiber Incoming pain Descending neural pathway that pathways can gate incoming pain signals A-delta fiber

In an influential effort to answer this question, Ronald Melzack and Patrick Wall (1965) devised the gate-control theory of pain. *Gate-control theory* holds that incoming pain sensations must pass through a "gate" in the spinal cord that can be closed, thus blocking ascending pain signals. The gate in this

model is not an anatomical structure but a pattern of neural activity that inhibits incoming pain signals. Melzack and Wall suggested that this imaginary gate can be closed by signals from peripheral receptors or by signals from the brain. They theorized that the latter mechanism can help explain how factors such

concept check 4.4 **Comparing Taste, Smell, and Touch** Check your understanding of taste, smell, and touch by comparing these sensory systems on the dimensions listed in the first column below. A few answers are supplied; see whether you can fill in the rest. The answers can be found in Appendix A. **Dimension Taste** Smell **Touch** 1. Stimulus Volatile chemicals in the air 2. Receptors Many (at least six types) 3. Location of Upper area of nasal passage receptors Sweet, sour, 4. Basic elements salty, bitter of perception

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ILLUSTRATED OVERVIEW OF FIVE MAJOR SENSES

SENSE

The Visual System: SIGHT



The Auditory System: HEARING

The Gustatory

System:

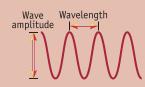
TASTE

The Olfactory System: / SMELL

The Tactile System: TOUCH

STIMULUS

Light is electromagnetic radiation that travels in waves. Humans can register only a slim portion of the total range of wavelengths, from 400 to 700 nanometers.





Sound waves are vibrations of molecules, which means that they must travel through some physical medium, such as air. Humans

can hear wavelengths between 20 and 20,000 Hz.



Wavelength Amplitude

The stimuli for taste generally are chemical substances that are soluble (dissolvable in water). These stimuli are dissolved in the mouth's saliva.



The stimuli are volatile chemical substances that can evaporate and be carried in the air. These chemical stimuli are dissolved in the mucus of the nose.

The stimuli are mechanical, thermal, and chemical energy that impinge on the skin.



ELEMENTS OF THE STIMULUS

Light waves vary in *amplitude, wavelength,* and *purity,* which influence perceptions as shown below.

| Physical properties | Related perceptions |
|---------------------|---------------------|
| Wavelength | Hue (color) |
| Amplitude | Brightness |
| Purity | Saturation |

Sound waves vary in *amplitude, wavelength,* and *purity,* which influence perceptions, as shown below.

| Physical properties | Related perceptions |
|------------------------|---------------------|
| Amplitude | Loudness |
| Frequency | Pitch |
| Purity | Timbre |

It is generally, but not universally, agreed that there are four primary tastes: *sweet, sour, bitter,* and *salty*.

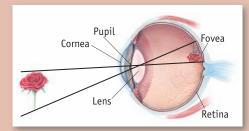
Efforts to identify primary odors have proven unsatisfactory. If primary odors exist, there must be a great many of them.

Receptors in the skin can register *pressure*, warmth, cold, and pain.



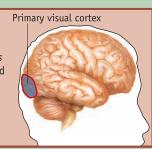
NATURE AND LOCATION OF RECEPTORS

The retina, which is neural tissue lining the inside back surface of the eye, contains millions of receptor cells called rods and cones. Rods play a key role in night and peripheral vision; cones play a key role in daylight and color vision.

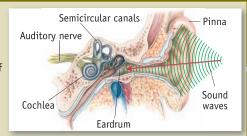


BRAIN PATHWAYS
IN INITIAL PROCESSING

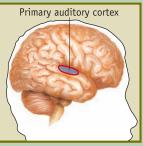
Neural impulses are routed through the *LGN* in the *thalamus* and then distributed to the *primary visual cortex* at the back of the *occipital lobe*.



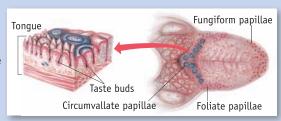
The receptors for hearing are tiny hair cells that line the basilar membrane that runs the length of the cochlea, a fluid-filled, coiled tunnel in the inner ear.



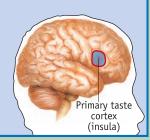
Neural impulses are routed through the *thalamus* and then sent to the *primary auditory cortex*, which is mostly located in the *temporal lobe*.



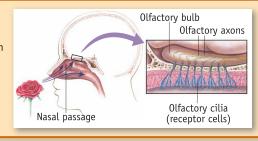
The gustatory receptors are clusters of taste cells found in the taste buds that line the trenches around tiny bumps in the tongue. Taste cells have a short life span (about 10 days) and are constantly being replaced.



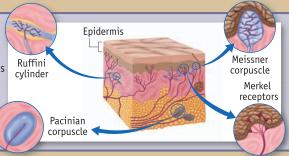
Neural impulses are routed through the *thalamus* and on to the *insular cortex* in the frontal lobe.



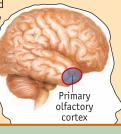
The receptors for smell are olfactory cilia, hairlike structures in the upper portion of the nasal passages. Like taste cells, they have a short lifespan (about 30–60 days) and are constantly being replaced.



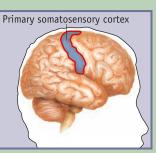
The human skin is saturated with at least six types of sensory receptors. The four types shown here respond to pressure, whereas free nerve endings in the skin respond to pain, warmth, and cold.



Neural impulses are routed through the *olfactory bulb* and then sent directly to the *olfactory cortex* in the *temporal lobe* and other cortical areas. Smell is the only sensory input not routed through the thalamus.



Neural impulses are routed through the brainstem and thalamus and on to the somatosensory cortex in the parietal lobe.







People tend to assume that the perception of pain is an automatic result of bodily injuries, but the process of pain perception is much more subjective than widely appreciated. For example, in athletic endeavors an injury is often a major competitive setback, which may intensify one's pain.

as attention and expectations can shut off pain signals. As a whole, research suggests that the concept of a gating mechanism for pain has merit (Craig & Rollman, 1999; Sufka & Price, 2002). However, relatively little support has been found for the neural circuitry originally hypothesized by Melzack and Wall in the 1960s. Other neural mechanisms, discovered after gate-control theory was proposed, appear to be responsible for blocking the perception of pain.

One of these discoveries was the identification of endorphins. As discussed in Chapter 3, endorphins are the body's own natural morphinelike painkillers. Studies suggest that the endorphins play an important role in the modulation of pain (Pert, 2002). For example, the analgesic effects that can be achieved through the ancient Chinese art of acupuncture appear to involve endorphins (Cabyoglu, Ergene, & Tan, 2006). Endorphins are widely distributed in the central nervous system. Scientists are still working out the details of how they suppress pain (Zubieta et al., 2001).

The other discovery involved the identification of a descending neural pathway that mediates the suppression of pain (Basbaum & Jessell, 2000). This pathway appears to originate in an area of the midbrain called the *periaqueductal gray (PAG)*. Neural activity in this pathway is probably initiated by endorphins acting on PAG neurons, which eventually trigger impulses sent down neural circuits that mostly release serotonin. These circuits synapse in the spinal cord, where they appear to release more endorphins, thus inhibiting the activity of neurons that would normally transmit incoming pain impulses to the brain (see **Figure 4.56**). The painkilling effects of morphine appear to be at least partly attributable to activity in this descending pathway, as cutting the fibers in this

pathway reduces the analgesic effects of morphine (Jessell & Kelly, 1991). In contrast, activation of this pathway by electrical stimulation of the brain can produce an analgesic effect. Clearly, this pathway plays a central role in gating incoming pain signals.

Our understanding of the experience of pain continues to evolve. The newest discovery is that certain types of *glial cells* may contribute to the modulation of pain (Watkins, 2007). As noted in Chapter 3, only recently have neuroscientists realized that glial cells contribute to signal transmission in the nervous system (Fields, 2004). At least two types of glia in the spinal cord (astrocytes and microglia) appear to play an important role in chronic pain (Watkins & Maier, 2002). These glia are activated by immune system responses to infection or by signals from neurons in pain pathways. Once activated, these glial cells appear to "egg on neurons in the pain pathway," thus amplifying the experience of chronic pain (Watkins & Maier, 2003; Watkins et al., 2007). The discovery that glia play a role in the human pain system may eventually open up new avenues for treating chronic pain.

One final point merits emphasis as we close our tour of the human sensory systems. Although we have discussed the various sensory domains separately, it's important to remember that all the senses send signals to the same brain, where the information is pooled. We have already encountered examples of sensory integration. For example, it's at work when the sight and smell of food influence taste. Sensory integration is the norm in perceptual experience. For instance, when you sit around a campfire, you see it blazing, you hear it crackling, you smell it burning, and you feel the touch of its warmth. If you cook something over it, you may even taste it. Thus, perception involves building a unified model of the world out of integrated input from all the senses (Kayser, 2007; Stein, Wallace, & Stanford, 2001).

REVIEW of Key Learning Goals

4.23 The skin houses many types of sensory receptors. They respond to pressure, temperature, and pain. Tactile localization depends on receptive fields similar to those seen for vision. Some cells in the somatosensory cortex appear to function like feature detectors.

4.24 Pain signals are sent to the brain along two pathways that are characterized as fast and slow. The perception of pain is highly subjective and may be influenced by mood and distractions. Placebo effects in pain treatment and cultural variations in pain tolerance also highlight the subjective nature of pain perception.

4.25 Gate-control theory holds that incoming pain signals can be blocked in the spinal cord. Endorphins and a descending neural pathway appear responsible for the suppression of pain by the central nervous system. Recent studies indicate that glial cells contribute to the modulation of chronic pain.







Reflecting on the Chapter's Themes

In this chapter, three of our unifying themes stood out in sharp relief. Let's discuss the value of theoretical diversity first. Contradictory theories about behavior can be disconcerting and frustrating for theorists, researchers, teachers, and students alike. Yet this chapter provided two dramatic demonstrations of how theoretical diversity can lead to progress in the long run. For decades, the trichromatic and opponent process theories of color vision and the place and frequency theories of pitch perception were viewed as fundamentally incompatible. As you know, in each case the evidence eventually revealed that both theories were needed to fully explain the sensory processes that each sought to explain individually. If it hadn't been for these theoretical debates, current understanding of color vision and pitch perception might be far more primitive.

Our coverage of sensation and perception should also have enhanced your appreciation of why human experience of the world is highly subjective. As ambiguous figures and optical illusions clearly show, there is no one-to-one correspondence between sensory input and perceived experience of the world. Perception is an active process in which people organize and interpret the information received by the senses. These interpretations are shaped by a number of factors, including the environmental context and perceptual sets. Small wonder, then,

that people often perceive the same event in very different ways.

Finally, this chapter provided numerous examples of how cultural factors can shape behavior—in an area of research where one might expect to find little cultural influence. Most people are not surprised to learn that there are cultural differences in attitudes, values, social behavior, and development. But perception is widely viewed as a basic, universal process that should be invariant across cultures. In most respects it is, as the similarities among cultural groups in perception far outweigh the differences. Nonetheless, we saw cultural variations in depth perception, susceptibility to illusions, taste preferences, and pain tolerance. Thus, even a fundamental, heavily physiological process such as perception can be modified to some degree by one's cultural background.

The following Personal Application demonstrates the subjectivity of perception once again. It focuses on how painters have learned to use the principles of visual perception to achieve a variety of artistic goals.

REVIEW of Key Learning Goals

4.26 This chapter provided two dramatic demonstrations of the value of theoretical diversity. It also provided numerous examples of how and why people's experience of the world is highly subjective. Finally, it highlighted the importance of cultural background.



Key Learning Goals

4.26 Identify the three unifying themes that were highlighted in this chapter.



Theoretical Diversity



Subjectivity of Experience



Cultural Heritage

PERSONAL

Appreciating Art and Illusion

Answer the following multiple-choice question:

Artistic works such as paintings:

- ____ 1 render an accurate picture of reality.
- 2 create an illusion of reality.3 provide an interpretation of reality.
- ____ **4** make us think about the nature of reality.
- ____ **5** do all of the above.

The answer to this question is (5), "all of the above." Historically, artists have had many and varied purposes, including each of those listed in the question (Goldstein, 2001). To realize their goals, artists have had to use a number of principles of perception—sometimes quite deliberately, and sometimes not. Here we'll use the example of painting to explore the role of perceptual principles in art and illusion.

The goal of most early painters was to produce a believable picture of reality. This goal immediately created a problem familiar to most of us who have attempted to draw realistic pictures: The real world is three-dimensional, but a canvas or a sheet

APPLICATION

Key Learning Goals

4.27 Discuss how the Impressionists, Cubists, and Surrealists used various principles of visual perception.

4.28 Discuss how Escher, Vasarely, and Magritte used various principles of visual perception.

of paper is flat. Paradoxically, then, painters who set out to re-create reality had to do so by creating an illusion of three-dimensional reality.

Prior to the Renaissance, these efforts to create a convincing illusion of reality

Sensation and Perception

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were awkward by modern standards. Why? Because artists did not understand how to use depth cues. This fact is apparent in Figure 4.57, a religious scene painted around 1300. The painting clearly lacks a sense of depth. The people seem paper-thin. They have no real position in space.

Although earlier artists made some use of depth cues, Renaissance artists manipulated the full range of pictorial depth cues and really harnessed the crucial cue of linear perspective (Solso, 1994). Figure 4.58 dramatizes the resulting transition in art. This scene, painted by Italian Renaissance artists Gentile and Giovanni Bellini, seems much more realistic and lifelike than the painting in Figure 4.57 because it uses a number of pictorial depth cues. Notice how the buildings on the sides converge to make use of linear perspective. Additionally, distant objects are smaller than nearby ones, an application of relative size. This painting also uses height in plane, as well as interposition. By taking advantage of pictorial depth cues, an artist can enhance a painting's illusion of reality.

In the centuries since the Renaissance, painters have adopted a number of viewpoints about the portrayal of reality. For instance, the French Impressionists of the 19th century did not want to re-create the photographic "reality" of a scene. They set out to interpret a viewer's fleeting perception or impression of reality. To accomplish this end, they worked with color in unprecedented ways.

Consider, for instance, the work of Georges Seurat, a French artist who used a technique called pointillism. Seurat carefully studied what scientists knew about the composition of color in the 1880s, then applied this knowledge in a calculated, laboratory-like manner. Indeed, critics in his era dubbed him the "little chemist." Seurat constructed his paintings out of tiny dots of pure, intense colors. He used additive color mixing, a departure from the norm in painting, which usually depends on subtractive mixing of pigments. A famous result of Seurat's "scientific" approach to painting was Sunday Afternoon on the Island of La Grande Jatte (see Figure 4.59). As the work of Seurat illustrates, modernist paint-

CHAPTER 4

ers were moving away from attempts to recreate the world as it is literally seen.

If 19th-century painters liberated color, their successors at the turn of the 20th century liberated form. This was particularly true of the Cubists. Cubism was begun in 1909 by Pablo Picasso, a Spanish artist who went on to experiment with other styles in his prolific career. The Cubists didn't try to portray reality so much as to reassemble it. They attempted to reduce everything to combinations of geometric forms (lines, circles, triangles, rectangles, and such) laid out in a flat space, lacking depth. In a sense, they applied the theory of feature analysis to canvas, as they built their figures out of simple features.

The resulting paintings were decidedly unrealistic, but the painters would leave realistic fragments that provided clues about the subject. Picasso liked to challenge his viewers to decipher the subject of his paintings. Take a look at the painting in Figure 4.60 and see whether you can figure out what Picasso was portraying.

The work in **Figure 4.60** is titled *Violin and Grapes*. Note how Gestalt principles of perceptual organization are at work to create these forms. Proximity and similarity serve to bring the grapes together in the bottom right corner. Closure accounts for your being able to see the essence of the violin.



Figure 4.57

Master of the Arrest of Christ (detail, central part) by S. Francesco, Assisi, Italy (circa 1300). Notice how the absence of depth cues makes the painting seem flat and unrealistic.

Figure 4.58

Brera Predica di S. Marco Pinacoteca by Gentile and Giovanni
Bellini (circa 1480). In this painting, the Italian Renaissance artists use a number of depth cues—including linear perspective, relative size, height in plane, light and shadow, and interposition—to enhance the illusion of three-dimensional reality.



/Art Resource, Ne







Figure 4.59
Georges Seurat's Sunday Afternoon on the Island of La Grande Jatte (without artist's border) (1884–1886). Seurat used thousands of tiny dots of color and the principles of color mixing (see detail). The eye and brain combine the points into the colors the viewer actually sees.

Georges Seurat, French, 1859–1891, Sunday Afternoon on the Island of La Grande Jatte (and detail), oil on canvas, 1884–1886, 81-3/4 \times 121-1/4 inches (207.6 \times 308 cm), Helen Birch Bartlett Memorial Collection, 1926.224, © 1990 The Art Institute of Chicago. Photography © The Art Institute of Chicago.

Other Gestalt principles are the key to the effect achieved in the painting in **Figure 4.61** on the next page. This painting, by Marcel Duchamp, a French artist who blended Cubism and a style called Futurism, is titled *Nude Descending a Staircase*. The effect clearly depends on the Gestalt principle of continuity.

The Surrealists toyed with reality in a different way. Influenced by Sigmund Freud's writings on the unconscious, the Surrealists explored the world of dreams and fantasy. Specific elements in their paintings are often depicted realistically, but the strange combination of elements yields a disconcerting irrationality reminiscent of dreams. A prominent example of this style is Salvador Dali's Slave Market with the Disappearing Bust of Voltaire, shown in Figure 4.62. Notice the reversible figure near the center of the painting. The "bust of Voltaire" is made up of human figures in the distance, standing in front of an arch. Dali often used reversible figures to enhance the ambiguity of his bizarre visions.

Perhaps no one has been more creative in manipulating perceptual ambiguity than M. C. Escher, a modern Dutch artist. Escher closely followed the work of the Gestalt psychologists, and he readily acknowledged his debt to psychology as a source of inspiration (Teuber, 1974). *Waterfall*, a 1961

lithograph by Escher, is an impossible figure that appears to defy the law of gravity (see **Figure 4.63**). The puzzling problem here is

that a level channel of water terminates in a waterfall that "falls" into the same channel two levels "below." This drawing is made



Figure 4.60

Violin and Grapes by

Pablo Picasso (1912). This

painting makes use of the

Gestalt principles of proximity, similarity, and closure.

Pablo Picasso, Violin and Granes, Céret and Sorgues, spring-summer 1912. Oil on canvas. 20 x 24" (50.6 x 61 cm), collection. The Museum of Modern Art, New York, Mrs. David M. Levy Bequest (32, 1960), Digital image © The Museum of Modern Art/Licensed by SCALA/Art Resource, New York. © 2009 Estate of Pablo Picasso / Artists Rights Society (ARS), New York. Reproduction, including downloading is prohibited by copyright laws and international conventions without the express written permission of Artists Rights Society (ARS),





Figure 4.61

Marcel Duchamp's Nude Descending a Staircase, No 2 (1912). This painting uses the Gestalt principle of continuity and another Gestalt principle not discussed in the text, called common fate (elements that appear to move together tend to be grouped together).

Duchamp, Marcel, 1912, *Nude Descending a Staircase*, *No. 2*, oil on canvas, 58" x 35". Philadelphia Museum of Art: Louise and Walter Arensburg Collection, #1950-134-69. Reproduced by permission. © 2009 Artists Rights Society.

up of two of the impossible triangles shown earlier, in **Figure 4.45**. In case you need help seeing them, the waterfall itself forms one side of each triangle.

The Necker cube, a reversible figure mentioned earlier in the chapter, was the inspiration for Escher's 1958 lithograph *Belvedere*, shown in **Figure 4.64**. You have to look carefully to realize that this is another impossible figure. Note that the top story runs at a right angle from the first story. Note also how the pillars are twisted around. The pillars that start on one side of the building end up supporting the second story on the other side! Escher's debt to the Necker cube is manifested in several



Figure 4.62
Salvador Dali's Slave Market with the Disappearing Bust of Voltaire (1940). This painting playfully includes a reversible figure (in the center of the painting, two nuns form the bust of Voltaire, a philosopher known for his stringent criticisms of the Catholic church).

Salvador Dali, *The Slave Market with the Disappearing Bust of Voltaire*, (1940), Oil on canvas, 18-1/4 \times 25-3/8 inches. Collection of The Salvador Dali Museum, St. Petersburg, FL. Copyright © 2006 The Salvador Dali Museum, Inc. © 2009 Salvador Dali, Gala-Salvador Dali Foundation/Artists Rights Socity (ARS), New York.

places. Notice, for instance, the drawing of a Necker cube on the floor next to the seated boy (on the lower left).

Like Escher, Hungarian artist Victor Vasarely, who pioneered Kinetic Art, challenged viewers to think about the process of perception. His paintings are based on illusions, as squares seem to advance and recede, or spheres seem to inflate and deflate. For example, note how Vasareley used the depth cues of texture gradient and linear perspective to convey the look of great depth in his painting *Tukoer-Ter-Ur*, shown in Figure 4.65.

While Escher and Vasarely challenged viewers to think about perception, Belgian artist René Magritte challenged people to think about the conventions of painting. Many of his works depict paintings on an easel, with the "real" scene continuing unbroken at the edges. The painting in Figure 4.66 is such a picture within a picture. Ultimately, Magritte's painting blurs the line between the real world and the illusory world created by the artist, suggesting that there is no line—that everything is an illusion. In this way, Magritte "framed" the ageless, unanswerable question: What is reality?

REVIEW of Key Learning Goals

4.27 After the Renaissance, painters began to routinely use pictorial depth cues to make their scenes more lifelike. Nineteenth-century painters, such as the Impressionists, manipulated color mixing in creative, new ways. The Cubists were innovative in manipulating form, as they applied the theory of feature analysis to canvas. The Surrealists toyed with reality, exploring the world of fantasy and dreams.

4.28 Inspired by Gestalt psychology, Escher tried to stimulate viewers to think about the process of perception. Among other things, Escher worked with the Necker cube and the impossible triangle. Vasarely manipulated depth cues to create illusions, whereas Magritte challenged people to think about the conventions of painting and their relation to reality.







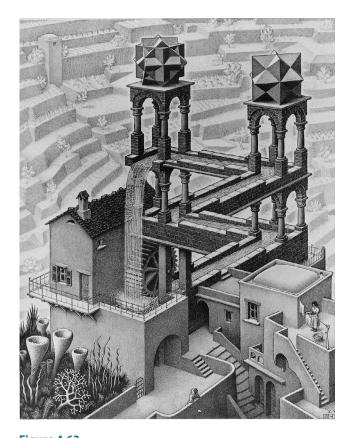


Figure 4.63
Escher's lithograph Waterfall (1961).
Escher's use of depth cues and impossible triangles deceives the brain into seeing water flow uphill.

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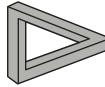




Figure 4.66
René Magritte's
Les Promenades
d'Euclide (1955).
Notice how the pair
of nearly identical
triangles look quite
different in different
contexts.

Magritte, Rene, Les Promenades d'Euclide, The Minneapolis Institute of Arts, The William Hood Dunwoody Fund. Copyright © 2009 Charly Herscovic, Brussels/Artists Rights Society (ARS) New York.

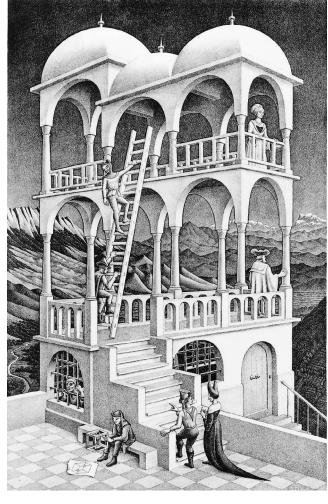




Figure 4.64

Escher's Belvedere (1958). This lithograph depicts an impossible figure inspired by the Necker cube. The cube appears in the architecture of the building, in the model held by the boy on the bench, and in the drawing lying at his feet.

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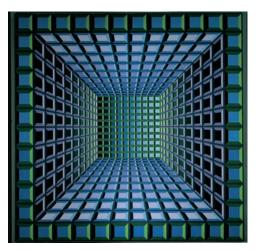


Figure 4.65
Victor Vasarely's
Tukoer-Ter-Ur
(1989). In this painting, Vasarely manipulates texture
gradients and linear
perspective to create a remarkable
illusion of depth.

Vasarely, Victor (1908– 1997) *Tukoer-Ter-Ur*, 1989. Acrylic on canvas, 220 × 220 cm. Private Collection, Monaco. © Erich Lessing / Art Resource, NY. Copyright © 2009 Artists Rights Society (ARS), New York/ADAGP, Paris



APPLICATION

Key Learning Goals

4.29 Understand how contrast effects can be manipulated to influence or distort judgments.

You're sitting at home one night, when the phone rings. It's Simone, an acquaintance from school who needs help with a recreational program for youngsters that she runs for the local park district. She tries to persuade you to volunteer four hours of your time every Friday night throughout the school year to supervise the volleyball program. The thought of giving up your Friday nights and adding this sizable obligation to your already busy schedule makes you cringe with horror. You politely explain to Simone that you can't possibly afford to give up that much time and you won't be able to help her. She accepts your rebuff graciously, but the next night she calls again. This time she wants to know whether you would be willing to supervise volleyball every third Friday. You still feel like it's a big obligation that you really don't want to take on, but the new request seems much more reasonable than the original one. So, with a sigh of resignation, you agree to Simone's request.

What's wrong with this picture? Well, there's nothing wrong with volunteering your time for a good cause, but you just succumbed to a social influence strategy called the "door-in-the face technique." The door-in-the-face technique involves making a large request that is likely to be turned down as a way

Recognizing Contrast Effects: It's All Relative

to increase the chances that people will agree to a smaller request later (see Figure 4.67). The name for this strategy is derived from the expectation that the initial request will be quickly rejected (the "door" is slammed in the "salesperson's" face). Although they may not be familiar with the strategy's name, many people use this manipulative tactic. For example, a husband who wants to coax his frugal wife into agreeing to buy a \$30,000 SUV might begin by proposing that they purchase a \$50,000 sports car. By the time the wife talks her husband out of the \$50,000 car, the \$30,000 price tag may look quite reasonable to her—which is what the husband wanted all along.

Research has demonstrated that the doorin-the-face technique is a highly effective persuasive strategy (Cialdini, 2001). One of the reasons it works so well is that it depends on a simple and pervasive perceptual principle. As noted throughout the chapter, in the domain of perceptual experience, everything is relative. This relativity means that people are easily swayed by contrast effects. For example, lighting a match or a small candle in a dark room will produce a burst of light that seems quite bright, but if you light the same match or candle in a welllit room, you may not even detect the additional illumination. The relativity of perception is apparent in the painting by Josef Albers shown in **Figure 4.68**. The two Xs are exactly the same color, but the X in the top half looks yellow, whereas the X in the bottom half looks brown. These varied perceptions occur because of contrast effects—the two X's are contrasted against different background colors. Another example of how contrast effects can influence perception can be seen in **Figure 4.69**. The middle disk in each panel is exactly the same size, but the one in the top panel looks larger because it is surrounded by much smaller disks.

The same principles of relativity and contrast that operate when we are making judgments about the intensity, color, or size of visual stimuli also affect the way we make judgments in a wide variety of domains. For example, a 6'3" basketball player, who is really quite tall, can look downright small when surrounded by teammates who are all over 6'8". And a salary of \$42,000 per year for your first full-time job may seem like a princely sum, until a close friend gets an offer of \$75,000 a year. The assertion that everything is relative raises the issue of relative to what? Comparitors are people, objects, events, and other standards used as a baseline for comparison in making judgments. It is fairly easy to manipulate many types of judgments by selecting extreme comparitors that may be unrepresentative.

The influence of extreme comparitors was demonstrated in some interesting studies of judgments of physical attractiveness. In one study, undergraduate males were asked to rate the attractiveness of an average-looking female (who was described

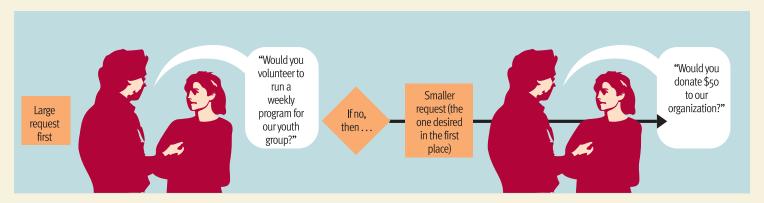


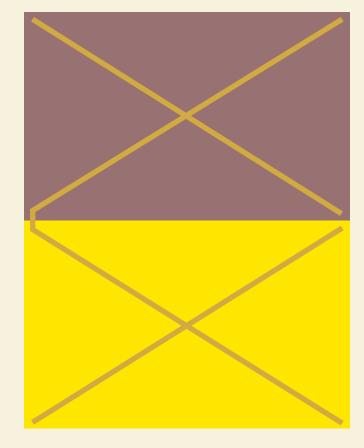
Figure 4.67

The door-in-the-face technique. The door-in-the-face technique is a frequently used compliance strategy in which you begin with a large request and work down to the smaller request you are really after. It depends in part on contrast effects.



Figure 4.68
Contrast effects in color perception. This composition by Joseph Albers shows how one color can be perceived differently when contrasted against different backgrounds. The top X looks yellow and the bottom X looks brown, but they're really the same color.

SOURCE: Albers, Joseph. *Interaction of Color*. Copyright © 1963 and reprinted by permission of the publisher, Yale University Press.

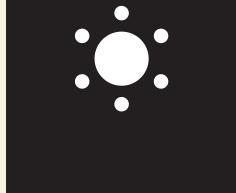


as a potential date for another male in the dorm) presented in a photo either just before or just after the participants watched a TV show dominated by strikingly beautiful women (Kenrick & Gutierres, 1980). The female was viewed as less attractive when the ratings were obtained just after the men had seen gorgeous women cavorting on TV as opposed to when they hadn't. In other studies, both male and female participants have rated themselves as less attractive after being exposed to many pictures of extremely attractive models (Little & Mannion, 2006; Thornton & Moore, 1993; Thornton & Maurice, 1999). Thus, contrast effects can influence important social judgments that are likely to affect how people feel about themselves and others.

Anyone who understands how easily judgments can be manipulated by a careful

choice of comparitors could influence your thinking. For example, a politician who is caught in some illegal or immoral act could sway public opinion by bringing to mind (perhaps subtly) the fact that many other politicians have committed acts that were much worse. When considered against a backdrop of more extreme comparitors, the politician's transgression will probably seem less offensive. A defense attorney could use a similar strategy in an attempt to obtain a lighter sentence for a client by comparing the client's offense to much more serious crimes. And a realtor who wants to sell you an expensive house that will require huge mortgage payments will be quick to mention other homeowners who have taken on even larger mortgages.

In summary, critical thinking is facilitated by conscious awareness of the way



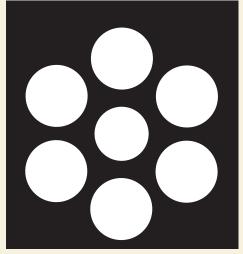


Figure 4.69
Contrast effects in size perception. The middle disk in the top panel looks larger than the middle disk in the bottom panel, but they really are exactly the same size. This illusion occurs because of contrast effects created by the surrounding disks.

comparitors can influence and perhaps distort a wide range of judgments. In particular, it pays to be vigilant about the possibility that others may manipulate contrast effects in their persuasive efforts. One way to reduce the influence of contrast effects is to consciously consider comparitors that are both worse and better than the event you are judging, as a way of balancing the effects of the two extremes.

Table 4.2 Critical Thinking Skills Discussed in This Application

| Table 4.2 Critical Filliking Skins Discussed in This Application | | |
|--|--|--|
| Skill | Description | |
| Understanding how contrast effects can influence judgments and decisions | The critical thinker appreciates how striking contrasts can be manipulated to influence many types of judgments. | |
| Recognizing when extreme comparitors are being used | The critical thinker is on the lookout for extreme comparitors that distort judgments. | |

REVIEW of Key Learning Goals

4.29 The study of perception often highlights the relativity of experience. This relativity can be manipulated by arranging for contrast effects. Critical thinking is enhanced by an awareness of how extreme comparitors can distort many judgments.





CHAPTER

RECAP

Key Ideas

Psychophysics: Basic Concepts and Issues

- Absolute thresholds, which indicate the minimum stimulus intensity that is detectable in a sensory system, are not really absolute. The size of a just noticeable difference tends to be a constant proportion of the size of the initial stimulus.
- According to signal-detection theory, the detection of sensory inputs is influenced by noise in the system and by decision-making strategies. In recent decades, it has become apparent that perception can occur without awareness. However, subliminal persuasion does not appear to be a serious problem. Prolonged stimulation may lead to sensory adaptation.

The Visual System: Essentials of Sight

- Light varies in terms of wavelength, amplitude, and purity. Light enters the eye through the cornea and pupil and is focused on the retina by the lens. Rods and cones are the visual receptors found in the retina. Cones play a key role in daylight vision and color perception, and rods are critical to night vision and peripheral vision. Dark and light adaptation both involve changes in the retina's sensitivity to light.
- The retina transforms light into neural impulses that are sent to the brain via the optic nerve. Receptive fields are areas in the retina that affect the firing of visual cells. Two visual pathways, which engage in parallel processing, send signals through the thalamus to the primary visual cortex. From there, visual signals are shuttled along pathways that have been characterized as the *what* and *where* pathways. Some neurons appear to be uniquely responsive to faces and other highly specific stimuli.
- Perceptions of color (hue) are primarily a function of light wavelength, while amplitude affects brightness and purity affects saturation. Perceptions of many varied colors depend on processes that resemble additive color mixing. The evidence now suggests that both the trichromatic and opponent process theories are necessary to account for color vision.

The Visual System: Perceptual Processes

- Form perception depends on the selection and interpretation of visual inputs, as illustrated by inattentional blindness and perceptual sets. According to feature analysis theories, people detect specific elements in stimuli and build them into forms through bottom-up processing. However, evidence suggests that form perception also involves top-down processing.
- Gestalt psychology emphasized that the whole may be greater than the sum of its parts (features), as illustrated by Gestalt principles of form perception. Other approaches to form perception emphasize that people develop perceptual hypotheses about the distal stimuli that could be responsible for the proximal stimuli that are sensed.
- Depth perception depends primarily on monocular cues. Binocular cues such as retinal disparity and convergence can also contribute to depth perception. Conscious perceptions of geographical slant tend to be greatly exaggerated, but haptic judgments seem largely immune to this perceptual bias.
- Perceptual constancies help viewers deal with the ever-shifting nature of proximal stimuli. Visual illusions demonstrate that perceptual hypotheses can be inaccurate and that perceptions are not simple reflections of objective reality.

The Auditory System: Hearing

- Sound varies in terms of wavelength (frequency), amplitude, and purity. These properties affect mainly perceptions of pitch, loudness, and timbre, respectively. Auditory signals are transmitted through the thalamus to the auditory cortex in the temporal lobe.
- Modern evidence suggests that place theory and frequency theory are complementary rather than incompatible explanations of pitch perception. People pinpoint the source of sounds by comparing interear differences in the intensity and timing of sounds.

The Chemical Senses: Taste and Smell

The taste buds are sensitive to four basic tastes: sweet, sour, bitter, and salty. Taste preferences are largely learned and are heavily influenced by one's cultural background. Supertasters are more sensitive to bitter and sweet tastes than others are, which leads them to have relatively healthy consumption habits.

Like taste, smell is a chemical sense. Chemical stimuli activate olfactory receptors lining the nasal passages. Most of these receptors respond to more than one odor. Humans exhibit surprising difficulty attaching names to odors.

The Sense of Touch

- Sensory receptors in the skin respond to pressure, temperature, and pain. Pain signals are sent to the brain along two pathways characterized as fast and slow. The perception of pain is highly subjective and may be influenced by mood, attention, personality, and culture.
- Gate-control theory holds that incoming pain signals can be blocked in the spinal cord. Endorphins and a descending neural pathway appear responsible for the suppression of pain by the central nervous system.

Reflecting on the Chapter's Themes

■ This chapter provided two dramatic demonstrations of the value of theoretical diversity. It also provided numerous examples of how and why our experience of the world is highly subjective. Finally, it highlighted the importance of cultural background.

PERSONAL APPLICATION Appreciating Art and Illusion

■ The principles of visual perception are often applied to artistic endeavors. Painters routinely use pictorial depth cues to make their scenes more lifelike. Color mixing, feature analysis, Gestalt principles, reversible figures, and impossible figures have also been used in influential paintings.

CRITICAL THINKING APPLICATION Recognizing Contrast Effects: It's All Relative

■ The study of perception often highlights the relativity of experience. This relativity can be manipulated by arranging for contrast effects. Critical thinking is enhanced by an awareness of how comparitors can distort many judgments.

Key Terms

Absolute threshold (p. 131) Additive color mixing (p. 143) Afterimage (p. 145) Auditory localization (p. 164) Basilar membrane (p. 162) Binocular depth cues (p. 152) Bottom-up processing (p. 148) Cochlea (p. 162) Color blindness (p. 144) Complementary colors (p. 145) Cones (p. 138) Convergence (p. 153) Dark adaptation (p. 138) Depth perception (p. 152) Distal stimuli (p. 151) Farsightedness (p. 137) Feature analysis (p. 148) Feature detectors (p. 141) Fovea (p. 138) Frequency theory (p. 163) Gate-control theory (p. 171) Gustatory system (p. 165) Impossible figures (p. 158) Inattentional blindness (p. 147) Just noticeable difference (JND) (p. 131) Lateral antagonism (p. 139) Lens (p. 135) Light adaptation (p. 138) Monocular depth cues (p. 153) Motion parallax (p. 153) Nearsightedness (p. 137) Olfactory system (p. 165) Opponent process theory (p. 145) Optic chiasm (p. 140) Optic disk (p. 137)

Parallel processing (p. 140) Perception (p. 130) Perceptual constancy (p. 157) Perceptual hypothesis (p. 151) Perceptual set (p. 147) Phi phenomenon (p. 149) Pictorial depth cues (p. 153) Place theory (p. 163) Proximal stimuli (p. 151) Psychophysics (p. 130) Pupil (p. 137) Receptive field of a visual cell (p. 139) Retina (p. 137) Retinal disparity (p. 153) Reversible figure (p. 146) Rods (p. 138) Sensation (p. 130) Sensory adaptation (p. 133) Signal-detection theory (p. 131) Subjective contours (p. 148) Subliminal perception (p. 132) Subtractive color mixing (p. 143) Top-down processing (p. 148) Trichromatic theory (p. 144) Visual illusion (p. 157)

Key People

Linda Bartoshuk (pp. 166–167) Gustav Fechner (pp. 130–131) Hermann von Helmholtz (pp. 144, 163) David Hubel and Torsten Wiesel (pp. 141–142) Ronald Melzack and Patrick Wall (pp. 171, 174) Max Wertheimer (p. 149)

CHAPTER

- In psychophysical research, the absolute threshold has been arbitrarily defined as:
 - A. the stimulus intensity that can be detected 100% of the time.
 - B. the stimulus intensity that can be detected 50% of the time.
 - the minimum amount of difference in intensity needed to tell two stimuli apart.
 - D. a constant proportion of the size of the initial stimulus.
- A tone-deaf person would probably not be able to tell two musical notes apart unless they were very different. We could say that this person has a relatively large:
 - A. just noticeable difference.
 - B. relative threshold.
 - C. absolute threshold.
 - D. detection threshold.
- 3. In their study of the influence of subliminal perception, Karremans and his colleagues (2006) found:
 - A. absolutely no evidence of such influence.
 - B. evidence that subliminal stimuli influenced subjects' drink preferences.
- C. that subliminal stimuli do not really exist.
- D. that it is nearly impossible to measure subliminal effects.
- 4. In farsightedness:
 - A. close objects are seen clearly but distant objects appear blurry.
 - B. the focus of light from close objects falls behind the retina.
 - C. the focus of light from distant objects falls a little short of the retina.
 - D. A and B
 - E. A and C.
- 5. The collection of rod and cone receptors that funnel signals to a particular visual cell in the retina make up that cell's:
 - A. blind spo
- C. opponent process field.
- B. optic disk.
- D. receptive field.
- 6. The visual pathway that has been characterized as ______ travels through the dorsal stream to the parietal lobes, whereas the pathway that has been labeled the ______ travels through the ventral stream to the temporal lobes.
 - A. the what pathway; the where pathway
 - B. the *where* pathway; the *what* pathway
 - C. the opponent process pathway; the trichromatic pathway
 - D. the trichromatic pathway; the opponent process pathway
- 7. Which theory would predict that the American flag would have a green, black, and yellow afterimage?
 - A. subtractive color mixing
 - B. opponent process theory
 - C. additive color mixing
 - D. trichromatic theory
- **8.** The illusion of movement created by presenting visual stimuli in rapid succession is called:
 - A. convergence.
- C. motion parallax.
- B. retinal disparity.
- D. the phi phenomenon.
- 9. In a painting, train tracks may look as if they go off into the distance because the artist draws the tracks as converging lines, a pictorial cue to depth known as:
 - A. interposition.
- C. convergence.
- B. texture gradient.
- D. linear perspective.
- 10. Sarah has just finished a long, exhausting 6-mile run. She and her friend Jamal are gazing at a hill they need to climb to get back to their car. Jamal asks Sarah, "Gee, how steep do you think that hill is?" Based on research by Proffitt and his colleagues, Sarah is likely to:
 - A. make a reasonably accurate estimate of the hill's slant, as most people do.
 - B. underestimate the hill's slant, as most people do.
 - C. overestimate the hill's slant, but to a lesser degree than she would have before her exhausting run.
 - D. overestimate the hill's slant to an even greater degree than she would have before her exhausting run.

- 11. The fact that cultural groups with less exposure to carpentered buildings are less susceptible to the Müller-Lyer illusion suggests that:
 - A. not all cultures test perceptual hypotheses.

PRACTICE TEST

- B. people in technologically advanced cultures are more gullible.
- Illusions can be experienced only by cultures that have been exposed to the concept of illusions.
- D. perceptual inferences can be shaped by experience.
- 12. Perception of pitch can best be explained by:
 - A. place theory.
 - B. frequency theory.
 - C. both place theory and frequency theory.
 - D. neither theory.
- 13. In what way(s) is the sense of taste like the sense of smell?
 - A. There are four primary stimulus groups for both senses.
 - B. Both systems are routed through the thalamus on the way to the
 - C. The physical stimuli for both senses are chemical substances dissolved in fluid.
 - D. All of the above.
 - E. None of the above.
- **14.** Which school of painting applied the theory of feature analysis to canvas by building figures out of simple features?
 - A. Kineticism
- C. Surrealism
- B. Impressionism
- D. Cubism
- **15.** In the study by Kenrick and Gutierres (1980), exposing male subjects to a TV show dominated by extremely beautiful women:
 - A. had no effect on their ratings of the attractiveness of a prospective date.
 - B. increased their ratings of the attractiveness of a prospective date.
 - C. decreased their ratings of the attractiveness of a prospective date.
 - D. increased their ratings of their own attractiveness.

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| 13 C pp. 165, 168 | 8 D b. 1 4 9 | 3 B p. 133 |
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| 11 D pp. 159–160 | 6 B p. 142 | 1 B p. 131 |
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