CHAPTER
3
SENSATION

CHAPTER OUTLINE

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People with faceblindness such as Duncan Mitchell can see faces, of course. They see the parts that make up a facial configuration—an oval shape with two eyes, a nose, and a mouth. But they lack the specialized processing ability most of us take for granted that allows us to detect the subtle differences that make each individual face unique. Although they can detect face-related information just fine, prosopagnosics have difficulty with finding that information meaningful—with seeing that face as a friend or foe.

Disorders such as faceblindness illustrate how much we depend on our senses to function normally. Our senses offer a window to the world, providing us with not only an awareness, understanding, and appreciation of the world’s beauty, but alerting us to its dangers. Our senses enable us to feel the gentlest of breezes, see flickering lights miles away, and hear the soft murmuring of distant songbirds.

In the next four modules, we focus on the field of psychology that is concerned with the ways our bodies take in information through the senses and the ways we interpret that information. We will explore both sensation and perception. Sensation encompasses the processes by which our sense organs receive information from the environment. Perception is the brain’s and the sense organs’ sorting out, interpretation, analysis, and integration of stimuli.

Although perception clearly represents a step beyond sensation, in practice it is sometimes difficult to find the precise boundary between the two. The primary difference is that sensation can be thought of as an organism’s first encounter with a raw sensory stimulus, whereas perception is the process by which that stimulus is interpreted, analyzed, and integrated with other sensory information. For example, if we were considering sensation, we might ask about the loudness of a ringing fire alarm. If we were considering perception, we might ask whether someone recognizes the ringing sound as an alarm and identifies its meaning.

To a psychologist interested in understanding the causes of behavior, sensation and perception are fundamental topics because so much of our behavior is a reflection of how we react to and interpret stimuli from the world around us. The areas of sensation and perception deal with a wide range of questions—among them, how we respond to the characteristics of physical stimuli; what processes enable us to see, hear, and experience pain; why visual illusions fool us; and how we distinguish one person from another.
Sensing the World Around Us

LEARNING OUTCOMES
8.1 Define absolute thresholds.
8.2 Explain the difference threshold and Weber’s law.
8.3 Discuss sensory adaptation.

As Isabel sat down to Thanksgiving dinner, her husband carried the turkey in on a tray and placed it squarely in the center of the table. The noise level, already high from the talking and laughter of family members, grew louder still. As Isabel picked up her fork, the smell of the turkey reached her and she felt her stomach growl hungrily. The sight and sound of her family around the table, along with the smells and tastes of the holiday meal, triggered happy childhood memories and put Isabel in a relaxed, contented mood.

Put yourself in this setting and consider how different it might be if any one of your senses was not functioning. What if you were blind and unable to see the faces of your family members or the welcome shape of the golden-brown turkey? What if you had no sense of hearing and could not listen to the conversations of family members or were unable to feel your stomach growl, smell the dinner, or taste the food? Clearly, you would experience the dinner very differently than would someone whose sensory apparatus was intact.

Moreover, the sensations mentioned above barely scratch the surface of sensory experience. Although perhaps you were taught, as I was, that there are just five senses—sight, sound, taste, smell, and touch—that enumeration is too modest. Human sensory capabilities go well beyond the basic five senses. For example, we are sensitive not merely to touch but to a considerably wider set of stimuli—pain, pressure, temperature, and vibration, to name a few.

To consider how psychologists understand the senses and, more broadly, sensation and perception, we first need a basic working vocabulary. In formal terms, **sensation** is the activation of the sense organs by a source of physical energy. **Perception** is the sorting out, interpretation, analysis, and integration of stimuli by the sense organs and brain. A **stimulus** is any passing source of physical energy that produces a response in a sense organ.

Stimuli vary in both type and intensity. Different types of stimuli activate different sense organs. For instance, we can differentiate light stimuli (which activate the sense of sight and allow us to see the colors of a tree in autumn) from sound stimuli (which, through the sense of hearing, permit us to hear the sounds of an orchestra).
How sensitive are you?

To test your awareness of the capabilities of your senses, answer the following questions:

1. How far can a candle flame be seen on a clear, dark night?
   - a. From a distance of 10 miles
   - b. From a distance of 30 miles

2. How far can the ticking of a watch be heard under quiet conditions?
   - a. From 5 feet away
   - b. From 20 feet away

3. How much sugar is needed to allow it to be detected when dissolved in 2 gallons of water?
   - a. 2 tablespoons
   - b. 1 teaspoon

4. Over what area can a drop of perfume be detected?
   - a. A 5-foot by 5-foot area
   - b. A 3-room apartment

**Scoring:** In each case, the answer is b, illustrating the tremendous sensitivity of our senses.

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**Psychophysics** The study of the relationship between the physical aspects of stimuli and our psychological experience of them.

**Absolute threshold** The smallest intensity of a stimulus that must be present for the stimulus to be detected.

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**LO1 Absolute Thresholds: Detecting What’s Out There**

Just when does a stimulus become strong enough to be detected by our sense organs? The answer to this question requires an understanding of the concept of absolute threshold. An **absolute threshold** is the smallest intensity of a stimulus that must be present for it to be detected (Aazh & Moore, 2007).

Our senses are extremely responsive to stimuli. For example, the sense of touch is so sensitive that we can feel a bee’s wing falling on our cheeks when it is dropped from a distance of one centimeter. Test your knowledge of the absolute thresholds of other senses by completing the questionnaire in Figure 1.

Of course, the absolute thresholds we have been discussing are measured under ideal conditions. Normally our senses cannot detect stimulation quite as well because of the presence of noise. Noise, as defined by psychophysicists, is background stimulation that interferes with the perception of other stimuli. Hence, noise refers not just to auditory stimuli, as the word suggests, but also to unwanted stimuli that interfere with other senses.

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**Figure 1** This test can shed some light on how sensitive the human senses are. (Source: Galanter, 1962.)
Suppose you wanted to choose the six best apples from a supermarket display—the biggest, reddest, and sweetest apples. One approach would be to compare one apple with another systematically until you were left with a few so similar that you could not tell the difference between them. At that point, it wouldn’t matter which ones you chose.

Psychologists have discussed this comparison problem in terms of the **difference threshold**, the smallest level of added (or reduced) stimulation required to sense that a change in stimulation has occurred. Thus, the difference threshold is the minimum change in stimulation required to detect the difference between two stimuli, and so it also is called a **just noticeable difference** (Nittouer & Lowenstein, 2007).

The stimulus value that constitutes a just noticeable difference depends on the initial intensity of the stimulus. The relationship between changes in the original value of a stimulus and the degree to which a change will be noticed forms one of the basic laws of psychophysics: **Weber’s law**. Weber’s law (with Weber pronounced “vay-ber”) states that a just noticeable difference is a constant proportion of the intensity of an initial stimulus.

For example, Weber found that the just noticeable difference for weight is 1:50. Consequently, it takes a 1-ounce increase in a 50-ounce weight to produce a noticeable difference, and it would take a 10-ounce increase to produce a noticeable difference if the initial weight were 500 ounces. In both cases, the same proportional increase is necessary to produce a just noticeable difference—1:50 = 10:500. Similarly, the just noticeable difference distinguishing changes in loudness between sounds is larger for sounds that are initially loud than it is for sounds that are initially soft, but the proportional increase remains the same.

Weber’s law helps explain why a person in a quiet room is more startled by the ringing of a telephone than is a person in an already noisy room.

Weber’s law helps explain why a person in a quiet room is more startled by the ringing of a telephone than is a person in an already noisy room. Weber’s law helps explain why a person in a quiet room is more startled by the ringing of a telephone than is a person in an already noisy room. To produce the same amount of reaction in a noisy room, a telephone ring might have to approximate the loudness of cathedral bells. Similarly, when the moon is visible during the late afternoon, it appears relatively dim—yet against a dark night sky, it seems quite bright.
Sensory Adaptation: Turning Down Our Responses

You enter a movie theater, and the smell of popcorn is everywhere. A few minutes later, though, you barely notice the smell. The reason you acclimate to the odor is sensory adaptation. Adaptation is an adjustment in sensory capacity after prolonged exposure to unchanging stimuli. Adaptation occurs as people become accustomed to a stimulus and change their frame of reference. In a sense, our brain mentally turns down the volume of the stimulation it’s experiencing (Calin-Jageman & Fischer, 2007).

One example of adaptation is the decrease in sensitivity that occurs after repeated exposure to a strong stimulus. If you were to hear a loud tone over and over again, eventually it would begin to sound softer. Similarly, although jumping into a cold lake may be temporarily unpleasant, eventually we probably would get used to the temperature.

This apparent decline in sensitivity to sensory stimuli is due to the inability of the sensory nerve receptors to fire off messages to the brain indefinitely. Because these receptor cells are most responsive to changes in stimulation, constant stimulation is not effective in producing a sustained reaction.

R E C A P

Define absolute thresholds.
- Sensation is the activation of the sense organs by any source of physical energy. In contrast, perception is the process by which we sort out, interpret, analyze, and integrate stimuli to which our senses are exposed. (p. 84)
- Psychophysics studies the relationship between the physical nature of stimuli and the sensory responses they evoke. (p. 85)
- The absolute threshold is the smallest amount of physical intensity at which a stimulus can be detected. Under ideal conditions absolute thresholds are extraordinarily sensitive, but the presence of noise (background stimuli that interfere with other stimuli) reduces detection capabilities. (p. 85)

Explain the difference threshold and Weber’s law.
- The difference threshold, or just noticeable difference, is the smallest change in the level of stimulation required to sense that a change has occurred. According to Weber’s law, a just noticeable difference is a constant proportion of the intensity of an initial stimulus. (p. 86)

Discuss sensory adaptation.
- Sensory adaptation occurs when we become accustomed to a constant stimulus and change our evaluation of it. Repeated exposure to a stimulus results in an apparent decline in sensitivity to it. (p. 87)
**EVALUATE**

1. __________ is the stimulation of the sense organs; __________ is the sorting out, interpretation, analysis, and integration of stimuli by the sense organs and the brain.

2. The term *absolute threshold* refers to the __________ intensity of a stimulus that must be present for the stimulus to be detected.

3. Weber discovered that for a difference between two stimuli to be perceptible, the stimuli must differ by at least a __________ proportion.

4. After completing a very difficult rock climb in the morning, Carmella found the afternoon climb unexpectedly easy. This case illustrates the phenomenon of __________.

**RETHINK**

Do you think it is possible to have sensation without perception? Is it possible to have perception without sensation?

**KEY TERMS**

- **Sensation** p. 84
- **Perception** p. 84
- **Stimulus** p. 84
- **Psychophysics** p. 85
- **Absolute threshold** p. 85
- **Difference threshold (just noticeable difference)** p. 86
- **Weber's law** p. 86
- **Adaptation** p. 87
If, as poets say, the eyes provide a window to the soul, they also provide us with a window to the world. Our visual capabilities permit us to admire and react to scenes ranging from the beauty of a sunset, to the configuration of a lover’s face, to the words written on the pages of a book.

Vision starts with light, the physical energy that stimulates the eye. Light is a form of electromagnetic radiation waves, which, as shown in Figure 1, are measured in wavelengths. The sizes of wavelengths correspond to different types of energy. The range of wavelengths that humans are sensitive to—called the visual spectrum—is relatively small.

Vision starts with light, the physical energy that stimulates the eye. Light waves coming from some object outside the body (such as the butterfly in Figure 2) are sensed by the only organ that is capable of responding to the visible spectrum: the eye. Our eyes convert light to a form that can be used by the neurons that serve as messengers to the brain. The neurons themselves take up a relatively small percentage of the total eye. Most of the eye is a mechanical device that is similar in many respects to a traditional, nondigital electronic camera that uses film, as you can see in Figure 2.

**Figure 1** The visible spectrum—the range of wavelengths to which people are sensitive—is only a small part of the kinds of wavelengths present in our environment. Is it a benefit or disadvantage to our everyday lives that we aren’t more sensitive to a broader range of visual stimuli? Why?
Despite the similarities between the eye and a traditional camera, vision involves processes that are far more complex and sophisticated than those of any camera. Furthermore, once an image reaches the neuronal receptors of the eye, the eye/camera analogy ends, for the processing of the visual image in the brain is more reflective of a computer than it is of a camera.

**Figure 2** Although human vision is far more complicated than the most sophisticated camera, in some ways basic visual processes are analogous to those used in traditional, nondigital photography.

**LO1** **Illuminating the Structure of the Eye**

The ray of light being reflected off the butterfly in Figure 2 first travels through the cornea, a transparent, protective window. The cornea, because of its curvature, bends (or refracts) light as it passes through to focus it more sharply. After moving through the cornea, the light traverses the pupil. The pupil is a dark hole in the center of the iris, the colored part of the eye, which in humans ranges from a light blue to a dark brown. The size of the pupil opening depends on the amount of light in the environment. The dimmer the surroundings are, the more the pupil opens to allow more light to enter.

Once light passes through the pupil, it enters the lens, which is directly behind the pupil. The lens acts to bend the rays of light so that they are properly...
focused on the rear of the eye. The lens focuses light by changing its own thickness, a process called accommodation: It becomes flatter when viewing distant objects and rounder when looking at closer objects.

**Reaching the Retina**

Having traveled through the pupil and lens, our image of the butterfly finally reaches its ultimate destination in the eye—the retina. Here the electromagnetic energy of light is converted to electrical impulses for transmission to the brain. It is important to note that because of the physical properties of light, the image has reversed itself in traveling through the lens, and it reaches the retina upside down (relative to its original position). Although it might seem that this reversal would cause difficulties in understanding and moving about the world, this is not the case. The brain interprets the image in terms of its original position.

The retina consists of a thin layer of nerve cells at the back of the eyeball (see Figure 3). There are two kinds of light-sensitive receptor cells in the retina. The names they have been given describe their shapes: rods and cones. **Rods** are thin, cylindrical receptor cells that are highly sensitive to light. **Cones** are cone-shaped, light-sensitive receptor cells that are responsible for sharp focus and color perception, particularly in bright light. The rods and cones are distributed unevenly throughout the retina. Cones are concentrated on the part of the retina called the *fovea*. The fovea is a particularly sensitive region of the retina. If you want to focus on something of particular interest, you will automatically try to center the image on the fovea to see it more sharply.

The rods and cones are not only structurally dissimilar but they also play distinctly different roles in vision. Cones are primarily responsible for the sharply focused perception of color, particularly in brightly lit situations; rods are related to vision in dimly lit situations and are largely insensitive to color and to details as sharp as those the cones are capable of recognizing. The rods play a key role in *peripheral vision*—seeing objects that are outside the main center of focus—and in night vision.

**Sending the Message from the Eye to the Brain**

When light energy strikes the rods and cones, it triggers a neural response that moves out of the back of the eyeball and into the brain through a bundle of ganglion axons called the **optic nerve**.
**Figure 3** The basic cells of the eye. Light entering the eye travels through the ganglion and bipolar cells and strikes the light-sensitive rods and cones located at the back of the eye. The rods and cones then transmit nerve impulses to the brain via the bipolar and ganglion cells. *(Source: Shier, Butler, & Lewis, 2000.)*

**Figure 4** To find your blind spot, close your right eye and look at the haunted house with your left eye. You will see the ghost on the periphery of your vision. Now, while staring at the house, move the page toward you. When the book is about a foot from your eye, the ghost will disappear. At this moment, the image of the ghost is falling on your blind spot. But also notice how, when the page is at that distance, not only does the ghost seem to disappear, but the line seems to run continuously through the area where the ghost used to be. This shows how we automatically compensate for missing information by using nearby material to complete what is unseen. That’s the reason you never notice the blind spot. What is missing is replaced by what is seen next to the blind spot. Can you think of any advantages that this tendency to provide missing information gives humans as a species?
Because the opening for the optic nerve passes through the retina, there are no rods or cones in the area, and that creates a blind spot. Normally, however, this absence of nerve cells does not interfere with vision because you automatically compensate for the missing part of your field of vision. (To find your blind spot, see Figure 4.)

Once beyond the eye itself, the neural impulses relating to the image move through the optic nerve. As the optic nerve leaves the eyeball, its path does not take the most direct route to the part of the brain right behind the eye. Instead, the optic nerves from each eye meet at a point roughly between the two eyes—called the optic chiasm (pronounced ki-asm)—where each optic nerve then splits.

When the optic nerves split, the nerve impulses coming from the right half of each retina are sent to the right side of the brain, and the impulses arriving from the left half of each retina are sent to the left side of the brain. Because the image on the retinas is reversed and upside down, however, those images coming from the right half of each retina actually originated in the field of vision to the person’s left, and the images coming from the left half of each retina originated in the field of vision to the person’s right (see Figure 5).

**Figure 5** Because the optic nerve coming from each eye splits at the optic chiasm, the image to a person’s right is sent to the left side of the brain and the image to the person’s left is transmitted to the right side of the brain. (Source: Mader, 2000.)
Most of us rarely think of our own vision, but optometrists and their assistants focus on it daily. What are some other careers that have a sensory focus?

Feature detection | The activation of neurons in the cortex by visual stimuli of specific shapes or patterns.

**Processing the Visual Message**

Most processing of visual images takes place in the visual cortex of the brain, and it is here that the most complex kinds of processing occur. Many neurons in the cortex are extraordinarily specialized, being activated only by visual stimuli of a particular shape or pattern—a process known as feature detection.

Researchers have found that some cells are activated only by lines of a particular width, shape, or orientation. Other cells are activated only by moving, as opposed to stationary, stimuli (Hubel & Wiesel, 2004; Pelli, Burns, & Farell, 2006).

More recent work has added to our knowledge of the complex ways in which visual information coming from individual neurons is combined and processed. Different parts of the brain process nerve impulses in several individual systems simultaneously. For instance, one system relates to shapes, one to colors, and others to movement, location, and depth. Furthermore, different parts of the brain are involved in the perception of specific kinds of stimuli, showing distinctions, for example, between the perception of human faces, animals, and inanimate stimuli. The brain’s integration of visual information does not occur in any single step or location in the brain but instead is a process that occurs on several levels simultaneously (Winston, O’Doherty, & Kilner, 2006; Werblin & Roska, 2007; Werner, Pinna, & Spillmann, 2007).

**LO2 Color Vision and Color Blindness: The Seven-Million-Color Spectrum**

Although the range of wavelengths to which humans are sensitive is relatively narrow, at least in comparison with the entire electromagnetic spectrum, the portion to which we are capable of responding allows us great flexibility in sensing the world. Nowhere is this clearer than in terms of the number of colors we can discern (Bruce, Green, & Georgeson, 1997; Rabin, 2004).

Although the variety of colors that people are generally able to distinguish is vast, there are certain individuals whose ability to perceive color is quite limited—the color-blind. Interestingly, the condition of these individuals has provided some of the most important clues to understanding how color vision operates (Neitz, Neitz, & Kainz, 1996; Bonnardel, 2006).

A person with normal color vision is capable of distinguishing no less than 7 million different colors, but approximately 50 men or 1 in 5,000 women are color-blind. For most people with color blindness, the world looks quite dull. Red fire engines appear yellow, green grass seems yellow, and the three colors
of a traffic light all look yellow. In fact, in the most common form of color blindness, all red and green objects are seen as yellow. There are other forms of color blindness as well, but they are quite rare. In yellow-blue blindness, people are unable to tell the difference between yellow and blue, and in the most extreme case an individual perceives no color at all. To such a person the world looks something like the picture on a black-and-white television set.

Explaining Color Vision

To understand why some people are color-blind, we need to consider the basics of color vision. There are two processes involved. The first process is explained by the trichromatic theory of color vision. This theory suggests that there are three kinds of cones in the retina, each of which responds primarily to a specific range of wavelengths. One is most responsive to blue-violet colors, one to green, and the third to yellow-red (Brown & Wald, 1964). According to trichromatic theory, perception of color is influenced by the relative strength with which each of the three kinds of cones is activated. If we see a blue sky, the blue-violet cones are primarily triggered, and the others show less activity.

However, there are aspects of color vision that the trichromatic theory is less successful at explaining. For example, the theory does not explain what happens after you stare at something like the flag shown in Figure 6 for about a minute. Try this yourself and then look at a blank white page: you’ll see an image of the traditional red, white, and blue U.S. flag. Where there was

![Figure 6](image-url)
yellow, you’ll see blue, and where there were green and black, you’ll see red and white.

The phenomenon you have just experienced is called an *afterimage*. It occurs because activity in the retina continues even when you are no longer staring at the original picture. However, it also demonstrates that the trichromatic theory does not explain color vision completely. Why should the colors in the afterimage be different from those in the original?

Because trichromatic processes do not provide a full explanation of color vision, alternative explanations have been proposed. According to the **opponent-process theory of color vision**, receptor cells are linked in pairs, working in opposition to each other. Specifically, there is a blue-yellow pairing, a red-green pairing, and a black-white pairing. If an object reflects light that contains more blue than yellow, it will stimulate the firing of the cells sensitive to blue, simultaneously discouraging or inhibiting the firing of receptor cells sensitive to yellow—and the object will appear blue. If, in contrast, a light contains more yellow than blue, the cells that respond to yellow will be stimulated to fire while the blue ones are inhibited, and the object will appear yellow (D. N. Robinson, 2007).

The opponent-process theory provides a good explanation for afterimages. When we stare at the yellow in the figure, for instance, our receptor cells for the yellow component of the yellow-blue pairing become fatigued and are less able to respond to yellow stimuli. In contrast, the receptor cells for the blue part of the pair are not tired, because they are not being stimulated. When we look at a white surface, the light reflected off it would normally stimulate both the yellow and the blue receptors equally. But the fatigue of the yellow receptors prevents this from happening. They temporarily do not respond to the yellow, which makes the white light appear to be blue. Because the other colors in the figure do the same thing relative to their specific opponents, the afterimage produces the opponent colors—for a while. The afterimage lasts only a short time, because the fatigue of the yellow receptors is soon overcome, and the white light begins to be perceived more accurately.

Both opponent processes and trichromatic mechanisms are at work in allowing us to see color. However, they operate in different parts of the visual sensing system. Trichromatic processes work within the retina itself, whereas opponent mechanisms operate both in the retina and at later stages of neuronal processing (Gegenfurtner, 2003; Chen, Zhou, & Gong, 2004; Baraas, Foster, & Amano, 2006).

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**Opponent-process theory of color vision**
The theory that receptor cells for color are linked in pairs, working in opposition to each other.

**STUDY ALERT**
Know the distinctions between the trichromatic and opponent-process theories of color vision.

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**RECAP**

**Explain the basic structure of the eye.**
- Vision depends on sensitivity to light that is either reflected off objects or produced by an energy source. The eye shapes the light into an image that is transformed into nerve impulses and interpreted by the brain. (p. 89)
- As light enters the eye, it passes through the cornea, pupil, and lens and ultimately reaches the retina, where the electromagnetic energy of light is converted to nerve impulses for transmission to the brain. These impulses leave the eye via the optic nerve. (p. 90)
- The visual information gathered by the rods and cones is transferred through the optic nerve, which leads to the optic chiasm—the point where the optic nerve splits. (p. 93)
Compare and contrast color vision with color blindness.

- Color vision seems to be based on two processes described by the trichromatic theory and the opponent-process theory. (p. 95)
- The trichromatic theory suggests that there are three kinds of cones in the retina, each of which is responsive to a certain range of colors. The opponent-process theory presumes pairs of different types of cells in the eye that work in opposition to each other. (p. 95)

E V A L U A T E

1. Light entering the eye first passes through the __________, a protective window.
2. The structure that converts light into usable neural messages is called the __________.
3. A woman with blue eyes could be described as having blue pigment in her __________.
4. What is the process by which the thickness of the lens is changed in order to focus light properly?
5. The proper sequence of structures that light passes through in the eye is the __________, __________, __________, and __________.
6. Match each type of visual receptor with its function.
   a. Rods 1. Used for dim light, largely insensitive to color.
   b. Cones 2. Detect color, good in bright light.
7. __________ theory states that there are three types of cones in the retina, each of which responds primarily to a different color.

R E T H I N K

If the eye had a second lens that “unreversed” the image hitting the retina, do you think there would be changes in the way people perceive the world?

K E Y   T E R M S

- Retina p. 91
- Rods p. 91
- Cones p. 91
- Optic nerve p. 91
- Feature detection p. 94
- Trichromatic theory of color vision p. 95
- Opponent-process theory of color vision p. 96
The blastoff was easy compared with what the astronaut was experiencing now: space sickness. The constant nausea and vomiting were enough to make him wonder why he had worked so hard to become an astronaut. Even though he had been warned that there was a two-thirds chance that his first experience in space would cause these symptoms, he wasn’t prepared for how terribly sick he really felt.

Whether or not the astronaut wishes he could head right back to the earth, his experience, a major problem for space travelers, is related to a basic sensory process: the sense of motion and balance. This sense allows people to navigate their bodies through the world and keep themselves upright without falling. Along with hearing—the process by which sound waves are translated into understandable and meaningful forms—the sense of motion and balance resides in the ear.

Sensing Sound

Although many of us think primarily of the outer ear when we speak of the ear, that structure is only one simple part of the whole. The outer ear acts as a reverse megaphone, designed to collect and bring sounds into the internal portions of the ear (see Figure 1). The location of the outer ears on different sides of the head helps with sound localization, the process by which we identify the direction from which a sound is coming. Wave patterns in the air enter each ear at a slightly different time, and the brain uses the discrepancy as a clue to the sound’s point of origin. In addition, the two outer ears delay or amplify sounds of particular frequencies to different degrees.

**Sound** is the movement of air molecules brought about by a source of vibration. Sounds, arriving at the outer ear in the form of wavelike vibrations, are funneled into the *auditory canal*, a tube-like passage that leads to the eardrum. The *eardrum* is aptly named because it operates like a miniature drum, vibrating when sound waves hit it. The more intense the sound, the more the eardrum vibrates. These vibrations are then transferred into the *middle ear*, a tiny chamber containing three bones (the *hammer*, the...
anvil, and the stirrup) that transmit vibrations to the oval window, a thin membrane leading to the inner ear.

The inner ear is the portion of the ear that changes the sound vibrations into a form in which they can be transmitted to the brain. (As you will see, it also contains the organs that allow us to locate our position and determine how we are moving through space.) When sound enters the inner ear through the oval window, it moves into the cochlea, a coiled tube that looks something like a snail and is filled with fluid that vibrates in response to sound. Inside the cochlea is the basilar membrane, a structure that runs through the center of the cochlea, dividing it into an upper chamber and a lower chamber. The basilar membrane is covered with hair cells. When the hair cells are bent by the vibrations entering the cochlea, the cells send a neural message to the brain (Cho, 2000; Zhou, Liu, & Davis, 2005).

When an auditory message leaves the ear, it is transmitted to the auditory cortex of the brain through a complex series of neural interconnections. As the message is transmitted, it is communicated through neurons that respond to specific types of sounds. Within the auditory cortex itself, there are neurons that respond selectively to very specific sorts of sound features, such as clicks and whistles. Some neurons respond only to a specific pattern of sounds, such as a steady tone but not an intermittent one. Furthermore, specific neurons transfer information about a sound’s location through their particular pattern of firing (Middlebrooks et al., 2005; Wang et al., 2005; Tervaniemi, Jacobsen, & Röttger, 2006).

Neighboring cells in the auditory cortex of the brain are responsive to similar frequencies. The auditory cortex, then, provides us with a “map” of sound frequencies, just as the visual cortex furnishes a representation of the visual field. In addition, because of the asymmetry in the two hemispheres of the brain (which we discussed in the last chapter), the left and right ears process sound differently.
Chapter 3
Sensation and Perception

The right ear reacts more to speech, while the left ear responds more to music (Sininger & Cone-Wesson, 2004, 2006).

### Balance: The Ups and Downs of Life

Several structures of the ear are related more to our sense of balance than to our hearing. The **semicircular canals** of the inner ear (refer to Figure 1) consist of three tubes containing fluid that sloshes through them when the head moves, signaling rotational or angular movement to the brain. The pull on our bodies caused by the acceleration of forward, backward, or up-and-down motion, as well as the constant pull of gravity, is sensed by the **otoliths**, tiny, motion-sensitive crystals in the semicircular canals. When we move, these crystals shift like sands on a windy beach. The brain’s inexperience in interpreting messages from the weightless otoliths is the cause of the space sickness commonly experienced by two-thirds of all space travelers (Flam, 1991; Stern & Koch, 1996).

**LO2 Smell and Taste**

Until he bit into a piece of raw cabbage on that February evening . . . , Raymond Fowler had not thought much about the sense of taste. The cabbage, part of a pasta dish he was preparing for his family’s dinner, had an odd, burning taste, but he did not pay it much attention. Then a few minutes later, his daughter handed him a glass of cola, and he took a swallow. “It was like sulfuric acid,” he said. “It was like the hottest thing you could imagine boring into your mouth.” (Goode, 1999, pp. D1–D2)

It was evident that something was very wrong with Fowler’s sense of taste. After extensive testing, it became clear that he had damaged the nerves involved in his sense of taste, probably because of a viral infection or a medicine he was taking. (Luckily for him, a few months later his sense of taste returned to normal.)

Even without disruptions in our ability to perceive the world such as those experienced by Fowler, we all know the important roles that taste and smell play. We’ll consider these two senses next.

**Smell**

Although many animals have keener abilities to detect odors than we do, the human sense of smell (*olfaction*) permits us to detect more than 10,000 separate smells. We also have a good memory for smells, and long-forgotten events and memories can be brought back with the mere whiff of an odor associated with a memory (DiLorenzo & Youngentob, 2003; Stevenson & Case, 2005; Willander & Larsson, 2006).
Results of “sniff tests” have shown that women generally have a better sense of smell than men do (Herz & Engen, 1996). People also have the ability to distinguish males from females on the basis of smell alone. In one experiment, blindfolded students who were asked to sniff the breath of a female or male volunteer who was hidden from view were able to distinguish the sex of the donor at better than chance levels. People can also distinguish happy from sad emotions by sniffing underarm smells, and women are able to identify their babies solely on the basis of smell just a few hours after birth (Doty et al., 1982; Haviland-Jones & Chen, 1999).

The sense of smell is sparked when the molecules of a substance enter the nasal passages and meet olfactory cells, the receptor neurons of the nose, which are spread across the nasal cavity. More than 1,000 separate types of receptors have been identified on those cells so far. Each of these receptors is so specialized that it responds only to a small band of different odors. The responses of the separate olfactory cells are then transmitted to the brain, where they are combined into recognition of a particular smell (Marshall, Laing, & Jinks, 2006; Murphy et al., 2004; Zou & Buck, 2006).

**Taste**

The sense of taste (gustation) involves receptor cells that respond to four basic stimulus qualities: sweet, sour, salty, and bitter. Although the specialization of the receptor cells leads them to respond most strongly to a particular type of taste, they also are capable of responding to other tastes as well. Ultimately, every taste is simply a combination of the basic flavor qualities, in the same way that the primary colors blend into a vast variety of shades and hues (DiLorenzo & Youngentob, 2003; Yeomans, Tepper, & Ritzschel, 2007).

The receptor cells for taste are located in roughly 10,000 taste buds, which are distributed across the tongue and other parts of the mouth and throat. The taste buds wear out and are replaced every 10 days or so. That’s a good thing, because if our taste buds weren’t constantly reproducing, we’d lose the ability to taste after we’d accidentally burned our tongues.

The sense of taste differs significantly from one person to another, largely as a result of genetic factors. Some people, dubbed “supertasters,” are highly sensitive to taste; they have twice as many taste receptors as “nontasters,” who are relatively insensitive to taste. Supertasters (who, for unknown reasons, are more likely to be female than male) find sweets sweeter, cream creamier, and spicy dishes spicier, and weaker concentrations of flavor are enough to satisfy any cravings they may have. In contrast, because they aren’t so sensitive to taste, nontasters may seek out relatively sweeter and fattier foods in order to maximize the taste. As a consequence, they may be prone to obesity (Bartoshuk, 2000; Snyder, Fast, & Bartoshuk, 2004; Pickering & Gordon, 2006).

Are you a supertaster? To find out, complete the accompanying Try It! questionnaire.

**The sense of taste (gustation) involves receptor cells that respond to four basic stimulus qualities: sweet, sour, salty, and bitter.**

There are 10,000 taste buds on the tongue and other parts of the mouth. Taste buds wear out and are replaced every 10 days. What would happen if taste buds were not generated?
1. Taste Bud Count

Punch a hole with a standard hole punch in a square of wax paper. Paint the front of your tongue with a cotton swab dipped in blue food coloring. Put wax paper on the tip of your tongue, just to the right of center. With a flashlight and magnifying glass, count the number of pink, unstained circles. They contain taste buds.

2. Sweet Taste

Rinse your mouth with water before tasting each sample. Put 1/2 cup sugar in a measuring cup, and then add enough water to make 1 cup. Mix. Coat front half of your tongue, including the tip, with a cotton swab dipped in the solution. Wait a few moments. Rate the sweetness according to the scale shown below.

3. Salt Taste

Put 2 teaspoons of salt in a measuring cup and add enough water to make 1 cup. Repeat the steps listed above, rating how salty the solution is.

4. Spicy Taste

Add 1 teaspoon of Tabasco sauce to 1 cup of water. Apply with a cotton swab to first half inch of the tongue, including the tip. Keep your tongue out of your mouth until the burn reaches a peak, then rate the burn according to the scale.

**Supertasters**

- No. of taste buds: 25 on average
- Sweet rating: 56 on average
- Tabasco: 64 on average

**Nontasters**

- No. of taste buds: 10
- Sweet rating: 32
- Tabasco: 31

Average tasters lie in between supertasters and nontasters. Bartoshuk and Lucchina lack the data at this time to rate salt reliably, but you can compare your results with others taking the test.


**LO3 The Skin Senses: Touch, Pressure, Temperature, and Pain**

It started innocently when Jennifer Darling hurt her right wrist during gym class. At first it seemed like a simple sprain. But even though the initial injury healed, the excruciating, burning pain accompanying it did not go away. Instead, it spread to her other arm and then to her legs. The pain, which Jennifer described as similar to “a hot iron on your arm,” was unbearable—and never stopped.

The source of Darling’s pain turned out to be a rare condition known as “reflex sympathetic dystrophy syndrome,” or RSDS for short. For a victim of RSDS, a stimulus as mild as a gentle breeze or the touch of a feather can produce agony. Even bright sunlight or a loud noise can trigger intense pain.
Pain like Darling’s can be devastating, yet a lack of pain can be equally bad. If you never experienced pain, for instance, you might not notice that your arm had brushed against a hot pan, and you would suffer a severe burn. Similarly, without the warning sign of abdominal pain that typically accompanies an inflamed appendix, your appendix might eventually rupture, spreading a fatal infection throughout your body.

In fact, all our skin senses—touch, pressure, temperature, and pain—play a critical role in survival, making us aware of potential danger to our bodies. Most of these senses operate through nerve receptor cells located at various depths throughout the skin, distributed unevenly throughout the body. For example, some areas, such as the fingertips, have many more receptor cells sensitive to touch and as a consequence are notably more sensitive than other areas of the body (Gardner & Kandel, 2000; see Figure 2).

Probably the most extensively researched skin sense is pain, and with good reason: people consult physicians and take medication for pain more than for any other symptom or condition. Losses to U.S. business productivity due to employee pain is more than $60 billion a year, and overall pain costs $100 billion a year in the United States alone. (Stewart et al., 2003; Pesmen, 2006).

Pain is a response to a great variety of different kinds of stimuli. A light that is too bright can produce pain, and sound that is too loud can be painful. One explanation is that pain is an outcome of cell injury; when a cell is damaged, regardless of the source of damage, it releases a chemical called substance P that transmits pain messages to the brain.

![Skin sensitivity in various areas of the body](image)

**Figure 2** Skin sensitivity in various areas of the body. The lower the average threshold is, the more sensitive a body part is. The fingers and thumb, lips, nose, cheeks, and big toe are the most sensitive. Why do you think certain areas are more sensitive than others? (Source: From D. R. Kenshalo, The Skin Senses, 1968. Courtesy of Charles C Thomas, Publisher, Ltd., Springfield, Illinois.)
Some people are more susceptible to pain than others. For example, women experience painful stimuli more intensely than men. These gender differences are associated with the production of hormones related to menstrual cycles. In addition, certain genes are linked to the experience of pain, so that we may inherit our sensitivity to pain (Apkarian et al., 2005; Edwards & Fillingim, 2007).

But the experience of pain is not determined by biological factors alone. For example, women report that the pain experienced in childbirth is moderated to some degree by the joyful nature of the situation. In contrast, even a minor stimulus can produce the perception of strong pain if it is accompanied by anxiety (like a visit to the dentist). Clearly, then, pain is a perceptual response that depends heavily on our emotions and thoughts (Hadjistavropoulos, Craig, & Fuchs-Lacelle, 2004; Rollman, 2004; Lang, Sorrell, & Rodgers, 2006).

From the perspective of . . .

**A Medical or Dental Assistant** How would you handle a patient who is anxiously awaiting treatment and complaining that her pain is getting worse?

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**Gate-control theory of pain** The theory that particular nerve receptors lead to specific areas of the brain related to pain.

According to the gate-control theory of pain, particular nerve receptors in the spinal cord lead to specific areas of the brain related to pain. When these receptors are activated because of an injury or problem with a part of the body, a “gate” to the brain is opened, allowing us to experience the sensation of pain (Melzack & Katz, 2004).

However, another set of neural receptors can, when stimulated, close the “gate” to the brain, thereby reducing the experience of pain. The gate can be shut in two different ways. First, other impulses can overwhelm the nerve pathways relating to pain, which are spread throughout the brain. In this case, nonpainful stimuli compete with and sometimes displace the neural message of pain, thereby shutting off the painful stimulus.

Psychological factors account for the second way a gate can be shut. Depending on an individual’s current emotions, interpretation of events, and previous experience, the brain can close a gate by sending a message down the spinal cord to an injured area, producing a reduction in or relief from pain. Thus, soldiers who are injured in battle may experience no pain. The lack of pain probably occurs because a soldier experiences such relief at still being alive that the brain sends a signal to the injury site to shut down the pain gate (Turk, 1994; Gatchel & Weisberg, 2000; Pincus & Morley, 2001).

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**Managing Pain**

Are you one of the 50 million people in the United States who suffer from chronic pain? Psychologists and medical specialists have devised several strategies to fight pain. Among the most important approaches are the following:
- **Medication.** Painkilling drugs are the most popular treatment in fighting pain. Drugs range from those which directly treat the source of the pain—such as reducing swelling in painful joints—to those which work on the symptoms. Medication can be in the form of pills, patches, injections, or liquids. In a recent innovation, drugs are pumped directly into the spinal cord (Pesmen, 2006).

- **Nerve and brain stimulation.** Pain can sometimes be relieved when a low-voltage electric current is passed through the specific part of the body that is in pain. In even more severe cases, electrodes can be implanted surgically directly into the brain, or a handheld battery pack can stimulate nerve cells to provide direct relief. This process is known as transcutaneous electrical nerve stimulation, or TENS (Tugay et al., 2007; Claydon et al., 2008).

- **Light therapy.** One of the newest forms of pain reduction involves exposure to specific wavelengths of red or infrared light. Certain kinds of light increase the production of enzymes that may promote healing (Evcik et al., 2007; Rastad, Ulfberg, & Lindberg, 2008).

- **Hypnosis.** For people who can be hypnotized, hypnosis can greatly relieve pain (Patterson, 2004; Neron & Stephenson, 2007).

- **Biofeedback and relaxation techniques.** Using biofeedback, people learn to control “involuntary” functions such as heartbeat and respiration. If the pain involves muscles, as in tension headaches or back pain, sufferers can be trained to relax their bodies systematically (Vitiello, Bonello, & Pollard, 2007).

- **Surgery.** In one of the most extreme methods, nerve fibers that carry pain messages to the brain can be cut surgically. Still, because of the danger that other bodily functions will be affected, surgery is a treatment of last resort, used most frequently with dying patients (Cullinane, Chu, & Mamelak, 2002; Lai, Chen, & Chien, 2007).

- **Cognitive restructuring.** Cognitive treatments are effective for people who continually say to themselves, “This pain will never stop,” “The pain is ruining my life,” or “I can’t take it anymore” and are thereby likely to make their pain even worse. By substituting more positive ways of thinking, people can increase their sense of control—and actually reduce the pain they experience (Spanos, Barber, & Lang, 2005; Bogart et al., 2007).

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**RECAP**

**Describe how we sense sound.**

- Sound, motion, and balance are centered in the ear. Sounds, in the form of vibrating airwaves, enter through the outer ear and travel through the auditory canal until they reach the eardrum. (p. 98)

- The vibrations of the eardrum are transmitted into the middle ear, which consists of three bones: the hammer, the anvil, and the stirrup.

These bones transmit vibrations to the oval window. (p. 98)

- In the inner ear, vibrations move into the cochlea, which encloses the basilar membrane. Hair cells on the basilar membrane change the mechanical energy of sound waves into nerve impulses that are transmitted to the brain. The ear is also involved in the sense of balance and motion. (p. 98)
Discuss smell and taste.
- Smell depends on olfactory cells (the receptor cells of the nose), and taste is centered in the tongue’s taste buds. (p. 101)

Distinguish the skin senses.
- The skin senses are responsible for the experiences of touch, pressure, temperature, and pain. Gate-control theory suggests that particular nerve receptors, when activated, open a “gate” to specific areas of the brain related to pain, and that another set of receptors closes the gate when stimulated. (p. 104)
- Among the techniques used frequently to alleviate pain are medication, hypnosis, biofeedback, relaxation techniques, surgery, nerve and brain stimulation, and cognitive therapy. (p. 105)

EVALUATE

1. The tubelike passage leading from the outer ear to the eardrum is known as the _________.
2. The purpose of the eardrum is to protect the sensitive nerves underneath it. It serves no purpose in actual hearing. True or false?
3. The three middle ear bones transmit their sound to the _________.
4. The three fluid-filled tubes in the inner ear that are responsible for our sense of balance are known as the _________.
5. Touch, pressure, temperature, and pain are collectively known as our _________.

RETHINK

Much research is being conducted on repairing faulty sensory organs through devices such as personal guidance systems and eyeglasses, among others. Do you think that researchers should attempt to improve normal sensory capabilities beyond their “natural” range (for example, make human visual or audio capabilities more sensitive than normal)? What benefits might this ability bring? What problems might it cause?

KEY TERMS

Sound p. 98
Eardrum p. 98
Cochlea (KOKE lee uh) p. 98
Basilar membrane p. 98
Hair cells p. 98
Semicircular canals p. 100
Skin senses p. 103
Gate-control theory of pain p. 104
Consider the vase shown in Figure 1A for a moment. Or is it a vase? Take another look, and instead you may see the profiles of two people.

Now that an alternative interpretation has been pointed out, you will probably shift back and forth between the two interpretations. Similarly, if you examine the shapes in Figure 1B long enough, you will probably experience a shift in what you’re seeing. The reason for these reversals is this: because each figure is two-dimensional, the usual means we employ for distinguishing the figure (the object being perceived) from the ground (the background or spaces within the object) do not work.

**Figure 1** When the usual cues we use to distinguish figure from ground are absent, we may shift back and forth between different views of the same figure. If you look at each of these objects long enough, you’ll probably experience a shift in what you’re seeing. In (A), you can see either a vase or the profiles of two people. (For another example of this, look at the cover of this book!) In (B), the shaded portion of the figure, called a Necker cube, can appear to be either the front or the back of the cube. Finally, in (C), you’ll be able to see a face of a woman if you look at the drawing long enough.
The fact that we can look at the same figure in more than one way illustrates an important point. We do not just passively respond to visual stimuli that happen to fall on our retinas. Instead, we actively try to organize and make sense of what we see.

We turn now from a focus on the initial response to a stimulus (sensation) to what our minds make of that stimulus—perception. Perception is a constructive process by which we go beyond the stimuli that are presented to us and attempt to construct a meaningful situation.

**LO 1 The Gestalt Laws of Organization**

Some of the most basic perceptual processes can be described by a series of principles that focus on the ways we organize bits and pieces of information into meaningful wholes. Known as gestalt laws of organization, these principles were set forth in the early 1900s by a group of German psychologists who studied patterns, or gestalts (Wertheimer, 1923). Those psychologists discovered a number of important principles that are valid for visual (as well as auditory) stimuli, illustrated in Figure 2: closure, proximity, similarity, and simplicity.

Figure 2A illustrates closure. We usually group elements to form enclosed or complete figures rather than open ones. We tend to ignore the breaks in Figure 2A and concentrate on the overall form. Figure 2B demonstrates the principle of proximity: We perceive elements that are closer together as grouped together. As a result, we tend to see pairs of dots rather than a row of single dots in Figure 2B.

**Gestalt laws of organization** A series of principles that describe how we organize bits and pieces of information into meaningful wholes.

**LO 1** We do not just passively respond to visual stimuli that happens to fall on our retinas. Instead, we actively try to organize and make sense of what we see.

**Figure 2** Organizing these various bits and pieces of information into meaningful wholes constitutes some of the most basic processes of perception, which are summed up in the gestalt laws of organization. Do you think any other species share this organizational tendency? How might we find out?
Elements that are similar in appearance we perceive as grouped together. We see, then, horizontal rows of circles and squares in Figure 2C instead of vertical mixed columns. Finally, in a general sense, the overriding gestalt principle is simplicity: When we observe a pattern, we perceive it in the most basic, straightforward manner that we can. For example, most of us see Figure 2D as a square with lines on two sides, rather than as the block letter \(W\) on top of the letter \(M\). If we have a choice of interpretations, we generally opt for the simpler one.

Although gestalt psychology no longer plays a prominent role in contemporary psychology, its legacy endures. One fundamental gestalt principle that remains influential is that two objects considered together form a whole that is different from the simple combination of the objects. Gestalt psychologists argued that the perception of stimuli in our environment goes well beyond the individual elements that we sense. Instead, it represents an active, constructive process carried out within the brain (Humphreys & Müller, 2000; Lehar, 2003; van der Helm, 2006; see Figure 3).

**LO 2 ** Top-Down and Bottom-Up Processing

Ca- yo- re-d t-is -en-en-e, w-ic- ha- ev-ry -hi-d l-tt-r m-ss-ng? It probably won’t take you too long to figure out that it says, “Can you read this sentence, which has every third letter missing?”

If perception were based primarily on breaking down a stimulus into its most basic elements, understanding the sentence, as well as other ambiguous stimuli, would not be possible. The fact that you were probably able to recognize such an imprecise stimulus illustrates that perception proceeds along two different avenues, called top-down processing and bottom-up processing.

In **top-down processing**, perception is guided by higher-level knowledge, experience, expectations, and motivations. You were able to figure out the
meaning of the sentence with the missing letters because of your prior reading experience, and because written English contains redundancies. Not every letter of each word is necessary to decode its meaning. Moreover, your expectations played a role in your being able to read the sentence. You were probably expecting a statement that had something to do with psychology, not a recipe for meatloaf.

Top-down processing is illustrated by the importance of context in determining how we perceive objects. Look, for example, at Figure 4. Most of us perceive that the first row consists of the letters A through F, while the second contains the numbers 10 through 14. But take a more careful look and you’ll see that the “B” and the “13” are identical. Clearly, our perception is affected by our expectations about the two sequences—even though the two stimuli are exactly the same.

However, top-down processing cannot occur on its own. Even though top-down processing allows us to fill in the gaps in ambiguous and out-of-context stimuli, we would be unable to perceive the meaning of such stimuli without bottom-up processing.

Bottom-up processing consists of the progression of recognizing and processing information from individual components of a stimulus and moving to the perception of the whole. We would make no headway in our recognition of the sentence without being able to perceive the individual shapes that make up the letters. Some perception, then, occurs at the level of the patterns and features of each of the separate letters.

Top-down and bottom-up processing occur simultaneously, and interact with each other, in our perception of the world around us. Bottom-up processing permits us to process the fundamental characteristics of stimuli, whereas top-down processing allows us to bring our experience to bear on perception. As we learn more about the complex processes involved in perception, we are developing a better understanding of how the brain continually interprets information from the senses and permits us to make responses appropriate to the environment (Buschman & Miller, 2007).

LO3 Perceptual Constancy

Consider what happens as you finish a conversation with a friend and she begins to walk away from you. As you watch her walk down the street, the image on your retina becomes smaller and smaller. Do you wonder why she is shrinking?

Of course not. Despite the very real change in the size of the retinal image, you factor into your thinking the knowledge that your friend is moving farther away from you because of perceptual constancy. Perceptual constancy is a phenomenon in which physical objects are perceived as unvarying and consistent despite changes in their appearance or in the physical environment.

In some cases, though, our application of perceptual constancy can mislead us. One good example of this involves the rising moon. When the moon first appears at night, close to the horizon, it seems to be huge—much larger than when it is high in the sky later in the evening. You may have thought that the apparent change in the size of the moon was caused by the moon’s being physically closer to the earth when it first appears. In fact, though, this is not
the case at all: the actual image of the moon on our retina is the same, whether it is low or high in the sky.

Instead, the moon appears to be larger when it is close to the horizon primarily because of the phenomenon of perceptual constancy. When the moon is near the horizon, the perceptual cues of intervening terrain and objects such as trees on the horizon produce a misleading sense of distance. The phenomenon of perceptual constancy leads us to take that assumed distance into account when we view the moon, and it leads us to misperceive the moon as relatively large.

In contrast, when the moon is high in the sky, we see it by itself, and we don’t try to compensate for its distance from us. In this case, then, perceptual constancy leads us to perceive it as relatively small. To demonstrate perceptual constancy for yourself, try looking at the moon when it is relatively low on the horizon through a paper-towel tube; the moon suddenly will appear to “shrink” back to normal size (Coren, 1992; Ross & Plug, 2002; Imamura & Nakamizo, 2006). Perceptual constancy applies not just to size (as with the moon illusion) but to shape and color as well. For example, despite the varying images on the retina as an airplane approaches, flies overhead, and disappears, we do not perceive the airplane as changing shape (Redding, 2002; Wickelgren, 2004).

**LO 4** Depth Perception: Translating 2-D to 3-D

As sophisticated as the retina is, the images projected onto it are flat and two-dimensional. Yet the world around us is three-dimensional, and we perceive it that way. How do we make the transformation from 2-D to 3-D?

The ability to view the world in three dimensions and to perceive distance—a skill known as **depth perception**—is due largely to the fact that we have two eyes. Because there is a certain distance between the eyes, a slightly
different image reaches each retina. The brain integrates the two images into one composite view, but it also recognizes the difference in images and uses it to estimate the distance of an object from us. The difference in the images seen by the left eye and the right eye is known as binocular disparity.

To get a sense of binocular disparity for yourself, hold a pencil at arm's length and look at it first with one eye and then with the other. There is little difference between the two views relative to the background. Now bring the pencil just six inches away from your face, and try the same thing. This time you will perceive a greater difference between the two views.

The fact that the discrepancy between the images in the two eyes varies according to the distance of objects that we view provides us with a means of determining distance. If we view two objects and one is considerably closer to us than the other is, the retinal disparity will be relatively large and we will have a greater sense of depth between the two. However, if the two objects are a similar distance from us, the retinal disparity will be minor, and we will perceive them as being a similar distance from us.

In some cases, certain cues permit us to obtain a sense of depth and distance with just one eye. These cues are known as monocular cues. One monocular cue—motion parallax—is the change in position of an object on the retina caused by movement of your body relative to the object. For example, suppose you are a passenger in a

From the perspective of . . .
A Computer Game Designer What are some techniques you might use to produce the appearance of three-dimensional terrain on a two-dimensional computer screen? What are some techniques you might use to suggest motion?
moving car, and you focus your eye on a stable object such as a tree. Objects that are closer than the tree will appear to move backward, and the nearer the object is, the more quickly it will appear to move. In contrast, objects beyond the tree will seem to move at a slower speed, but in the same direction as you are. Your brain is able to use these cues to calculate the relative distances of the tree and other objects.

Similarly, experience has taught us that if two objects are the same size, the one that makes a smaller image on the retina is farther away than is the one that provides a larger image—an example of the monocular cue of **relative size**. The quality of the image on the retina also helps us judge distance. The monocular cue of **texture gradient** provides information about distance because the details of things that are far away are less distinct (Proffitt, 2006).

Finally, anyone who has ever seen railroad tracks that seem to join together in the distance knows that distant objects appear to be closer together than are nearer ones, a phenomenon called linear perspective. People use **linear perspective** as a monocular cue in estimating distance, allowing the two-dimensional image on the retina to record the three-dimensional world (Bruce et al., 1997; Dobbins et al., 1998; Shimono & Wade, 2002; Bruggeman, Yonas, & Konczak, 2007).

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**LO 5 Motion Perception: As the World Turns**

When a batter tries to hit a pitched ball, the most important factor is the motion of the ball. How is a batter able to judge the speed and location of a target that is moving at some 90 miles per hour?

The answer rests in part on several cues that provide us with relevant information about the perception of motion. For one thing, the movement of an object across the retina is typically perceived relative to some stable, unmoving background. Moreover, if the stimulus is heading toward us, the image on the retina will expand in size, filling more and more of the visual field. In such cases, we assume that the stimulus is approaching—not that it is an expanding stimulus viewed at a constant distance.

It is not, however, just the movement of images across the retina that brings about the perception of motion. If it were, we would perceive the world as moving every time we moved our heads. Instead, one of the critical things we learn about perception is to factor information about our own head and eye movements along with information about changes in the retinal image.

**LO 6 Perceptual Illusions: The Deceptions of Perceptions**

If you look carefully at the Parthenon, one of the most famous buildings of ancient Greece, still standing at the top of an Athens hill, you’ll see that it was built with a bulge on one side. If it didn’t have that bulge—and quite a few other “tricks” like it, such as columns that incline inward—it would look as if it were crooked and about to fall down. Instead, it appears to stand completely straight, at right angles to the ground.

The fact that the Parthenon appears to be completely upright is the result of a series of visual illusions. **Visual illusions** are physical stimuli that consistently produce errors in perception.
consistently produce errors in perception. In the case of the Parthenon, the building appears to be completely square, as illustrated in Figure 5A. However, if it had been built that way, it would look to us as it does in Figure 5B. The reason for this is an illusion that makes right angles placed above a line appear as if they were bent. To offset the illusion, the Parthenon was constructed as in Figure 5C, with a slight upward curvature.

The Müller-Lyer illusion (illustrated in Figure 6) has fascinated psychologists for decades. Although the two lines are the same length, the one with the arrow tips pointing inward (Figure 6A, right) appears to be longer than the one with the arrow tips pointing outward (Figure 6A, left).

Although all kinds of explanations for visual illusions have been suggested, most concentrate either on the physical operation of the eye or on our misinterpretation of the visual stimulus. For example, one explanation for the Müller-Lyer illusion is that eye movements are greater when the arrow tips point inward, making us perceive the line as longer than it is when the arrow tips face outward. In contrast, a different explanation for the illusion suggests that we unconsciously attribute particular significance to each of the lines (Gregory, 1978; Redding & Hawley, 1993). When we see the line on the right in Figure 6A, we tend to perceive it as if it were the inside corner of a room extending away from us, as illustrated in Figure 6C. In contrast, when we view the line on the left in Figure 6A, we perceive it as the relatively close outside corner of a rectangular object such as the building corner in Figure 6B. Because previous experience leads us to assume that the outside corner is closer than the inside corner, we make the further assumption that the inside corner must therefore be larger.

Despite the complexity of the latter explanation, a good deal of evidence supports it. For instance, cross-cultural studies show that people raised in areas where there are few right angles—such as the Zulu in Africa—are much less susceptible to the illusion than are people who grow up where most structures are built using right angles and rectangles (Segall, Campbell, & Herskovits, 1966).
As the example of the Zulu indicates, the culture in which we are raised has clear consequences for how we perceive the world. Consider the drawing in Figure 7. Sometimes called the “devil’s tuning fork,” it is likely to produce a mind-boggling effect, as the center tine of the fork alternates between appearing and disappearing. Now try to reproduce the drawing on a piece of paper. Chances are that the task is nearly impossible for you—unless you are a member of an African tribe with little exposure to Western cultures. For such individuals, the task is simple; they have no trouble reproducing the figure. The reason is that Westerners automatically interpret the drawing as something that cannot exist in three dimensions, and they therefore are inhibited from reproducing it. The African tribal members, in contrast, do not make the assumption that the figure is “impossible” and instead view it in two dimensions, a perception that enables them to copy the figure with ease (Deregowski, 1973).

Cultural differences are also reflected in depth perception. A Western viewer of Figure 8 would interpret the hunter in the drawing as aiming for the antelope in the foreground, while an elephant stands under the tree in the background. A member of an isolated African tribe, however, interprets the scene very differently by assuming that the hunter is aiming at the elephant. Westerners use the difference in sizes between the two animals as a cue that the elephant is farther away than the antelope (Hudson, 1960).

The misinterpretations created by visual illusions are ultimately due, then, to errors in both fundamental visual processing and the way the
brain interprets the information it receives. But visual illusions, by illustrating something fundamental about perception, become more than mere psychological curiosities. There is a basic connection between our prior knowledge, needs, motivations, and expectations about how the world is put together and the way we perceive it. Our view of the world is very much an outcome, then, of fundamental psychological factors. Furthermore, each person perceives the environment in a way that is unique and special (Knoblich & Sebanz, 2006; Repp & Knoblich, 2007).

**Figure 8** Is the man aiming for the elephant or the antelope? Westerners assume that the differences in size between the two animals indicate that the elephant is farther away, and therefore the man is aiming for the antelope. In contrast, members of some African tribes, not used to depth cues in two-dimensional drawings, assume that the man is aiming for the elephant. (The drawing is based on Deregowski, 1973.) Do you think Westerners, who view the picture in three dimensions, could explain what they see to someone who views the scene in two dimensions and eventually get that person to view it in three dimensions?

**Recap**

**Explain the gestalt laws of organization.**

- Perception is a constructive process in which people go beyond the stimuli that are physically present and try to construct a meaningful interpretation. (p. 108)

- The gestalt laws of organization are used to describe the way in which we organize bits and pieces of information into meaningful wholes, known as gestalts, through closure, proximity, similarity, and simplicity. (p. 108)
Identify top-down and bottom-up processing.
- In top-down processing, perception is guided by higher-level knowledge, experience, expectations, and motivations. In bottom-up processing, perception consists of the progression of recognizing and processing information from individual components of a stimulus and moving to the perception of the whole. (p. 109)

Define perceptual constancy.
- Perceptual constancy permits us to perceive stimuli as unvarying in size, shape, and color despite changes in the environment or the appearance of the objects being perceived. (p. 110)

Explain depth perception.
- Depth perception is the ability to perceive distance and view the world in three dimensions even though the images projected on our retinas are two-dimensional. We are able to judge depth and distance as a result of binocular disparity and monocular cues, such as motion parallax, the relative size of images on the retina, and linear perspective. (p. 111)

Relate motion perception to daily life.
- Motion perception depends on cues such as the perceived movement of an object across the retina and information about how the head and eyes are moving. (p. 113)

Determine the importance of perceptual illusions.
- Visual illusions are physical stimuli that consistently produce errors in perception, causing judgments that do not reflect the physical reality of a stimulus accurately. One of the best-known illusions is the Müller-Lyer illusion. (p. 113)
- Visual illusions are usually the result of errors in the brain’s interpretation of visual stimuli. Furthermore, culture clearly affects how we perceive the world. (p. 114)

EVALUATE

1. Match each of the following organizational laws with its meaning:
   a. Closure 1. Elements close together are grouped together.
   b. Proximity 2. Patterns are perceived in the most basic, direct manner possible.
   c. Similarity 3. Groupings are made in terms of complete figures.
   d. Simplicity 4. Elements similar in appearance are grouped together.

2. Processing that involves higher functions such as expectations and motivations is known as ________, whereas processing that recognizes the individual components of a stimulus is known as ________.

3. When a car passes you on the road and appears to shrink as it gets farther away, the phenomenon of ________ permits you to realize that the car is not in fact getting smaller.

4. ________ is the ability to view the world in three dimensions instead of two.

5. The brain makes use of a phenomenon known as ________, or the difference in the images the two eyes see, to give three dimensions to sight.

6. Match the monocular cues with their definitions.
   a. Relative size 1. Straight lines seem to join together as they become more distant.
   b. Linear perspective 2. An object changes position on the retina as the head moves.
   c. Motion parallax 3. If two objects are the same size, the one producing the smaller retinal image is farther away.
In what ways do painters represent three-dimensional scenes in two dimensions on a canvas? Do you think artists in non-Western cultures use the same or different principles to represent three-dimensionality? Why?

Answers to Evaluate Questions
1. a-3, b-1, c-2; 2. top-down, bottom-up; 3. perceptual constancy; 4. depth perception; 5. binocular disparity.

KEY TERMS
- Gestalt laws of organization p. 108
- Top-down processing p. 109
- Bottom-up processing p. 110
- Depth perception p. 111
- Visual illusions p. 113

looking BACK

Psychology on the Web
1. Select one topic of personal interest to you that was mentioned in this set of modules (for instance, cochlear implants, visual illusions). Find one “serious” or scientific Web site and one “popular” or commercial Web site with information about the chosen topic. Compare the type, level, and reliability of the information that you find on each site. Write a summary of your findings.

2. Are there more gestalt laws of organization than the four we’ve considered (closure, proximity, similarity, and simplicity)? Find the answer to this question on the Web and write a summary of any additional gestalt laws you find.
the case of . . .

THE CAUTIOUS PILOT

Captain Kevin Mueller has been flying private and commercial aircraft for almost 30 years. His flight from Boston to Dallas on the night of November 4 was as routine as any other; Mueller and his copilot had run through their preflight routine in the darkness of the cockpit and, after a 20-minute delay, were cleared for takeoff. Halfway through the flight, Captain Mueller noticed something unusual out of the corner of his eye: a point of light that was initially very faint but growing brighter. It stood out against the backdrop of terrestrial light sources because it appeared to be much closer, and possibly moving. Knowing that no other aircraft were operating in the area, Mueller focused his attention on the mysterious light source, concerned only with whether it might pose a threat to the safety of his passengers and crew.

When at last Mueller still couldn't make out what the mysterious object was after observing it for several minutes, he decided to take no chances. He rapidly increased altitude to put more distance between his aircraft and the object, which eventually faded from view and did not return. A later investigation could make no determination of what Mueller saw, but concluded that he acted appropriately to protect his passengers.

1. Why would Captain Mueller and his copilot sit in darkness before taking off on a night flight?

2. Why would the mysterious object have first appeared to Mueller in his peripheral vision?

3. What cues might Captain Mueller have used to determine that the mysterious object was much closer to his aircraft than any light source on the ground? Why might it have been difficult to determine whether the object was actually moving?

4. Even though many of the passengers were awake and looking out their windows, only Captain Mueller and his copilot noticed anything amiss. Why might the passengers have failed to notice the object when it was so obvious to the pilots?

5. Several of the passengers did, however, notice when Captain Mueller changed altitude despite having no visual cues as a reference. Describe the sense that allowed these passengers to detect the aircraft’s motion.
Sensing the World Around Us

- Absolute Thresholds: Detecting What's Out There
- Difference Thresholds: Noticing Distinctions between Stimuli
- Sensory Adaptation: Turning Down Our Responses

Vision: Shedding Light on the Eye

- Illuminating the Structure of the Eye
- Color Vision and Color Blindness: The Seven-Million-Color Spectrum