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Chapter 4

Sensation and Perception

Chapter Outline

One of my hobbies is making wine, and one observation I have made over my wine-making years is that wine drinkers often prefer certain wines, with the most common preference involving red versus white. The basic difference between red and white wine is that red wines are typically heartier and bolder in flavor, whereas white wines tend to have a smoother and lighter taste. If you drink wine, you might even be passionate in your preference for one over the other. Yet as famous wine critic Robert Parker has duly noted, evaluating wine is a subjective experience and can be influenced by "the emotion of the moment."

This subjectivity was dramatically demonstrated when French researchers asked 57 wine experts to evaluate what looked like two glasses of wine, one red and one white (Morrot et al., 2001). What the experts did not realize was that these two wines were the same white wine; one had simply been tinted red with food coloring. Did this color deception influence the wine experts' taste perceptions? Yes. None of the experts realize that the red-tinted wine was really a white wine, and they even tended to describe the "red" wine in language typically used to describe red wines, praising its "heartiness" or mentioning its "crushed red fruit."

In a follow-up experiment involving these same wine experts, the researchers selected an average-priced French wine and served it in two different bottles; one bottle had a fancy label associated with a high-priced French wine and the other bottle had a simple label associated with ordinary table wine. Even though the wine experts tasted the exact same wine in these two different bottles, their differing expectations for the wine from each bottle resulted in nearly opposite ratings. They tended to judge the "fancy" wine using such positive terms as "agreeable, woody, complex, balanced and rounded," while using such negative terms for the "ordinary" wine as "weak, short, light, flat and faulty." Most of the experts (70%) said the wine with the fancy label was worth drinking, while only 21% said the cheaply labeled wine was worth drinking.

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A wine's aroma and its taste both contribute to what we perceive as its flavor. This building up of a perceptual experience from various sensations is referred to as bottom-up processing. The fact that even wine experts can be fooled into perceiving white wine as red wine or inexpensive wine as high-priced wine due to their expectations is due to top-down processing.

These wine evaluation experiments suggest that even people who are considered experts can be fooled into misperceiving what their senses are telling them. In this chapter, we continue our journey of discovery in psychology by examining the two interrelated processes of *sensation* and *perception*. **Sensation** is the process that detects stimuli from our bodies and our environment, whereas **perception** is the process that organizes those stimuli into meaningful objects and events (Wolfe et al., 2012).

Normally, we experience sensation and perception as one process, but they can be distinguished. For example, look at Figure 4–1. Initially, you may have a hard time seeing anything meaningful—that is, you may sense different shapes but perceive no meaningful pattern. In fact, some of you will give up before organizing these visual sensations into a coherent set of objects. This process of building a perceptual experience from smaller pieces of information is known as **bottom-up processing**. In the brain, bottom-up processing involves data being relayed from lower levels of mental processing to higher levels of processing, from the bottom up (Lenartowicz et al., 2011). Bottom-up processing will be the primary focus of the first part of this chapter, when we examine sensory processes.

Sensation
The process that detects stimuli from our bodies and our environment

Perception
The process that organizes sensations into meaningful objects and events

Bottom-up processing
The idea that perception is a process of building a perceptual experience from smaller pieces of information

Figure 4–1 Sensation and Perception

Detecting the different shapes in this figure involves the process of sensation, but seeing a meaningful image involves the process of perception. Which process did you experience first, sensation or perception? Is this noticeable delay in sensory and perceptual processing a common occurrence in your everyday life?

Perception can also occur through **top-down processing**—where perception of the whole is based on our memories, experiences, and expectations, which shape our perception of smaller sensory features of a stimulus (Jensen & Mathewson, 2011). The wine experiments demonstrate top-down processing. When the wine experts tasted the "red" and "white" wines, and later the "fancy" and "ordinary" wines, their senses detected the same stimuli in each pair because in reality, the red and white wines were the same, as were the expensive and ordinary, but the way they organized this sensory information into their flavor perceptions was shaped by their expectations about what they were tasting. Top-down processing will be the primary focus of the second half of this chapter, when we examine perceptual processes. Look again at Figure 4–1. When informed that this assortment of black lines depicts a horse and rider, you are now more likely to perceive the expected image based on your past experience with similar images. Similarly, try to decipher the following sentence:

> Fou_sc_re an_ s_ven _ears ag_ o_r fa_hers s_t fo_th on th_s cont_n_nt a n_w na_ion, c_nce_ved _n Lib_rt_ a_d d_d_cated to th_ pr_p_sit_on th_t a_l men ar_ cre_t_d eq_al.

Can you read the preceding sentence with many letters missing? If perception was based simply on bottom-up processing, you shouldn't be able to understand this sentence. However, the fact that you probably were able to identify the first sentence of Abraham Lincoln's *Gettysburg Address* is due to top-down processing, where your perception of these missing-letter words was based on your understanding of both the English language and US history.

We begin our analysis of these two interrelated processes by examining some basic principles that apply to all sensory systems. Next we will discuss the six senses of *vision, audition* (hearing), *olfaction* (smell), *gustation* (taste), *touch,* and *proprioception* (the sense of body position and movement). From there, we will examine how the brain organizes sensations into perceptions.

Top-down processing
The idea that perception of the whole is based on our memories, experiences, and expectations, which shape our perception of smaller sensory features of a stimulus

4.1 Basic Principles of Sensation

Can you sometimes overhear others' quiet conversations when you are considerably distant from them? Do you sometimes "tune out" distracting sensations around you? These are the sorts of questions of interest to the field of **psychophysics**, the study of how physical stimuli are translated into psychological experience.

Psychophysics
The study of how physical stimuli are translated into psychological experience

4.1a Our Sensory Receptors Convert Energy from Stimuli into Neural Impulses

While typing this sentence, I am eating a handful of peanut M&M's®. I can hear their crunch while chewing, and I know that this sound is a response to vibrations in the air, or *sound waves.* I am also noticing a sweet taste, which I know is a response to the dissolving chemicals in my mouth. I can even faintly smell the aroma of chocolate, which is a response to molecules in the air that I am inhaling through my nose. I also feel the last three M&M's in my hand, which is a response to their physical pressure on my skin. Finally, I see that these remaining candies are colored red, blue, and brown, which is a response to the light waves reflecting from their surfaces.

One thing to understand about this experience—and others like it—is that sound, light, and other kinds of stimuli from our surroundings cannot travel through our nerves to the brain. Instead, our sensory receptors convert the energy from these various stimuli into neural impulses. This conversion process, which is a very basic aspect of bottom-up processing, is called **transduction**; it takes place at structures called *sensory receptors.* Following transduction, connecting neurons in the sensory receptors send this information to the brain. The brain then processes these neural impulses into what we experience.

Transduction
The process by which our sensory organs convert a stimulus's physical properties into neural impulses

One important fact to remember is that you can be aware of a stimulus in your environment only if you have sensory receptors that can transduce it. Human beings cannot see X-rays or hear very-high-frequency tones, and we cannot taste certain chemicals because we do not have sensory receptors that can convert these stimuli into neural impulses. These stimuli are just as real as those that we can transduce, but they are not a part of our sensory experience. Table 4–1 lists the stimuli and sensory receptors for each sense.

Table 4–1 The Stimuli and Sensory Receptors for Each Primary Sense

Sense	Stimulus	Sensory Receptors
Vision	Light waves	Light-sensitive rods and cones in the retina of the eye
Hearing	Sound waves	Pressure-sensitive hair cells in the cochlea of the inner ear
Taste	Molecules dissolved in fluid on the tongue	Taste cells in the taste buds of the tongue
Smell	Molecules dissolved in fluid on mucous membranes in the nose	Sensitive ends of olfactory neurons in the mucous membranes
Touch	Pressure on the skin	Sensitive ends of touch neurons in the skin

4.1b Our Senses Vary in Their Sensitivity Thresholds

German scientist Gustav Fechner (1801–1887), who was a pioneer in psychophysics, introduced the term **absolute threshold** to explain instances of detecting minimal stimuli (Fechner, 1966). An absolute threshold is the lowest level of intensity of a given stimulus that a person can detect half the time. Psychologists measure absolute thresholds by presenting a stimulus (for example, a light or a sound) to a person at different

Absolute threshold
The lowest level of intensity of a given stimulus that a person can detect half the time

intensities and determining what is the lowest level detectable 50% of the time. Some examples of absolute thresholds for various senses are listed in Table 4–2.

Table 4–2 Examples of Absolute Thresholds

Stimulus	Absolute Threshold
Vision	A candle seen at 30 miles on a dark, clear night
Hearing	The tick of a watch at 20 feet under quiet conditions
Taste	One teaspoon of sugar in 2 gallons of water
Smell	One drop of perfume diffused into a three-room apartment
Touch	The wing of a fly falling on your cheek from a distance of 0.5 inch

Source: Eugene Galanter, "New Directions in Psychology," 1962.

Several studies have found that the absolute threshold for a given sense varies between people (Rabin & Cain, 1986). For instance, due to the damaging effects that tobacco smoke has on nasal cavities, smokers or people regularly exposed to tobacco smoke have a less sensitive sense of smell than nonsmokers (Richardson & Zucco, 1989). As people age, their absolute thresholds for all senses increase, which means that greater stimulation is necessary to detect stimuli (Schiffman, 1997; Stevens, 1989).

The assumption underlying the absolute threshold concept is that there is a minimum intensity level at which a stimulus is consistently detected. However, according to **signal detection theory**, the detection of a stimulus is also influenced by the observer's decision-making strategy or criterion. Consistent with the notion of top-down processing, two important factors that shape this decision-making are (1) the observer's expectations about the probability that the stimulus will occur and (2) the rewards and costs associated with detecting or not detecting the stimulus (Harder et al., 1989). For example, suppose you were looking for shooting stars on a night when you mistakenly thought there was a meteor shower. Due to your false expectation, you probably would detect faint, fleeting flashes of light in the sky more often than if you expected no meteor shower. Detecting these flashes might also be affected by how important this task was to you. If astronomy were your favorite hobby, you might "see" more flashes than if stargazing were merely a lark.

Signal detection theory
The theory that explains how detection of a stimulus is influenced by observers' expectations

One major contribution of signal detection theory is that it points out that we do not have a single absolute threshold for a given sense. Whether or not we perceive a particular stimulus depends on the situation and what expectations and motives we bring to it. Such knowledge is important because many signal detection tasks carry life-and-death implications. Consider the task of a medical technician who is screening numerous X-rays every hour for possible signs of disease. Are those faint markings on the lungs normal, or do they indicate the early stages of cancer? Studies demonstrate that when people try to judge whether a faint stimulus is present or absent, their vigilance diminishes after about 30 minutes due to fatigue. Although such fatigue effects won't cause any serious consequences when looking for shooting stars, they could prove disastrous in the medical lab.

Besides detecting a weak stimulus, we often must detect changes in the intensity of a stimulus or discriminate between two similar stimuli. The smallest difference between two stimuli that can be detected half the time is known as the **difference threshold** (also called the *just-noticeable difference,* or *JND*). For example, what is the minimum amount of difference that you can detect in the sweetness of two soft drinks?

Difference threshold
The smallest difference between two stimuli that can be detected half the time; also called *just-noticeable difference,* or *JND*

Weber's law states that a weak stimulus does not require much change before a person notices that it has changed, but a stronger stimulus requires a proportionately greater change before it is noticed. When power-lifting, you would notice a weight difference after about 3% of the current weight is either added or taken away.

In 1834, Ernst Weber (1795–1878), Fechner's brother-in-law, discovered that the amount of change in stimulation necessary to produce a just-noticeable difference is a constant proportion of the original stimulus. The size of the difference threshold depends on the intensity of the stimuli being compared (Laming, 1985; Norwich, 1987). A weak or small stimulus does not require much change before you notice that the stimulus has changed, but a strong or large stimulus requires a proportionately greater change before you notice the change. For example, you will easily notice the weight difference when holding a 1-pound bag versus a 2-pound bag but will not notice a difference between a 100-pound bag and a 101-pound bag. According to **Weber's law**, to be noticed as different, two stimuli must differ by a constant minimum percentage rather than by a constant amount. The smallest noticeable change in weight is about 3%. Thus, you would need to add 2 more pounds to the 101-pound bag to reach the difference threshold.

Weber's law
The principle that to be noticed as different, two stimuli must differ by a constant minimum percentage rather than by a constant amount

As you can see from Table 4–3, the values of these proportions vary a great deal for the different senses. Although you can detect a change in sound frequency of 0.3% (one-third of 1%), it requires a 7% increase to detect a difference threshold in smell and a whopping 20% increase to detect a difference in taste! This means that your sense of hearing is much more sensitive than your sense of taste.

Table 4–3 Difference Thresholds: How Much Must a Stimulus Change to Be Noticeable?

Stimulus	Initial Stimulus	Change	Amount of Average Necessary Change
Sound frequency	3 Hz	.009 Hz	0.3%
Light brightness	700 lm	14 lm	2.0%
Weight heftiness	100 lbs.	3 lbs.	3.0%
Odor concentration	21 units	1.5 units	7.0%
Pressure intensity	50 units	7 units	14.0%
Taste concentration	100 units	20 units	20.0%

4.1c Our Sensory Receptors Adapt to Unchanging Stimuli

During my first year in graduate school, I attended City College of New York and rode the subway to school each day. At first, the noise was so distracting that I not only had difficulty reading but also, invariably, came home with a headache. Yet, within a few days, the subway noise seemed to diminish, and I was comfortably reading and headache-free when riding it. This example illustrates **sensory adaptation**, the tendency for our sensory receptors to have decreasing responsiveness to stimuli that continue without change. The most common explanation for sensory adaptation is that it is caused by our

Sensory adaptation
The tendency for our sensory receptors to show decreasing responsiveness to stimuli that continue without change

nerve cells firing less frequently after high levels of stimulation (Rajimehr et al., 2004; Yamaguchi et al., 2004).

From an evolutionary perspective, sensory adaptation makes sense. Animals that tune out constant unchanging stimuli that provide no new information should be better able to detect more useful information for survival. However, sensory adaptation is occasionally disadvantageous. For example, while tuning out subway noises increased my ability to study for exams, I sometimes didn't hear the conductor call out my stop, causing me to arrive late for class!

Auditory adaptation occurs much more slowly than adaptation to odors, tastes, and skin sensations (Scharf, 1983). For example, we adapt to smells very quickly, with the perceived magnitude of odor decay occurring at the rate of about 2.5% each second (Cain, 1978). Within 1 minute, odor adaptation is essentially complete, and the perceived magnitude of the smell is about 30% of the initial magnitude. We still smell it, but not as intensely. Try a little demonstration on yourself. Place a substance with a strong odor—perhaps some onion, perfume, or shaving lotion—near your nose for a few minutes. Its odor will seem less intense over time. Next, remove the substance for 5 minutes and then smell it again. Now it should smell as strong as it did when you first smelled it.

Review

- Stimuli must be transduced into neural impulses to be understood by the brain.
- Absolute threshold is the lowest level of intensity of a given stimulus that a person can detect half the time.
- According to signal detection theory, detection of a stimulus is influenced by both stimulus intensity and the observer's decision-making strategy.
- Difference threshold is the smallest difference between two stimuli that can be detected half the time.
- Sensory adaptation refers to our sensory receptors' decreasing responsiveness to an unchanging stimulus.

4.2 Vision

Because scientific inquiry has discovered more about the visual system than any of the other senses, I not only examine this sense first but also later use the visual system to explain the major principles of perception.

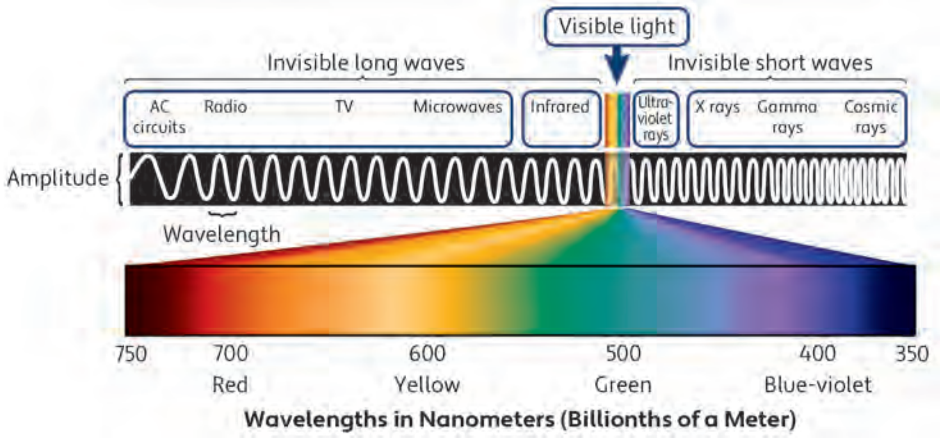
4.2a We See Only a Narrow Band of Electromagnetic Radiation

Light is a form of energy known as *electromagnetic energy.* This energy is all around us and travels in waves of different lengths and intensities, created by the vibration of electrically charged particles. A **wavelength** is the distance between two peaks of adjacent waves. Our eyes can detect the wavelengths of *visible light,* which range from 400 to 750 nanometers, with a nanometer being 1 billionth of a meter. Within this range of visible light, the colors we see are determined by the size of the wavelength (refer to Figure 4–2). The shorter wavelengths are experienced as violet, the intermediate ones as blue, green, and yellow, and the longer ones as red. Other forms of electromagnetic energy that our eyes cannot detect because they fall outside this 400- to 750-nanometer range are radio, infrared, ultraviolet, and X-ray radiation.

Wavelength
The distance between two peaks of adjacent waves

Figure 4–2 The Electromagnetic Spectrum

Humans sense only a narrow band of electromagnetic energy, ranging from 400 to 750 nanometers. Within this narrow band, light at different wavelengths is experienced as different colors.



4.2b Light Passes Through the Cornea, Pupil, and Lens Before Focusing on the Retina

Cornea
A clear membrane covering the front of the eyeball that aids in visual acuity by bending light that falls on its surface

Pupil
A hole in the center of the iris that regulates how much light enters the eye

Iris
A ring of muscles in the eye that range in color from light blue to dark brown

Light enters the eye through the cornea, a clear membrane covering the front of the eyeball (see Figure 4–3). The cornea bends the light falling on its surface just enough to focus it at the back of the eye. From the **cornea**, light passes through a pocket of fluid known as the *aqueous humor,* which carries oxygen and other nutrients to the cornea and lens. Next, light passes through a hole in the *iris,* called the **pupil**. The **iris** is a ring of muscles that functions much like the diaphragm of a camera. As illustrated in Figure 4–4, in dim light, muscle fibers in the iris dilate (open) the pupil, letting in more light; in bright light, the pupil constricts, letting in less light. Pupil size is affected not only by light. When you're psychologically aroused or interested in something, your pupils dilate (Hess, 1975).

Figure 4–3 Major Structures of the Human Eye

Light first passes through the cornea, pupil, and lens and is then focused on the retina at the back of the eye. The point of sharpest vision on the retina is the fovea.

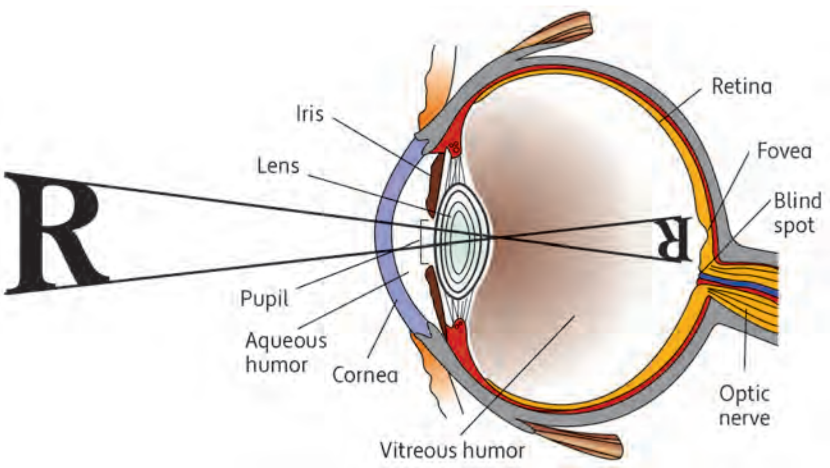
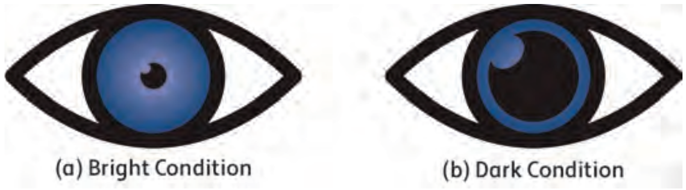


Figure 4-4 Light Adaptation by the Eye

The black spots in the middle of these two eyeballs show how small and large the pupil becomes when you are in bright light (a) and darkness (b).



After passing through the pupil, light enters a clear, elastic, disc-shaped structure called the **lens**, which refocuses the light with the aid of muscles attached to it. A clear image of distant objects is achieved by these muscles stretching and flattening the lens, while relaxing the lens and making it more spherical results in a clear image of near objects. Because the lens changes shape without any willful action, people often mistakenly assume that everything, near and far, is always in focus. To demonstrate to yourself that this is not the case, close one eye and look at a distant object; then, while still focusing on this object, begin moving a pencil toward you while paying attention to—but not focusing on—the pencil point. As the pencil gets closer, notice that the point becomes blurred and appears to be doubled. When the pencil is about 12 inches away, focus on the point; you will notice that the faraway object becomes blurred. As you move the pencil to within a couple of inches of your eyes, you will no longer be able to bring the point into focus because the lens has reached its maximum curvature and cannot get any fatter. This distance at which your lens can no longer accommodate and bring the pencil point into focus is called the *near point.* As you get older (past the age of 45), the distance of the near point will increase because aging causes a reduction in the elasticity of the lens.

Lens
An elastic, disc-shaped structure that focuses light

After being focused by the lens, light travels through the *vitreous humor,* which is a clear, jellylike liquid that occupies the space behind the lens, and is then projected onto a light-sensitive surface at the back of the eye known as the **retina**. As people age, the vitreous humor inside their eyes may thicken, causing tiny clumps of cells to form and float around. If you have these "floaters," you can see them; they look like specks, strands, webs, or other shapes. Actually, what you see are the shadows of these floating cells and fibers projected on the retina. One of the best ways to see floaters is to close your eyes while looking at a light source, and then watch for tiny strands, dots, or squiggles to float through your field of vision. A similar effect can often be achieved by keeping your eyes open and looking at a blank white background. In almost all cases, floaters are normal and perfectly harmless eye events. However, seeing floaters accompanied by flashes of light or peripheral vision loss could indicate a serious medical condition, such as diabetes, retinal hemorrhage, or the beginning stages of retinal detachment.

Retina
A light-sensitive surface at the back of the eye

Besides the minor annoyance of floaters, abnormalities in the cornea's outer membrane wall and abnormalities in the lens can affect *visual acuity,* which is the sharpness of the visual image at the retina. *Myopia,* or nearsightedness—decreased acuity for distant objects—occurs when the cornea and lens focus the image in front of the retina. In contrast, *hyperopia,* or farsightedness—blurred vision for near objects—occurs when the eye focuses the image on a point beyond the retina. These eye defects affect many people, but they can be easily corrected by wearing glasses or contact lenses that alter the eye's focus. More modern medical procedures, such as laser surgery, can also restore visual acuity by shaving off minute portions of the cornea and restoring proper curvature so that light striking the eye is bent correctly.

Rods
Receptor neurons in the eye located at the edges of the retina that are sensitive to the brightness of light

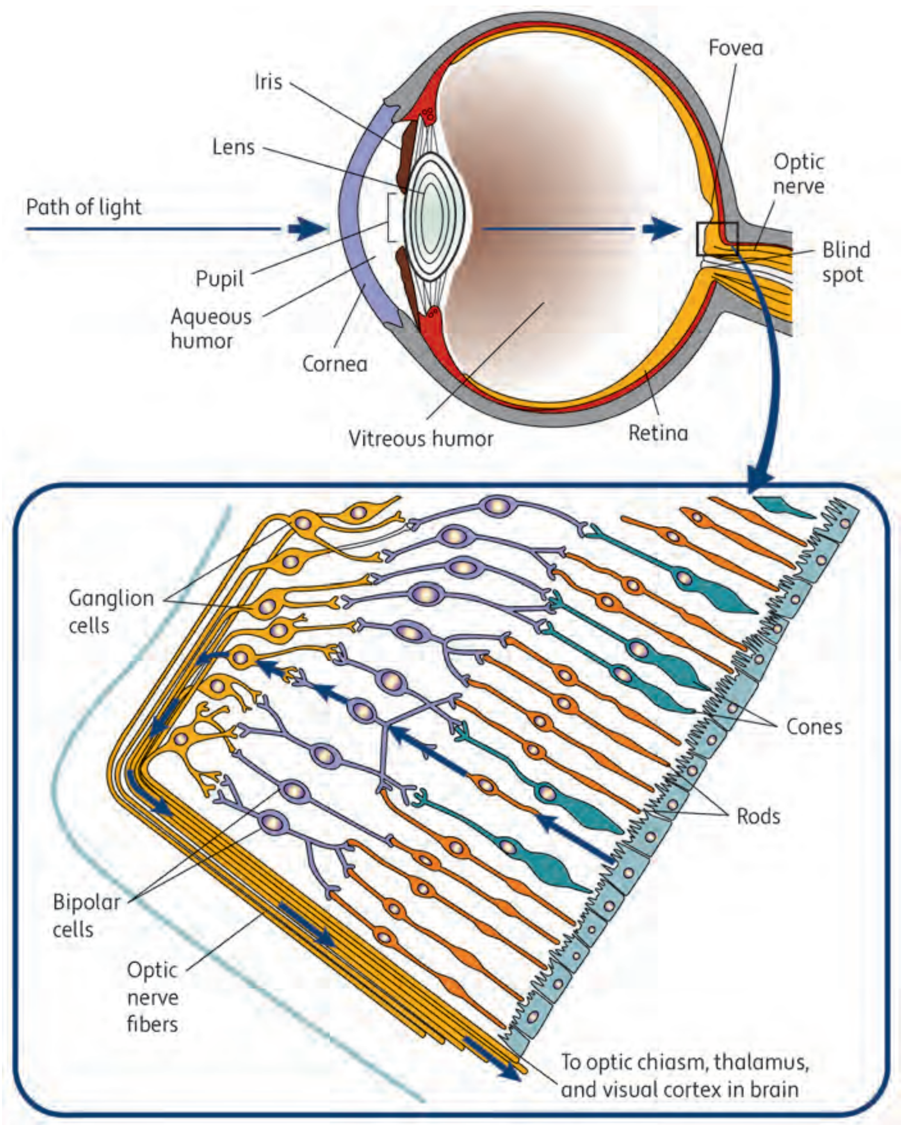
Cones
Receptor neurons in the eye, located near the center of the retina, which mediate color vision

Fovea
The retina's area of central focus

Returning to our discussion of the retina, would it surprise you to learn that it is actually a piece of the brain that migrates to the eye during early fetal development (Gregory, 1998)? Below its outer layer of cells resides a layer of sensory receptors, called *photoreceptors,* which convert incoming light into neural impulses (Greenstein et al., 2004). There are two basic kinds of photoreceptors: **rods** and **cones** (see Figure 4–5). The rods, located at the edges of the retina, are extremely sensitive to light and are central to the detection of patterns of black, white, and gray. The rods function best under low-light conditions and, thus, are most useful at night. In contrast to the rods, the cones require much more light to be activated and play a key role in color vision. Most cones are concentrated in a small area near the center of the retina known as the **fovea**, which is the area of central focus. A human retina contains about 125 million rods and 7 million cones (Pugh, 1988). As you would expect, animals that are most active at night, such as owls and rats, have all-rod eyes, whereas daytime animals, such as lizards and chipmunks, have mostly cone-dominant retinas (Tansley, 1965; Wagner, 2001).

Figure 4–5 How Light Travels Through the Eye

When light passes through the eye and falls on the retina, it passes through several layers of cells before striking and activating sensory receptors called photoreceptors. The two different kinds of photoreceptors are rods and cones. The rods detect patterns of black, white, and gray, whereas the cones play a key role in color vision. When activated, rods and cones send neural impulses to bipolar cells that, in turn, activate the ganglion cells (Chen et al., 2004). The axons of the ganglion cells converge to form the optic nerve, which sends information to the brain.



When light reaches the back of the eye and strikes the retina, it passes through several layers of cells below the retina's surface before reaching the rods and cones. Once activated by this light energy, the rods and cones generate neural signals that activate adjacent *bipolar cells,* which in turn activate neighboring *ganglion cells* (see Figure 4–5). The axons of the ganglion cells converge like the strands of a rope to form the **optic nerve**, which carries information from the retina to the brain. Before the information is sent on to the brain, however, a great deal of complex information processing takes place in the retina (Slaughter, 1990). This processing occurs in the bipolar and ganglion cells, where information from the rods and cones is integrated and compressed so that it can be more easily transmitted along the optic nerve.

When viewing a scene similar to this on a moonlit night, your world looks relatively colorless because only your rod photoreceptors are functioning under these low-light conditions. Your color-sensitive cone photoreceptors are not sufficiently stimulated by night light.

The portion of the retina where the optic nerve leaves the eye contains no rods or cones, which means that images falling there are not seen (Ramachandran, 1992). This area is called the **blind spot** in the field of vision. One reason you are not more aware of your blind spot is that when an image falls on the blind spot of one eye, it falls on the receptors of the other—thus you still detect the image. Another reason you don't often perceive the blind spot, even with one-eyed vision, is that it is located off to the side of your visual field; thus, objects near this area are never in sharp focus. Finally, perhaps the most important reason that you are not aware of the blind spot is that your visual system somehow "fills in" the place where the image disappears. Thus, when you try the blind spot demonstration in Figure 4–6, the place where the happy face used to be isn't replaced by a "hole" or by "nothingness" but rather by the white surrounding it.

Optic nerve
The bundle of nerve cells that carries information from the retina to the brain

Blind spot
The area on the retina where the optic nerve leaves the eye; contains no receptor cells

Figure 4-6 The Blind Spot

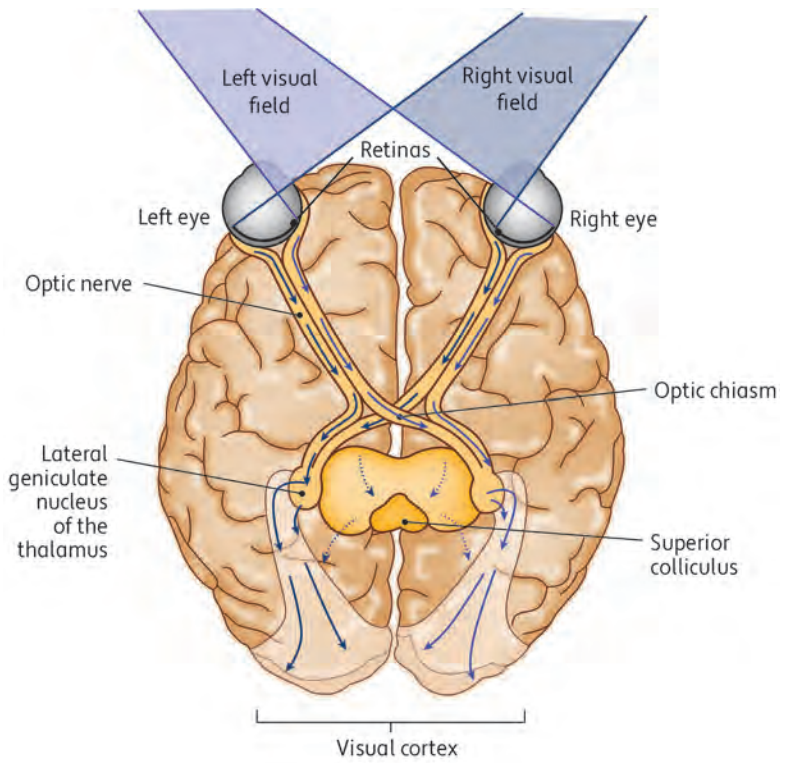
You can experience your own blind spot by closing your right eye and lining up the cross with your left eye. Slowly move your head back and forth. When the image is between 6 and 18 inches away from your eye, the image of the happy face falls on your blind spot and disappears from sight.

4.2c Visual Information Is Transmitted to Both Brain Hemispheres

After they leave the eyes, the axons of the ganglion cells that make up the optic nerve separate, and half of them cross to the other side of the head at the *optic chiasm* (pronounced "KYE-az-um"), which is at the bottom of the brain. As illustrated in Figure 4–7, the axons from the right side of each eye are connected to the right hemisphere of the brain and those from the left side of each eye are connected to the left hemisphere. Thus, visual information in a person's *left visual field,* which is the area to the left of the person, will go to the right hemisphere, while the exact opposite will be true for information in the person's *right visual field.* This splitting and crossing over of the optic nerve is important because it ensures that signals from both eyes go to both brain hemispheres.

Figure 4-7 The Brain's Visual Pathways

Information from the right half of the visual field strikes the left side of each retina and is sent by the optic nerve to the left cerebral hemisphere. Information from the left half of the visual field strikes the right side of each retina and is sent to the right cerebral hemisphere. After reaching the optic chiasm, a minor pathway goes to the superior colliculus in the midbrain, but the major visual pathway is to the lateral geniculate nucleus of the thalamus. From there, visual information is sent to the occipital lobe, or visual cortex (Dow, 2002).



A short distance after leaving the optic chiasm, the optic nerve fibers diverge along two pathways. Most of the nerve fibers (80%) are connected to the *lateral geniculate nucleus* of the thalamus, while most of the rest of the nerve fibers are attached to the *superior colliculus* in the midbrain. The superior colliculus is the evolutionarily older of the two brain structures and is the primary area for visual processing in less developed animals, like frogs. In humans, the superior colliculus is involved in controlling eye movements. In contrast to this more primitive brain structure, the lateral geniculate nucleus is a kidney-bean-shaped cluster of neurons that performs much more detailed visual analysis. Six different layers of cells in the lateral geniculate nucleus not only organize information about color and other aspects of the visual field reaching it from the retina but also create a "map" of visual space in the retina, where each location on the lateral geniculate nucleus corresponds to a location on the retina (Mollon, 1990).

From the lateral geniculate nucleus, visual information is sent to areas in the occipital lobe that make up the visual cortex. To understand how cells in the visual cortex communicate with one another, in the late 1950s, David Hubel and Torsten Wiesel placed microelectrodes in this area of a cat's brain to record action potentials from individual neurons. To stimulate action potentials, the researchers projected spots of light onto a screen with a slide projector, but they were initially unable to get the neurons to fire with any regularity. Then, quite by accident, as they were inserting a glass slide containing a spot stimulus into their projector, a neuron began firing like crazy. What Hubel and Wiesel discovered was that the rapid neural firing was in response, not to the image of the spot, but to the image of the straight edge of the slide as it moved downward on the projector screen! They proposed that cells in the visual cortex known as **feature detectors** respond only to a highly specific *feature* or characteristic of a visual stimulus, such as a straight edge, an angle, movement of a spot, or brightness (Hubel & Wiesel, 1965a, 1965b). This information is then passed on to other cells that in turn respond only to more complex features. Through this interaction among many types of visual neurons, each responsible for specific tasks, our brain is provided with the basic building blocks of visual perception that it then assembles into a meaningful whole (Hubel, 1996; Jiang et al., 2002; Rolls & Deco, 2002). This groundbreaking research by Hubel and Wiesel earned them the Nobel Prize in Physiology or Medicine in 1981.

Feature detectors
Cells in the visual cortex that respond only to a highly specific feature of a visual stimulus, such as a straight edge, an angle, movement of a spot, or brightness

4.2d Colors Are Created in Our Visual System

What does it really mean when we say that a leaf is green? Does the leaf actually possess the color we perceive? The answer is "no." An object appears as a particular color because it absorbs certain wavelengths of light and reflects others. The color green is not actually *in* the leaf, nor is it in the light waves reflected from it. Instead, the color resides in our own visual system. The leaf absorbs all the wavelengths of light except those that *evoke* the sensation of green in our minds. There is nothing inherently "blue" about short wavelengths or "red" about long wavelengths. These wavelengths are simply energy. Colors are *created* by our nervous system in response to these wavelengths.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Artists construct their paintings so that when light strikes them, the paintings' surfaces absorb certain wavelengths of light and reflect others. In our eyes, this light is converted into neural impulses and sent to the brain for further processing. Most of us can agree on the different colors that we see in our world because our visual systems operate in roughly the same manner.

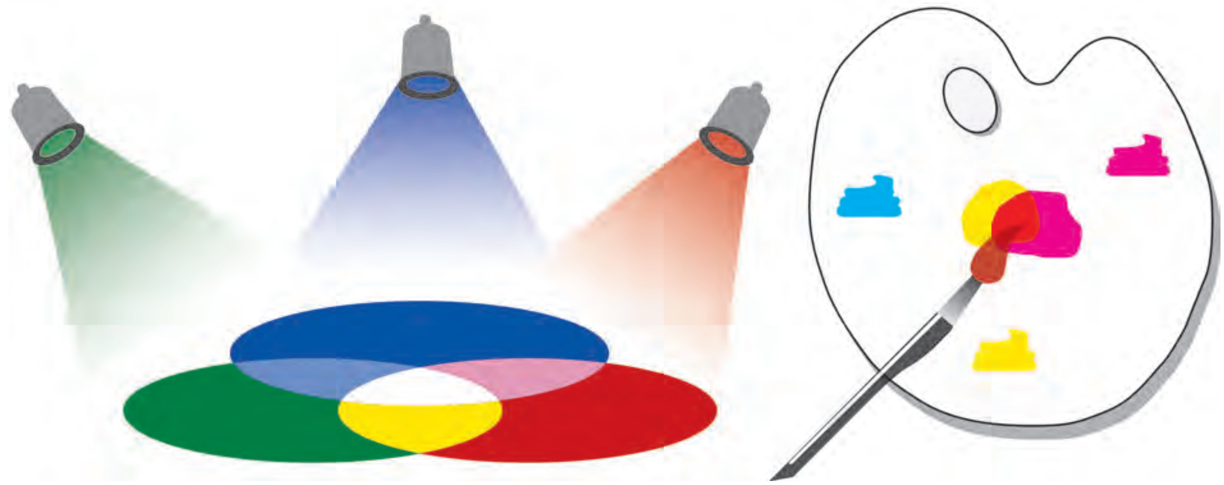
Because the experience of colors is created by the nervous system, species differ in what they see when looking at the same object (Smith et al., 2002). For example, although honeybees have *trichromatic* vision like us, their three kinds of color receptors are spread out over a much wider band of the spectrum than our own; thus, they are sensitive to light in the ultraviolet range (Menzel & Backhaus, 1989). Pigeons have color vision based on five kinds of receptors (*pentachromatic* vision)—thus they undoubtedly see the world differently than do we (Varela et al., 1993). Astonishingly, our difference threshold for colors is so low that the average person can discriminate about 2 million different colors (Abramov & Gordon, 1994; Gouras, 1991).

4.2e Both Trichromatic Theory and Opponent–Process Theory Explain Color Vision

Any color can be created by combining the light wavelengths of the three primary colors—red, green, and blue (Hunt, 1998). Combining red, green, and blue lights makes white light. This mixing of different light wavelengths is known as *additive color mixing* because the process adds wavelengths and thus increases light. In contrast, when you mix paint pigments, you are *subtracting* wavelengths from the reflected light. Each color you mix in absorbs (or subtracts) more wavelengths, resulting in fewer being reflected back. The colors that result when you mix pigments are different from the colors that result when you combine the primary colors of light. Magenta, cyan, and yellow are called the primary pigments. In *subtractive color mixing,* combining magenta, cyan, and yellow pigments results in no light waves being reflected—and you see black. Figure 4–8 illustrates these two types of color mixing.

Figure 4-8 Additive and Subtractive Color Mixing

(*Left*) The three primary light colors—red, green, and blue—combine to create all the other colors of light. Mixing light of different wavelengths involves *additive color mixing* because the process adds wavelengths and thus increases light. (*Right*) Mixing color pigments in paint involves *subtractive color mixing* because the process subtracts wavelengths of reflected light and thus decreases light. Magenta, cyan, and yellow are the primary pigments. Paint with any of these colors absorbs one primary color of light and reflects the other two.



Trichromatic theory
A theory of color perception proposing that three types of color receptors in the retina produce the primary color sensations of red, green, and blue

To explain how our visual system causes us to experience this color mixing, two 19th-century scientists—first, the English physician Thomas Young (1773–1829) and later the German physiologist Hermann von Helmholtz (1821–1894)—hypothesized that the retina has three types of color receptors and that differing sensitivities to the different light waves are associated with these three primary colors. According to what came to be called the Young–Helmholtz **trichromatic theory**, light of a particular wavelength stimulates these three types of receptors to different degrees, and the resulting pattern of neural activity among these receptors results in color perception (Finger & Wade, 2002).

More than 100 years after the trichromatic theory was offered as an explanation for color vision, George Wald verified the existence of three different types of cones in the retina (Brown & Wald, 1964; Wald, 1964), a discovery that earned him a Nobel Prize. As trichromatic theory proposed, each cone is most sensitive to a particular wavelength of light. Long-wavelength cones (L-cones) are most sensitive to wavelengths of about 555 nanometers, which are perceived as red. Middle-wavelength cones (M-cones) produce the sensation of green and are most sensitive to wavelengths of about 525 nanometers. Finally, short-wavelength cones (S-cones), which produce the sensation of blue, are most sensitive to wavelengths of about 450 nanometers. By combining different stimulation levels from these three kinds of cones, our visual system produces a multitude of different color sensations.

Self-Discovery Questionnaire 4–1

Are You Color-Blind?

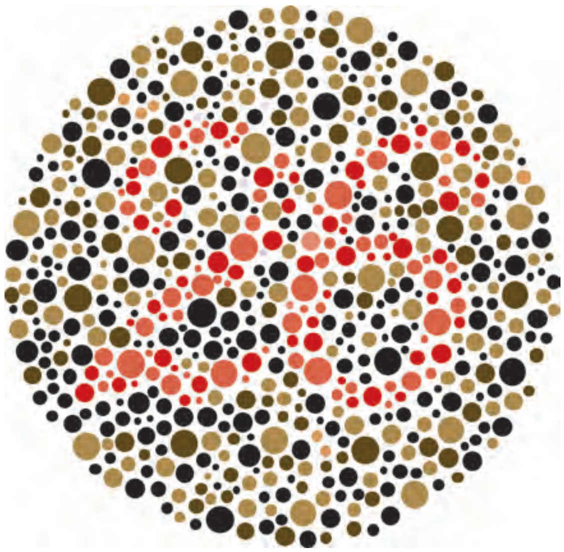


Figure 4–9 Color Blindness

In this test for red-green color blindness, a red 26 is presented against a background of green dots. People who are red-green color-blind do not perceive the number 26 but instead see only a random array of dots.

The trichromatic theory provides a partial explanation for **color blindness**, which is a deficiency in the ability to distinguish among colors (see Figure 4–9 in *Self-Discovery Questionnaire 4–1*). Approximately 1 in 50 people is color-blind, with about 90% of these being male because the defect is genetic and carried on the X chromosome. A male who inherits the trait on his single X chromosome will be color-blind, but a female must inherit the trait on both of her X chromosomes to be color-blind.

Color blindness
A deficiency in the ability to distinguish among colors

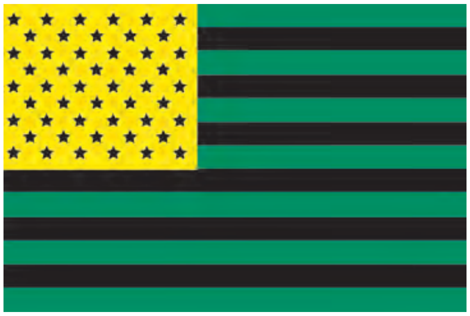
Actually, the term *color blindness* is misleading because most people classified as color-blind are *dichromats*—they can see two primary colors but are insensitive to the third because the cone that is sensitive to that color is nonfunctional (Gouras, 1991; Ladd-Franklin, 1929). In contrast, only about 10 people out of 1 million have the rare form of color blindness where they have no functioning cones. These *monochromats* see everything in shades of white, gray, and black. Thus, while the relatively rare monochromats are truly color-blind, *color deficiency* is a more accurate term to describe the much more prevalent dichromats.

Afterimages
Visual images that persist after a stimulus has been removed

Opponent-process theory
A theory proposing that color perception depends on receptors that make opposing responses to three pairs of colors

At roughly the same time that Helmholtz was championing the trichromatic theory, German physiologist Ewald Hering (1834–1918) proposed a competing theory. His ideas were sparked by the observation of **afterimages**, which are visual images that persist after a stimulus has been removed (Figure 4–10). Pointing out that the trichromatic theory could not explain this visual phenomenon, Hering proposed a theory that could—namely, his **opponent-process theory**. This theory argues that all colors are derived from three opposing color processes: black-white, red-green, and blue-yellow. The black-white opponent process determines the brightness of what we see, while the other two processes determine color perception. Stimulation of one color inhibits its opposing color. When stimulation stops, the opposing color is seen as an afterimage.

Figure 4-10 Afterimage
Gaze steadily for about a minute at the lower right corner of the yellow field of stars, and then look at the white space beside the flag. What do you see? The "Old Glory" you see is composed of the complementary colors in your visual system. Why do these colors reverse in this manner?



A century after Hering proposed his theory, research by Russell de Valois and his colleagues (1966) supported its basic propositions. After leaving the cones, visual information is processed in terms of the opposing colors by certain bipolar and ganglion cells in the retina and certain cells in the thalamus, which are collectively known as *opponent cells.* These opponent cells respond to light at one end of the spectrum with an increase in nerve firing and to light at the other end of the spectrum with an inhibition of spontaneous activity. Opponent cells that are inhibited from firing by a particular wavelength (which we experience as a particular color) produce a burst of firing as soon as that wavelength is removed. Similarly, cells that fire in response to a particular wavelength stop firing when that wavelength is removed (Zrenner et al., 1990). The result of this inhibition and firing of opponent cells is that we experience *negative afterimages* due to a "rebound effect" in opponent cells.

The best work of artists in any age is the work of innocence liberated by technical knowledge. The laboratory experiments that led to the theory of pure color equipped the impressionists to paint nature as if it had only just been created.

—Nancy Hale, US writer, 1908–1988

Opponent-process theory explains why people who are color-blind to red are also color-blind to green. The opponent-process cells responsible for perceiving red are also responsible for perceiving green. Thus, when these opponent cells are nonfunctional, a person cannot perceive red *or* green. The same is true for those opponent cells responsible for blue-yellow perception.

Although Hering formulated his theory in opposition to trichromatic theory, research indicates that *both* theories accurately represent the process of color perception, but at two different stages in the visual process. In the first stage of color processing, the trichromatic theory explains how the retina's red, green, and blue color-sensitive cone receptors match the wavelength of the light stimulus. In the second stage, the opponent-process theory explains how opponent cells in both the retina and in the thalamus of the brain are either stimulated or inhibited from firing by wavelengths of varying sizes. Put more simply, trichromatic theory explains most of the visual processing occurring in the eye, and opponent-process theory explains the processing occurring between the eye and the brain.

Review

- Light is a form of electromagnetic energy that passes through the cornea, pupil, and lens and then is projected onto the retina.
- Below the retina's surface reside two kinds of photoreceptors: rods, which function best under low-light conditions, and cones, which require much more light to be activated and play a key role in color vision.
- Rods and cones generate neural signals that activate adjacent bipolar cells, which activate ganglion cells.
- Behind the eyes, ganglion cell axons of the optic nerve separate, with half crossing to the other side of the head at the optic chiasm.
- Most optic nerve fibers run to the lateral geniculate nucleus, which performs detailed visual analysis.
- The experience of color is created by our nervous system in response to different wavelengths of light.
- Trichromatic theory explains most of the visual processing occurring in the eye.
- Opponent-process theory explains visual processing occurring between the eye and the brain.

4.3 Hearing

Stop reading for a minute, look around, and notice what your sense of vision tells you about your surroundings. Next, close your eyes, listen carefully, and notice what your sense of hearing, or **audition**, tells you.

Audition
The sense of hearing

When I did this exercise while looking around my den, I noticed my computer screen, my desk, a lamp, an antique clock, a phone, two windows, and many stacks and shelves of books and journal articles. When I closed my eyes and listened, my experience changed dramatically. Now I noticed the clock ticking, the computer fan whirring, the robins in our yard chirping, and the geese in the nearby woods honking. I also heard the soft rustle of my daughter's papers as she did her homework in the kitchen and the sound of a plane flying high overhead. Although these sensations were present when I looked around the room, I had not noticed them.

This exercise demonstrates that hearing is an important, though sometimes unrecognized, sense (Plack, 2005). From an evolutionary perspective, hearing was essential for our ancestors' survival, helping them detect the approach of predatory animals, locate food, and communicate with others (Nathan, 1982). Yet, how exactly does hearing take place?

4.3a Sound Waves Are the Stimuli for Hearing

Sound depends on a wave of pressure created when an object vibrates. The vibration causes molecules in an elastic medium—such as air, water, or solid material—to move together and apart in a rhythmic fashion. Like ripples on a pond, these pulsations move away from the vibrating object as **sound waves**, growing weaker as they travel farther from their source. Although sound waves weaken with increased distance, their speed remains constant, about 1,070 feet (or 330 meters) per second in air and about 4,724 feet (or 1,440 meters) per second in water. The number of sound waves that pass a given

Sound waves
Pressure changes in a medium (air, water, solids) caused by the vibrations of molecules

point in 1 second is the sound's *frequency*. Sound frequency is measured in *Hertz* (*Hz*), which is named after the 19th-century German physicist Heinrich Hertz (1857–1894). One Hz equals 1 cycle per second. The physical quality of sound frequency roughly corresponds to the psychological experience of *pitch*. Although people are most sensitive to sounds at frequencies between 2,000 and 5,000 Hz (Gulick et al., 1989), young adults can typically hear tones with frequencies as low as 20 Hz and as high as 20,000 Hz (Gelfand, 1981). As people age, their lower limit of hearing changes very little; however, the upper range falls steadily from adolescence onward.

The height of a sound wave is its *amplitude* and corresponds to the psychological experience of the loudness of a sound. Amplitude is measured in *decibels* (*dB*). The greater the amplitude is, the louder the sound, with perceived loudness doubling about every 10 decibels (Stevens, 1955). By definition, 0 dB is the minimal detectable sound for normal hearing. A whisper has amplitude of about 20 dB, normal conversation occurs at about 60 dB, and a jet aircraft taking off nearby has amplitude of about 140 dB. Exposure to sounds over 120 dB, such as a shotgun blast or a jet aircraft motor, can be painful and may cause hearing damage (Henry, 1984). Prolonged exposure to sounds over 90 dB—such as those found in industrial settings, subway trains, and rock concerts—can contribute to permanent hearing loss. Table 4–4 provides examples of some common sounds and their danger levels.

Table 4–4 Decibel Level of Some Common Sounds

Decibels	Source	Exposure Danger
180	Rocket launch	Hearing loss certain within 150 feet of launch pad
140	Shotgun blast, jet aircraft engine	Any exposure dangerous
120	Sandblaster, thunderclap	Immediate danger
100	Heavy auto traffic, lawn mower	2 hours or longer
60	Normal conversation	No danger
40	Quiet office	No danger
30	Quiet library	No danger
20	Soft whisper	No danger
0	Minimal detectable sound	No danger

One of the annoyances of modern-day living is widespread exposure to excess noise. Noise levels above 65 dB not only are irritating but can also cause sleep disturbances in all age groups and learning deficits in children (Bullinger et al., 1999). For example, in one study investigating the effects of aircraft noise on children's cognitive development, researchers tested German children living near the old and new sites of the Munich International Airport (Hygge et al. 2002). The impending closing and opening of the two airports located in different areas of the city provided researchers with the opportunity to observe how the exposure to and elimination of loud airport noise affected children's attention, reading ability, long-term memory, and speech perception. Children were tested three times: once before and twice after the airport switch-over. Following the switch, children living near the now-closed airport showed improvements in all four cognitive areas; children living near the new airport—where noise levels were now high—experienced deficits in all areas. These findings provide strong evidence that chronic exposure to noise levels above 65 dB can adversely affect children's cognitive development. It further suggests that these deficits can be reversed if children are removed from their noisy surroundings.

Most sounds are a combination of many different waves of different frequencies. This *complexity* corresponds to the psychological experience of *timbre.* Just as we can differentiate the sounds of different musical instruments because of the different frequencies of sound they blend together, we can also recognize the voices of different people over the telephone due to their unique sound-frequency blending. To experience a simple example of timbre perception, first clap your hands together while holding them flat, and then clap them again when they are cupped. Clapping with cupped hands produces a greater combination of low-frequency sound waves than clapping with flat hands—thus, it is a more complex sound.

Cochlea
The coiled, fluid-filled tube in the inner ear that contains the hairlike auditory receptors

Journey of Discovery

The amplitude of sound waves generated by mobile digital music players can get as high as 120 decibels, which is comparable to the sound level produced by a sandblasting machine. At these levels, you risk hearing damage after 7½ minutes of exposure. How do you know if your player is too loud?

4.3b The Auditory System Consists of the Outer Ear, Middle Ear, and Inner Ear

The evolution of the modern mammalian ear can be traced back to the primitive internal ears found in some types of fish that consist of a system of looping passages filled with fluid (von Békésy, 1960; Stebbins, 1980). Mammals, birds, and some reptiles have a more complex system of looping passages that contains a **cochlea** (pronounced COKE-lee-ah), a coiled, fluid-filled tube in the inner ear that contains hairlike auditory receptor cells. The ears of mammals have three small bones to transmit vibrations to the cochlea, whereas the ears of birds and reptiles have only one bone (Hackett & Kaas, 2003).

Franzoi

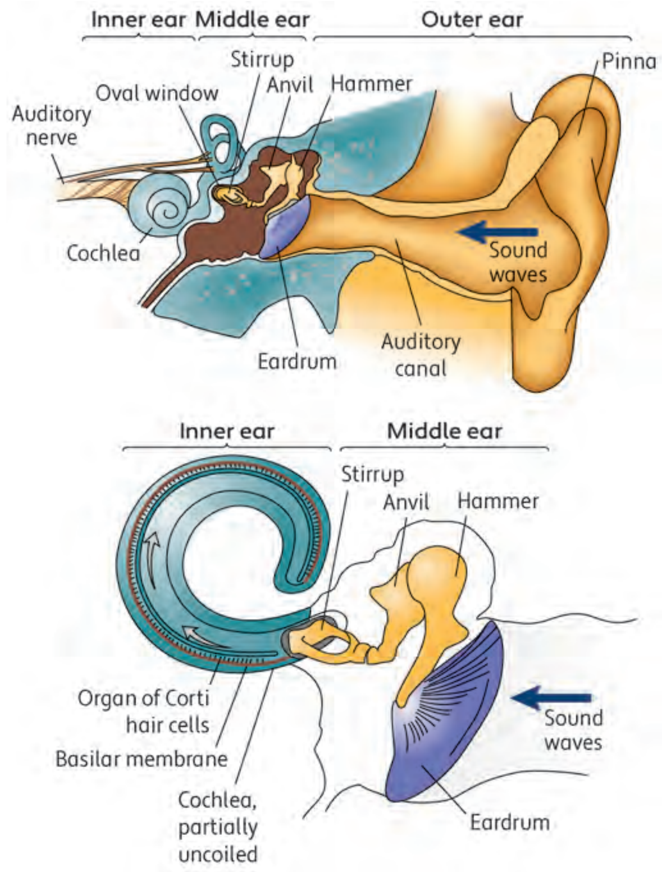
You hear a bell ringing because your ears respond to sound waves generated by the metal gong striking the bell's sides. How do the frequency, amplitude, and complexity of the sound waves generated by the bell affect what you hear?

Operation of the Ear

The ear can be divided into three major parts: the *outer ear, middle ear,* and *inner ear* (see Figure 4–11). The most visible part of the outer ear is the *pinna,* which is the skin-covered cartilage visible from the outside. Only mammals have pinnae. The funnel shape is useful for channeling sound waves to the other part of the outer ear, the *auditory canal.* This passageway is about an inch long, and as sound waves resonate in the auditory canal, their amplification is doubled.

Figure 4-11 The Human Ear

The outer ear directs sounds to the eardrum. From there, the bones of the middle ear (hammer, anvil, and stirrup) greatly amplify the sound through the oval window to the inner ear. The vibrations of the oval window cause pressure waves in the cochlear fluid, which, in turn, cause the basilar membrane to move, bending the hair cells on its surface. This stimulation triggers action potentials in the bundles of sensory neurons that form the auditory nerve, which then sends information to the brain.



Eardrum
A thin, flexible membrane at the end of the auditory canal that vibrates in sequence with sound waves

At the end of the auditory canal is a thin, flexible membrane, known as the **eardrum**, which vibrates in sequence with the sound waves. Beyond the eardrum is the middle ear. As the eardrum vibrates, it sets in motion those three tiny, interconnected bones—the hammer, anvil, and stirrup—known collectively as *ossicles*. The ossicles, which are the tiniest bones in the body, further amplify the sound waves two or three times before transmitting them to the liquid-filled inner ear.

The main parts of the inner ear are the *oval window, cochlea,* and *organ of Corti.* The stirrup is attached to the oval window, which is a thin membrane that transmits the sound waves from the stirrup to the cochlea. As mentioned earlier, the cochlea is a coiled, fluid-filled tube. The vibrations of the oval window cause pressure waves in the cochlear fluid. Running down the middle of the cochlea is a rubberlike membrane, known as the *basilar membrane,* which moves in a wavelike fashion in response to these pressure waves. Lying on top of the basilar membrane is the organ of Corti, which contains 16,000–20,000 receptors for hearing, called *hair cells.* When movement of the basilar membrane stimulates these hair cells, this stimulation triggers action potentials in bundles of sensory neurons forming the *auditory nerve,* which transmits auditory information to the brain. Which of the hair cells are stimulated determines which neurons fire and how rapidly they fire, and the resulting pattern of firing determines the sort of sound we hear.

Perceiving the Location of a Sound

The ability to locate objects in space solely based on the sounds they make is known as **sound localization**. People with only one functioning ear have difficulty accurately locating sounds. To experience this auditory fact, close your eyes and ask a friend to make a noise from somewhere in the room. Point to your friend's location and then open your eyes to determine your accuracy. Next, place your index finger in one ear and repeat this exercise. The reason two ears are better than one is that sounds coming from points other than those equidistant between your two ears reach one ear slightly before they reach the other. Sounds reaching the closer ear may also be slightly more intense because the head blocks some of the sound waves reaching the ear on the other side of the head (Getzmann, 2003). Because your ears are only about 6 inches apart, the time lag for the sound reaching the farthest ear is extremely short; thus, the difference in intensity is extremely small. Yet even such small differences provide your auditory system with sufficient information to locate the sound (Middlebrooks & Green, 1991; Phillips & Brugge, 1985).

Sound localization
The ability to locate objects in space solely on the basis of the sounds they make

4.3c Different Theories Explain Different Aspects of Pitch Perception

How does the auditory system convert sound waves into perceptions of pitch? Like our understanding of color perception, our current understanding of pitch perception is based on two theories that were once considered incompatible.

Place theory contends that we hear different pitches because different sound waves trigger the hair cells on different portions, or *places,* of the cochlea's basilar membrane. The brain detects the frequency of a tone according to which place along the membrane is most activated. Place theory was first proposed by Hermann von Helmholtz (1863), the codeveloper of trichromatic color theory, and later tested and refined by Hungarian scientist Georg von Békésy (1899–1972) (1947, 1957), who won a Nobel Prize for this work in 1961. High-frequency tones trigger the greatest activity at the beginning of the cochlea's basilar membrane, where the oval window is located, according to von Békésy's research.

Place theory
A theory that pitch is determined by which place along the cochlea's basilar membrane is most activated

When music fails to agree to the ear, to soothe the ear and the heart and the senses, then it has missed its point.

—Maria Callas, Greek soprano, 1923–1977

Although place theory explains how we hear high-frequency tones, it cannot account for how we perceive very low-frequency tones. The problem is that at very low frequencies, the entire basilar membrane vibrates uniformly; thus, no one place is more activated than another. One theory that can explain the perception of low-frequency tones is **frequency theory**, which was first proposed by English physicist Ernest Rutherford (1861–1937) in 1886. According to frequency theory, the basilar membrane vibrates at the same frequency as the incoming sound wave, which in turn triggers neural impulses to the brain at this same rate. Thus, a sound wave of 800 Hz will set the basilar membrane vibrating 800 times per second, which will cause neurons to fire at 800 times per second.

Frequency theory
A theory that pitch is determined by the frequency with which the basilar membrane vibrates

One important problem with frequency theory is that individual neurons cannot fire more than 1,000 times per second. Because of this fact, frequency theory cannot explain people perceiving sounds with frequencies above 1,000 Hz. A revision of frequency theory—namely, psychologist Ernest Wever's **volley theory**—contends that neurons work in groups and alternate firing, thus achieving a combined frequency of firing well above 1,000 times per second (Wever, 1949; Wever & Bray, 1937). Studies indicate that such alternate firing of groups of auditory nerves can generate volleys of up to 5,000 impulses per second (Zwislocki, 1981).

Volley theory
A theory of pitch stating that neurons work in groups and alternate firing, thus achieving a combined frequency corresponding to the frequency of the sound wave

Based on what we now know, it appears that place theory, frequency theory, and volley theory account for different aspects of pitch perception. Place theory best explains high-frequency sounds, whereas frequency theory can best explain the perception of low-frequency sounds. For sounds between 1,000 and 5,000 Hz, pitch perception seems to be best explained by volley theory, which is a revision of frequency theory.

4.3d There Are Two General Types of Hearing Impairment

Hearing impairment is one of the most common birth defects, occurring in about 3 in 1,000 newborns. Hearing loss that is present at birth is called *congenital hearing loss* (Yuan et al., 2024). Genetic factors are believed to cause about half of all congenital hearing-loss cases, but infections during pregnancy—such as rubella (German measles), herpes, or syphilis—are also known causes (Beasley & Amedee, 2001).

Millions of adults have some degree of hearing impairment, ranging from mild to severe. Because the process of loss is gradual, individuals who have this disorder may not realize that their hearing is diminishing. Older adults are the age group most affected by this condition, with high-pitched sounds being the most difficult to hear (Marcincuk & Roland, 2002). About 33% of adults between the ages of 65 and 75 have some degree of hearing loss, with this figure rising to at least 50% among those older than 75 (Bagai et al., 2006). Individuals who are hearing impaired may experience several of the following symptoms:

1. Conversations are difficult to understand, especially when there is background noise.
2. The higher pitches of women's voices are harder to hear than the lower pitches of men's voices.
3. Certain sounds seem annoying or overly loud.
4. A ringing, roaring, or hissing sound may occur in one or both ears.

The damage that causes hearing impairment involves defects in one or more areas of the auditory system (Beasley & Amedee, 2001). Abnormalities with the mechanical system that carries sound waves to the cochlea cause *conductive hearing loss.* These middle ear problems often involve a punctured eardrum or reduced functioning of the tiny bones making up the ossicles. Whatever the cause, the result is that the middle ear is less able to send sound waves to the inner ear. A common treatment for conductive hearing loss is digital hearing aids, which are tiny instruments worn just inside the outer ear. Hearing aids amplify vibrations for frequencies that are troublesome—usually high frequencies—and compress sound so that soft sounds are amplified. Because the effectiveness of these external hearing aids is sometimes diminished due to perspiration in the outer ear and noise distortion, implantable hearing aids employing more advanced technology are increasingly common. One such device consists of a micromagnet that is surgically placed on a segment of the tiny bones in the middle ear with an external sound processor that uses electromagnetic waves instead of air pressure to amplify volume (Hough et al., 2002).

The more common type of hearing impairment is *sensorineural hearing loss,* or *nerve deafness.* This condition involves a defect in the neural mechanisms that create nerve impulses in the inner ear or send them to the auditory cortex. Problems in the auditory cortex can also result in this type of hearing loss. Most sensorineural hearing loss occurs because hair cells in the cochlea are damaged by disease, injury, or aging (Oghalai, 2005). We are born with about 3,500 inner hair cells in the cochlea and about 12,000 outer hair cells , but the number gradually declines over time. Unlike birds and sharks that can regenerate lost hair cells, humans and other mammals do not have this ability.

Adobe Stock

Individuals with conductive hearing loss often wear digital hearing aids, which are worn just inside the outer ear. Implantable hearing devices are also available.

Currently, the only means of restoring hearing in some people with nerve deafness is a *cochlear implant,* which bypasses damaged or missing hair cells to send electrical signals through an array of electrodes within the cochlea (Gantz & Turner, 2003; Hallberg et al., 2005). The implant actually consists of three separate parts: headpiece, speech processor, and receiver. The headpiece contains a microphone and transmitter and is worn just behind the ear. It picks up sounds and sends them to the cell-phone-sized processor that fits in a pocket or is worn on a belt. The processor converts sounds into electronic signals that are sent to the receiver, which is a small disc about the size of a quarter that is surgically implanted as far into the cochlea as possible. The receiver sends the sound signals to the brain (Zwolan et al., 2020). About 740,000 people in the world have received cochlear implants, with costs ranging from $50,000 to $100,000. Young children born with hearing loss are the best candidates for this device, although some older adults with profound or severe hearing loss are beginning to receive these implants as well (Pisoni, 2008). Besides mechanical remedies, many people with hearing loss rely upon lip reading and sign language.

Researchers have discovered that susceptibility to age-related hearing loss is due to defects that develop in several genes, which, in turn, destroy inner-ear hair cells (Noben-Trauth et al., 2003). Studies with genetically modified mice and guinea pigs have found that deleting a specific gene permits the growth of new hair cells (Kawamoto et al., 2003; Sage et al., 2005). These findings provide invaluable insights into the genetics of hearing and increase the possibility that, in the future, medical science will be able to regenerate lost hair cells and thereby restore hearing in those suffering from nerve deafness (Leclère et al., 2024).

Review

- Frequency refers to the number of sound waves that pass a given point in 1 second, and corresponds to the experience of pitch.
- Amplitude is the height of a sound wave and corresponds to the experience of loudness.
- Complexity is the extent to which a sound is composed of different frequencies and corresponds to the experience of timbre.
- Sound localization is the ability to locate objects in space due to the sounds they make.
- Place theory best explains high-frequency sounds.
- Frequency theory best explains low-frequency sounds.
- Volley theory best explains intermediate sounds.
- Conductive hearing loss involves abnormalities in the mechanical system that carries sound waves to the cochlea.
- Sensorineural hearing loss, or nerve deafness, involves a defect in the neural mechanisms that create nerve impulses in the inner ear or send them to the auditory cortex.

4.4 Your Other Senses

Through natural selection, animals come to possess the sensory mechanisms they need to survive in their specific environment. This is why animals that inhabit similar environments have similar sensory mechanisms. Our own human senses share the most similarity to those species that are our closest cousins on the evolutionary tree, namely, other primates (Hodos & Butler, 2001). Like all primates, we primarily rely on our vision, with hearing being our distant second sense. These two sensory systems are classified as *higher senses* in humans, meaning they are extremely important to our survival. In contrast, the senses of taste, smell, touch, and proprioception are classified as *minor senses* because they are not considered as crucial to sustaining life.

4.4a Smell and Taste Represent "Far" and "Near" Chemical Senses

As life evolved from the sea to the land, two anatomically separate chemical sensory mechanisms developed. These two distinct senses—namely, taste and smell—came to serve different functions. The sense of taste became a "near" sense, providing the last check on the acceptability of food, while the sense of smell became a "far" sense, able to detect stimuli from a much farther distance.

Smell

Olfaction
The sense of smell

Olfactory epithelium
A thin layer of tissue at the top of the nasal cavity that contains the olfactory receptor cells

Olfaction is the sense of smell, and its stimuli are airborne molecules. When you smell fresh-brewed coffee (see Figure 4–12), you are sensing molecules that have left the coffee and traveled through the air to your nose. These molecules then enter your nasal passages and reach tiny receptor cells at the top of the nasal cavity. These olfactory receptors are located on a thin, dime-sized, mucus-coated layer of tissue known as the **olfactory epithelium**. The odor molecules from the coffee are then trapped and dissolved in the mucus of the epithelium, and this causes the olfactory receptor cells to transmit a neural impulse directly to the olfactory bulb at the base of the brain. From here, the signals are processed before being sent to the *primary olfactory cortex* located in the frontal lobes (Dade et al., 2002; McLean & Shipley, 1992). Olfaction is the only sensation that is not relayed through the thalamus on its way to the cortex. Once your brain has processed the airborne molecules, you appreciate the coffee's wonderful fragrance.

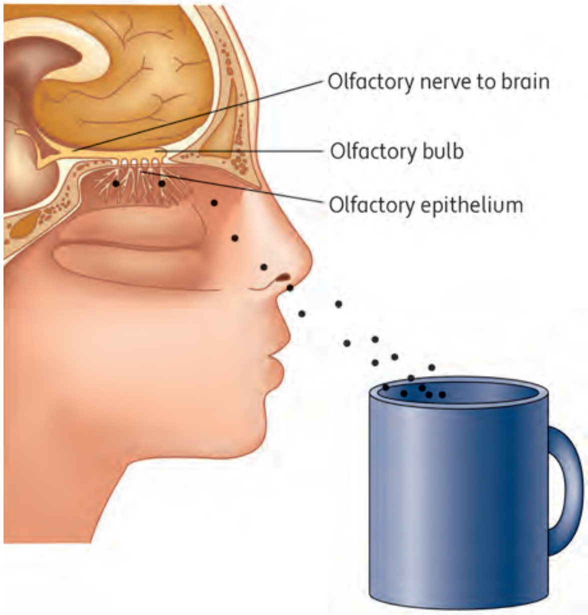
Info-Bit

Studies of various languages around the world reveal that between two-thirds and three-fourths of all words applying to the senses describe the two higher senses: vision and audition (Wilson, 1997).

Humans have about 400 different types of functioning olfactory receptor cells, with each type responding to only a limited family of odor molecules (DiLorenzo & Youngentob, 2003; Ressler et al., 1994). This large number of different types of receptors stands in sharp contrast to the three basic receptors involved in vision. Although we do not yet know exactly how the brain processes all the different types of olfactory information, scientists estimate that together these receptors allow us to distinguish among about 4,000 to 10,000 different smells (Malnic et al., 1999). The range of this smell estimate is so broad because no one has ever attempted to precisely measure the smells in the world that humans can detect (Gilbert, 2008).

Figure 4–12 The Olfactory System

Odor molecules in the air travel up the nasal passages to the receptor cells on the olfactory epithelium, where they are trapped and dissolved in the olfactory mucus. Receptor cells then send neural impulses to the olfactory bulb. From there, this information travels to the primary olfactory cortex in the frontal lobes.



Having so many types of olfactory receptors may mean that a great deal of the processing necessary for odor perception occurs in the nose itself. Despite the staggering number of odors that we can distinguish, for some unknown reason, we have a hard time correctly identifying and attaching names to specific odors. Thus, you may have a hard time correctly distinguishing the smell of smoke from that of soap.

Numerous studies indicate that we are drawn toward perfumelike fragrances, such as those of flowers and many food substances, and repulsed by foul and sulfurous odors (Miller, 1997b). This suggests that our olfactory systems evolved to help us distinguish things that are poisonous from those that are edible. Cross-cultural studies further suggest that the smells we pay most attention to are those that help us survive in our immediate surroundings (Classen et al., 1994). For example, the Dassanech people of southwestern Ethiopia are especially sensitive to the smells associated with their principal livelihood, raising cattle (Almagor, 1987). They identify the time of year by predictable changes in surrounding smells, such as the odors of decay and burning during the dry season and the fresh smell of new plant growth during the rainy season. Further, the smell of everything associated with cattle is considered good, and the Dassanech go out of their way to highlight those valued smells. Women smear liquid butter—*ghee*—on their bodies to ensure fertility and attract suitors, while men do the same with cow manure!

Olfactory sensitivity is substantially determined by the number of receptors in the epithelium. Animals with more receptors than other animals have much keener senses of smell. Whereas we humans have about 10 million olfactory receptors, dogs have an astounding 200 million receptors, putting us at the lower end of the scale of smell sensitivity. The olfactory systems of many animals also have specialized receptors to detect airborne chemicals known as **pheromones**, which are released by other members of the same species. Once detected, these pheromones directly affect the animals' behavior. Many species rely on pheromones to communicate their territorial boundaries, social status, and readiness to sexually reproduce (Luo et al., 2003).

Pheromones
Airborne chemicals that are released by animals and detected by other animals using specialized receptors and that affect the behavior of other animals of the same species

Do we humans emit and detect pheromones? If so, how might this shape our behavior? Brain scan studies have found that heterosexual women and homosexual men exhibit an involuntary sexual response in the brain's hypothalamus when exposed to the male pheromone *androstadien,* but this brain region is not aroused by the female pheromone *estratetraen* (Savic et al., 2005). A follow-up study with lesbian women found that their responses were similar to heterosexual men (Berglund et al., 2006). Despite such discoveries, scientists are still unsure about whether humans possess sexual attractant pheromones. Even if such substances exist, it is extremely unlikely that they will be found to have the sort of direct effect on sexual behavior that is found among many animal species because the human sexual response is much more complex than that of most other animals (see Chapter 9, Section 9.3). Rather than directly producing sexual attraction, it is much more likely that human sexual attractant pheromones would affect a person's mood and emotional states, which in turn would affect how the person interacts with other people.

Although human behavior is not as strongly shaped by olfactory information as the behavior of other species, we do have the ability to identify people by their olfactory cues. For example, based on the smell of breath, hands, and clothing, people are reasonably accurate in detecting another person's sex (Doty et al., 1982; Wallace, 1977). Further, at least one study has found that blindfolded mothers can identify with close to 95% accuracy the clothing worn by their own children by smell alone (Porter & Moore, 1981). Similarly, breastfeeding infants quickly learn to identify their mother's odor from that of other breastfeeding women (Porter, 1991). Although these studies suggest that humans as a group have a good deal of smell sensitivity, women's sensitivity is much higher than that of men—brain scans taken while people are smelling objects find that odors trigger more olfactory activation in women than in men (Yousem et al., 1999; Yousem et al., 2001).

Adobe Stock

Many people who were diagnosed with the COVID-19 virus experienced a temporary loss of smell.

Odors can also evoke memories and feelings associated with past events (Richardson & Zucco, 1989). For example, the smell of freshly cut grass or the scent of a specific perfume can mentally transport us back to a time in our lives when these odors associated with specific events.

As we age our sense of smell decreases, a condition known as *presbyosmia*, but this age-related problem is more common in men than in women; almost 25% of men in their 60s have a diminished sense of smell, while only about 10% of women do (National Institutes of Health: Senior Health, 2016). Although total loss of smell, or *anosmia*, is extremely rare, it is associated with certain respiratory infections. Recently, as many as 80% of people diagnosed with the COVID-19 virus—which is a respiratory infection—experienced a temporary loss of smell (and sometimes also a loss of taste).

Taste

Gustation
The sense of taste

Taste buds
Sensory receptor organs located on the tongue and inside the mouth and throat that contain the receptor cells for taste

As mentioned earlier, taste, or **gustation**, is a near sensation occurring when a substance makes contact with specialized receptor cells in the mouth and throat (Cacchione, 2008; Hellekant, 2024). About 50–150 of these receptor cells are contained in each of the 10,000 **taste buds** that are primarily located on the tongue. Some taste buds are also in the throat, on the insides of the cheeks, and on the roof of the mouth. The taste buds on the surface of the tongue are grouped together in structures called *papillae,* which in Latin means "pimple." Because of their constant contact with the chemicals they are designed to sense—as well as their exposure to bacteria, dirt, and dry air—the receptor cells wear out and die within 10 days. Fortunately, new cells emerge at the edge of the taste bud and migrate inward toward the center, replacing the old cells. Although this cycle of death and replacement of taste cells operates throughout our lives, it occurs more slowly in older adults, which is one reason their taste sensitivity becomes less acute (National Institutes of Health: Senior Health, 2016). But before you feel sorry for the older adults, if you are in your late teens or early 20s, you have already lost half the number of taste receptors that you had during early childhood. Children's greater number of taste buds may partly explain why they are often "fussy eaters."

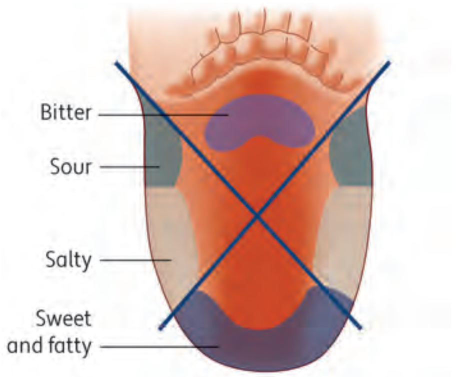
When these taste cells absorb chemicals dissolved in saliva, they trigger neural impulses that are transmitted to one of two brain areas. One pathway involves information first being sent to the thalamus and then to the primary gustatory cortex, where taste identification occurs. The second pathway leads to the limbic system and allows you to quickly respond to a taste prior to consciously identifying it, such as when you reflexively spit out sour milk (Sekuler & Blake, 1994).

In contrast to our olfactory system's ability to distinguish among about 10,000 different smells, our taste receptors can detect only a handful of taste sensations (Classen, 1993; Laing et al., 1993). The five most familiar taste sensations are sweetness (mostly sugars), sourness (mostly acids), saltiness (mostly salts), bitterness (mainly chemicals that have no food value or are toxic), and umami (a savory taste common in fermented and aged foods). However, most taste experiences are complex and result from the combined effects of receptor cells in the mouth and nose, which produce the different flavors you experience. Recently, a growing number of researchers contend that the unique taste of fat in food is another taste sensation, and they have named this possible sixth taste *oleogustus* ("oleo" is a Latin word for oily or fatty and "gustus" refers to taste). To qualify as a primary taste, a flavor needs to have a unique chemical signature and trigger specific receptors on our taste buds, which is the case for fat (Jaime-Lara et al., 2023). This possible sixth taste sensation is not a pleasant flavor (think of eating oxidized oil, not eating delicious, greasy pizza) and scientists speculate that this taste is more of a "warning system" for the human body.

Has anyone ever told you that the taste buds sensitive to sweetness are on the front of your tongue and the taste buds for saltiness and sourness are on the sides? If so, don't believe them. As depicted in Figure 4–13, this popular belief that the taste buds on different areas of the tongue detect different tastes is based on a mistranslation of a German paper that was written more than 100 years ago. To set the record straight, all your taste buds detect all taste qualities. Despite this fact, makers of expensive wine glasses still falsely claim that their different-shaped glasses will direct specific types of wine onto the areas of the tongue that will make that wine taste the best.

Figure 4–13 The Tongue Map Myth

Contrary to popular belief, different areas of the tongue are not more sensitive to one of the four primary tastes. All taste buds can detect all types of tastes.



Although the taste of a particular substance depends on whether one or more of the five basic taste sensations are activated, the flavor of this substance is a combination of both its smell and its taste (DiLorenzo & Youngentob, 2003). The important role that olfaction plays in the flavor experience was demonstrated by one study in which some research participants were allowed to both taste and smell substances placed on their tongues, while others were only allowed to taste them. Although over half the taste-smell participants were able to correctly identify chocolate, root beer, cherry, coffee, and garlic, less than 3% of the taste-only group could accurately identify those flavors (Mozell et al., 1969). To personally experience the role that olfaction plays in flavor perception, pinch your nostrils closed before approaching a particular food. Then, place the food in your mouth and swish it around while paying attention to the flavor. Next, release your nostrils, open your mouth slightly, and breathe in gently through both your mouth and your nose. You should experience a significant increase in the food's flavor.

Info-Bit

About 25% of people have a very large number of taste buds. These "supertasters" are extremely sensitive to bitter compounds, and they also perceive saccharin and sucrose as sweeter than other people do (Pickering & Robert, 2006). Due to this hypersensitivity, supertasters may face a higher cancer risk if they find broccoli and other veggies that carry cancer-preventing vitamins too bitter to stomach. On the positive side, supertasters' discriminating palates may lead to lower risk for obesity.

4.4b Touch Is Determined by the Skin Senses—Pressure, Temperature, and Pain

Every living thing has a "skin" of some sort that defines its boundaries with the environment, and every living thing has a sense of touch. Indeed, the average adult body has more than 2 square yards of skin receptors, making it the largest sensory organ. Our sense of touch is a combination of three skin senses: *pressure, temperature,* and *pain* (Klatzky & Lederman, 2008). Although the 5 million sense receptors in our skin consist of a variety of types, like our taste receptors, there is no one type of skin receptor that produces a specific sensory experience. Instead, it appears that the skin's sensory experiences are due to the pattern of stimulation of nerve impulses reaching the somatosensory cortex of the brain (Hsiao et al., 2003).

Info-Bit

Neuroscientists have identified a special set of thin nerves in humans that are especially sensitive to the soft touches generated by tender caresses and reassuring hugs—but not to rough touches, pinches, or jabs (Kirsch et al., 2018). These *affiliative touch* nerves stimulate the same brain areas activated by romantic love and sexual arousal and appear to provide the emotional aspects of touch. Researchers speculate that these nerves may have evolved to guide humans toward tenderness and nurturing behavior (Grandi & Bruni, 2023).

Pressure

The entire body is sensitive to pressure, but most of the cells in the somatosensory cortex are devoted to processing neural impulses coming from the fingers, lips, face, tongue, and genitals because these areas of the skin have the greatest concentration of receptors. That's why you are so much more sensitive to objects that come into contact with these skin areas than those contacting other regions.

Try the following exercise. First, touch your two index fingers together. Most people report about equal pressure intensity from both fingertips. Now lightly touch one fingertip repeatedly to your upper lip. Most people report sensations mostly on the lip and little or none from the fingertip. The reason your lip is more pressure sensitive than your finger when these two skin areas touch has to do with the relative lengths of their neural pathways to the brain. When touched simultaneously, neural impulses from the lip reach the brain 1 millisecond faster than those coming from the finger. Apparently, even when two places on the skin are being equally stimulated, the impulses that reach the brain first dictate where the sensation will be primarily experienced.

Temperature

The skin contains two kinds of temperature receptors, one sensitive to warm and the other to cold. In 1920, the structural psychologist J. Henry Alston discovered that the sensation of "hot" is triggered by the simultaneous stimulation of both the warm and the cold receptors (Alston, 1920). He demonstrated this phenomenon by intertwining two metal pipes, one containing cold water and the other containing warm water. When people grasped these two intertwined pipes, they quickly pulled away because they felt the sensation of intense heat. Of course, their skin was not actually scalded; Alston's unusual apparatus had simply fooled these people's brains into feeling intense heat. However, when you accidentally touch a hot stove with your fingers, the resulting sensation of intense heat in your fingers is correctly warning you about imminent harm to your skin.

Although temperature sensations depend on which type of receptor is stimulated, whether more warm or cold receptors are stimulated will depend on the difference between the temperature of the skin and that of the object you are feeling. This is why washing your hands in 60°F water feels warm when you come in from the cold but feels cool when in a hot environment.

Pain

In the spring of 2003, while 27-year-old Aron Ralston was solo canyoneering in Utah's Canyonlands National Park, an 800-pound boulder shifted and pinned his right arm to a 3-foot-wide canyon wall 60 feet above the ground. After 5 days of trying to free his arm, Aron decided that his only option was to cut off his pinned arm. "It occurred to me I could break my bones," Aron later said. "I was able to first snap the radius and then within another few minutes snap the ulna at the wrist and from there, I had the knife out and applied the tourniquet and went to task. It was a process that took about an hour." How was he able to cope with the blinding pain while cutting through his own flesh and bone? "I'm not sure how I handled it," Aron later said. "I felt pain and I coped with it. I moved on."

Aron Ralston amputated his own arm after it became pinned by a boulder while he was climbing canyon walls. His dramatic ordeal was depicted in the critically acclaimed 2010 movie, *127 Hours*, starring James Franco.

After freeing himself from the boulder, Aron fashioned a tourniquet around his partially severed limb, crawled through the canyon, and then rappelled to the canyon floor where he eventually was flown by helicopter to a nearby hospital. What is so remarkable about Aron's actions is that he performed self-surgery while ignoring all of his body's built-in defenses against the self-infliction of pain. Although pain is an unpleasant experience, it is important to survival because it serves as a warning system that signals danger and the risk of injury (Wall, 2000). In order to save his life, Aron had to largely ignore this sensory warning system.

Pain can also force people to cope appropriately with an injury by inducing them both to seek treatment and to be still to promote healing. The importance of this sense is dramatically demonstrated by those rare individuals who are born with insensitivity to pain due to improperly functioning nerve pathways that normally transmit pain signals to the brain (Sternbach, 1963). In one such case, a woman called Ms. C died at the age of 29 from massive infections caused by a lifetime of abrasion and unhealed injury (Melzack & Wall, 1982).

Pain is induced through tissue damage or intense stimulation of sensory receptors (Gatchel & Turk, 1999). Light that is too bright, noises that are too loud, or pressure that is too great will trigger the pain experience. Yet overstimulation can sometimes occur without eliciting pain, as demonstrated when you eat something that is too sweet for your sense of taste. The too-sweet substance has certainly overstimulated your taste receptors, but you feel no pain.

For we are born in other's pain, and perish in our own.

—Francis Thompson, English poet, 1859–1907

The sensation of pain appears to originate in *free nerve endings* in the skin, around muscles, and in internal organs. When intense stimuli cause cell and tissue damage, the damaged cells release chemicals—including a neurotransmitter called *substance P* (for pain)—that stimulate the free nerve endings, which in turn transmit pain signals to the brain (Beyer et al., 1991). People with the previously discussed rare disorder that makes them insensitive to pain have extremely low levels of substance P in or near the nerve endings (Pearson et al., 1982). Normal individuals do not experience pain in those areas of the body that have no free nerve endings, such as the cerebral cortex.

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When you hit your thumb with a hammer, you experience double pain. First, you feel a sharp, stinging pain caused by large-diameter nerve fibers (L-fibers) in the spinal cord that quickly transmit pain information to the brain. Second, you feel a dull or burning pain caused by small-diameter and slower-operating nerve fibers (S-fibers) in the spinal cord.

Two distinct peaks of pain are experienced upon suffering an injury, differing in quality and separated in time. For example, when you sprain your ankle or pound your thumb with a hammer, you experience what is known as *double pain* (Willis, 1985). The first is a sharp, stinging pain caused by large-diameter nerve fibers (called *L-fibers*) in the spinal cord that transmit pain information very quickly to the brain. The second is a dull or burning pain arising from small-diameter and slower-operating nerve fibers (called *S-fibers*) in the spinal cord. These small, slower-operating S-fibers transmit most pain signals (Coderre et al., 2003).

The most widely accepted theory of pain is Ronald Melzack and Patrick Wall's (1965) **gate control theory**, which proposes that the L-fibers and S-fibers open and close "gateways" for pain in the spinal cord. According to this theory, the fast-transmitting, large L-fibers not only carry information about sharp pain to the brain but also carry information about most other forms of tactile stimulation. Once their information is transmitted to the brain, they close the pain gate by inhibiting the firing of neurons with which they synapse. The thin, slower-transmitting S-fibers, which carry information about dull and burning pain to the brain, also synapse with these same neurons; thus, their pain information may arrive at a closed gate due to the faster operation of the L-fibers. When this happens, the pain information from the S-fibers cannot be sent to the brain.

Gate control theory
A theory of pain perception proposing that small and large nerve fibers open and close "gateways" for pain in the spinal cord

Gate control theory explains why rubbing, massaging, or even pinching a bruised or sore muscle can ease the pain. These actions activate the large and fast-transmitting L-fibers, which then close the pain gate to the stimuli transmitted by the thin and slower-operating S-fibers. Because most pain information is transmitted by the S-fibers, blocking these signals significantly reduces the pain experience. This also explains why placing ice on a sprained ankle eases pain. The ice not only reduces swelling but also, by triggering cold messages transmitted by the L-fibers, closes the gate on the S-fibers' pain signals.

Besides explaining normal pain, gate control theory can account for the type of pain that Aron and other amputees experience long after their limb has been removed. This *phantom limb pain* occurs when an amputee feels pain in a missing limb (Gagliese & Katz, 2000). How could Aron feel pain in his missing arm when the pain receptors in the skin no longer existed? According to gate control theory, when L-fibers are destroyed by amputation, the pain gates remain open, which permits random neural stimulation at the amputation site to trigger the experience of pain in the missing limb (Melzack, 1992).

Research indicates that the brain can also send messages to the spinal cord to close the pain gate, thus preventing pain messages from reaching the brain (Whitehead & Kuhn, 1990). In such instances, the brain's messengers are a class of substances known as *endorphins*. As discussed in Chapter 2, Section 2.1d, endorphins are the body's natural defense against pain and are released following an injury. The analgesic effects of endorphins helped Aron perform the self-surgery necessary to save his life, despite the pain it was causing him. Drugs such as morphine bind with endorphin receptors in the brain and greatly reduce the subjective experience of pain. Apparently, the ancient Chinese healing and pain-reducing technique of **acupuncture**, in which long, thin needles are inserted into the skin at specific points, stimulates the release of endorphins (Wang & Audette, 2008). Controlled clinical trials demonstrate that acupuncture is effective in alleviating pain caused by cancer, dental extractions, headaches, hemorrhoids, and degenerative arthritis (Backer et al., 2008; Chen et al., 2025). Similarly, a more modern pain-relief procedure, known as *transcutaneous electrical nerve stimulation (TENS),* electrically stimulates painful body regions and also stimulates the release of endorphins (Ögren et al., 2024). *Self-Discovery Questionnaire 4–2* discusses some psychological techniques for reducing pain.

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Acupuncture, which means "needle piercing," is the ancient Chinese medical practice of inserting very fine needles into the skin to stimulate specific areas in the body. Research suggests that acupuncture releases pain-reducing endorphins and is effective in easing pain.

Acupuncture
An ancient Chinese healing technique in which needles are inserted into the skin at specific points, stimulating the release of pain-reducing endorphins

One last point regarding touch sensation; with age there is increasing insensitivity to pressure, temperature, and pain (Martin, 2014). However, the ability to detect the roughness/smoothness or hardness/softness of objects does not diminish significantly with age (Bowden & McNulty, 2013). Although older adults are less sensitive to pain than younger adults, the actual experience of pain increases with age due to an increase in chronic pain.

Self-Discovery Questionnaire 4–2

Can You Use Psychology to Reduce Pain?

Brain scans of people experiencing pain suggest that their psychological response to pain is most associated with the frontal lobes of the cerebral cortex, which controls emotional expression and self-control (Duquette et al., 2008). More than any of our other senses, our experience of pain can be significantly influenced by a variety of psychological factors (Turk & Winter, 2006). For example, diverting people's attention away from painful stimulation to some other stimulus, such as soothing music or a pleasant image ("Imagine yourself on a warm, sunny beach") is an effective strategy to alleviate pain. Recognizing the benefits of distraction, dentists and other health-care workers provide music, videos, and a constant flow of conversation while performing painful procedures to divert a patient's attention away from the source of the pain.

Another psychological technique for reducing pain is to give someone a *placebo*, which is an inert substance that the person believes will produce a particular effect, such as pain relief. Studies indicate that up to 35% of patients with chronic pain get relief from taking placebos (Weisenberg, 1977). The reason these patients feel less pain is that, unlike those who do not experience relief, their brains produce higher levels of endorphins in response to the placebos. Quite literally, their brains are "fooled" into releasing pain-relieving chemicals because they expect pain relief from the fictitious drug in the placebos!

4.4c The Proprioceptive Senses Detect Body Movement and Location

Proprioceptive senses
Two additional sources of sensory information that detect body position and movement

In addition to the traditional five senses of vision, hearing, smell, taste, and touch, there are two additional sources of sense information, called **proprioceptive senses**, which detect body position and movement (Mercier et al., 2008). One type of proprioception, the *kinesthetic sense,* provides information about the movement and location of body parts with respect to one another. Kinesthetic information comes from receptors in muscles, joints, and ligaments (Gandevia et al., 1992). Without this feedback about where our body parts are located, we would have trouble performing any voluntary movement. You sometimes experience partial disruption of your kinesthetic sense when your leg "falls asleep" and you have trouble walking, or when a dentist numbs your jaw and talking and chewing become problematic.

Journey of Discovery

Based on what you know about your vestibular sense, why do you think it is difficult to walk in a straight line after spinning yourself around on a swing?

Another type of proprioception, the *vestibular sense* (or equilibrium), provides information on the position of the body in space—especially the head—by sensing gravity and motion (Highstein et al., 2004). Vestibular sense information comes from tiny, hairlike receptors located in the fluid-filled vestibular sacs and the semicircular canals of the inner ear, above the cochlea (refer back to Figure 4–10). Whenever the head moves, these receptors send messages through a part of the auditory cortex that is not involved in hearing, and this information helps us maintain our balance. Perhaps you recall how much fun it used to be—and maybe still is—to twirl yourself around on a swing at the park until you were silly with dizziness. What happened was that when you stopped twirling, the fluid in your semicircular ear canals and your vestibular receptors did not immediately return to a normal state; thus, you experienced the illusion of spinning while standing still. The vestibular imbalance caused by this twirling exercise is very similar to the vestibular imbalance caused by drunkenness. As people age, the functioning of the hairlike receptors in the inner ear declines, which can cause problems with balance and falling (Martin, 2014).

Review

- Humans have at least 100 different types of olfactory receptor cells, with each type responding to only a limited family of odor molecules.
- Most taste receptors are located on the tongue, in bumps called papillae.
- Humans detect five primary tastes: sweet, sour, salty, bitter, and umami.
- The skin is the largest sensory organ.
- Touch is a combination of three skin senses: pressure, temperature, and pain.
- Pain is induced through tissue damage or intense stimulation of sensory receptors.
- According to gate control theory, small and large nerve fibers open and close "gateways" for pain in the spinal cord.
- The following two proprioceptive senses detect body position and movement:
  - The kinesthetic sense provides information about the movement and location of body parts with respect to one another.
  - The vestibular sense provides information about the position of the body in space by sensing gravity and motion.

4.5 Perception

As defined at the beginning of the chapter, perception is the process that organizes sensations into meaningful objects and events. Yet one quirk in the evolution of our sensory systems is that the different types of sensory information (visual, auditory, smell, taste, and touch) are processed at slightly different speeds by different neural regions (Pafundo et al., 2016). Because of these speed processing differences, in order to create a unified representation of the external world, the brain automatically resynchronizes these sensory signals by waiting about a tenth of a second. This very slight delay in sensory processing means that perception is retroactive; that is, we have a delayed perception of the world. Beyond the fact that our perception of the world is very slightly "past tense," for some of our senses, such as taste and smell, the distinction between sensation and perception is so fine that it is virtually impossible to distinguish one from the other. For others, such as hearing and vision, psychologists have been able to make sufficiently clear distinctions between these two processes so that greater insight has been gained into how we assign meaning to sensory stimuli. Let's now examine this work.

4.5a Sensory Stimuli Are Organized into a Gestalt

In the summer of 1910 while gazing out the window of a moving train, Austro-Hungarian-born psychologist Max Wertheimer noticed that close, stationary objects (such as fences, trees, and buildings) appeared to race in the opposite direction of the train, while distant objects (such as mountains and clouds) seemed to slowly move along with the train. Wertheimer became so enthralled with understanding the psychological origins of what later came to be called *motion parallax* that he began conducting experiments that ultimately led to the development of a new school of thought in psychology, **Gestalt psychology**, which studies how the mind actively organizes stimuli into coherent wholes. According to Gestalt psychologists, our perceptions are to be understood, not as the mind passively responding to a cluster of individual sensations, but rather as the mind actively organizing sensory stimuli into a coherent whole, or **gestalt**.

Gestalt psychology
The approach to psychology that studies how the mind actively organizes stimuli into meaningful wholes

Gestalt
An organized and coherent whole

Form perception
The process by which sensations are organized into meaningful shapes and patterns

Figure–ground relationship
The Gestalt principle that when people focus on an object in their perceptual field, they automatically distinguish it from its surroundings

Form Perception

Form perception is the process by which sensations are organized into meaningful shapes and patterns. One basic rule of form perception, the **figure-ground relationship**, states that when people focus on an object in their perceptual field, they automatically distinguish it from its surroundings (see Figure 4–14). What they focus on is the *figure,* and everything else becomes the *ground.* For example, the words you are reading are the figures in your perceptual field, while the white surrounding the text is the ground. When there are not enough cues to reliably distinguish a figure from its ground, it is difficult to perceive the sought-after object. The blending of objects into their surroundings is the basic principle behind camouflage (Regan & Beverley, 1984).

Figure 4–14 Reversible Figure and Ground

Can you keep the "white vase" in mind without the "blue faces" intruding? Because the stimuli here are ambiguous, the figure-ground relationship continually reverses, changing what you perceive. This exercise nicely illustrates how the same stimulus can trigger more than one perception.

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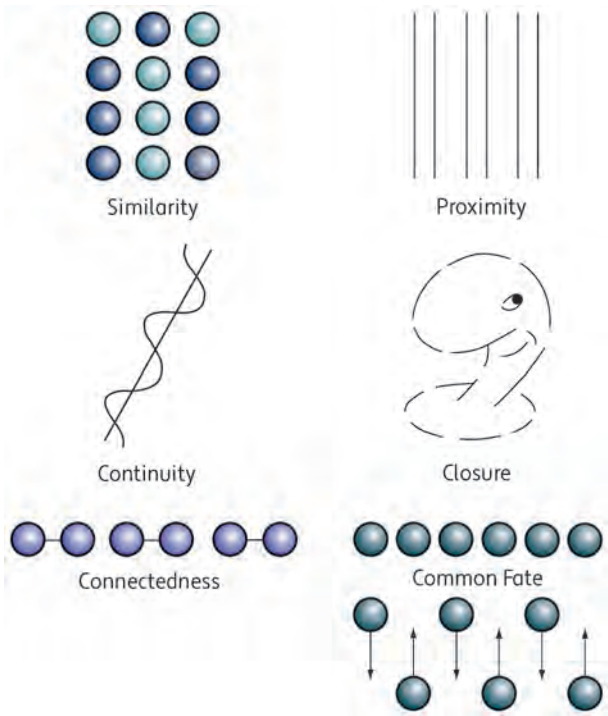
The figure-ground relationship applies to all the senses, not just vision. For example, I can distinguish the sound of my daughters' singing voices against the ground of the rest of the school chorus, the taste of cinnamon in pumpkin pie, and the smell of barbecued chicken at a county fair. In all instances, I perceive one object as the figure and the other sensory information as the background.

Once we distinguish figure from ground, we must next organize the figure into a meaningful form. To give meaning to these sensations, Gestalt psychologists identified the following additional principles, known collectively as the **laws of grouping** (see Figure 4–15), that describe how people group discrete stimuli together into a meaningful whole:

Laws of grouping
Simple gestalt principles describing how people tend to group discrete stimuli together into a meaningful whole

- *Similarity* We group together stimuli that are similar.
- *Proximity* We group nearby stimuli together.
- *Continuity* We perceive the contours of straight or curving lines as continuous, flowing patterns.
- *Connectedness* We perceive objects that are uniform and linked as a single unit.
- *Closure* We close the gaps in a figure and perceive it as a whole.
- *Common Fate* We perceive objects moving together in the same direction (sharing a "common fate") as belonging to a single group.

Figure 4-15 Gestalt Laws of Grouping
There are many ways to perceive the objects shown here, but people tend to organize them into groups based on specific perceptual "laws."



Depth Perception

In addition to organizing sensations into meaningful shapes and patterns, another aspect of visual perception involves organizing sensations in terms of the distance they are from us. To judge distance, our brains must transform the two-dimensional images that fall on our retinas into three-dimensional perceptions. This ability to perceive objects three-dimensionally is known as **depth perception** and depends on the use of both *binocular cues* and *monocular cues* (Jacobs, 2002).

Depth perception The ability to perceive objects three-dimensionally

Binocular cues are depth cues that require information from both eyes. Because our eyes are about 3 inches apart, they receive slightly different images on their retinas when looking at the same scene. This degree of difference between the two images—which is greater when objects are closer to us—is known as the binocular cue of retinal disparity. Our brains automatically fuse these two images into one and use the cue of *retinal disparity* to judge the distance of objects (Genovesio & Ferraina, 2004). You can

Binocular cues Depth cues that require information from both eyes


Franzoi

In the late 1800s, photographers created stereo pictures that mimicked the slightly different images seen by the two eyes. When viewers looked into a stereoscope, each eye saw only one of the two images and perceived a three-dimensional view of the scene. The stereoscope provided solid evidence that the visual system treats retinal disparity as a depth cue, regardless of whether the disparity is produced by real or simulated images of a scene.

see the difference between the views of your eyes by holding both forefingers vertically in front of you, one at 6 inches and the other at arm's length. Now, alternately close each eye while looking at both fingers. Notice that the closer finger appears to move farther side to side than the farther finger. If you focus on one finger with both eyes, you will see two images of the other finger. Stereoscopes and 3-D movies create the illusion of depth by presenting to each eye slightly different views of the same image.

Another binocular distance cue is *convergence,* which is the degree the eyes turn inward as an object gets closer. By receiving information on the angle of convergence from the muscles of your eyes, your brain automatically calculates the distance at which you are focusing. The eyestrain you experience after staring at a near object for a long time, such as a book or computer screen, is caused by continuous convergence (Tyrrell & Leibowitz, 1990).

While binocular cues result from both eyes working together, **monocular cues** are depth cues that require information from only one eye. Some of the more important monocular cues—some of which are illustrated in Figures 4–16 and 4–17—are as follows (Andre & Owens, 2003):

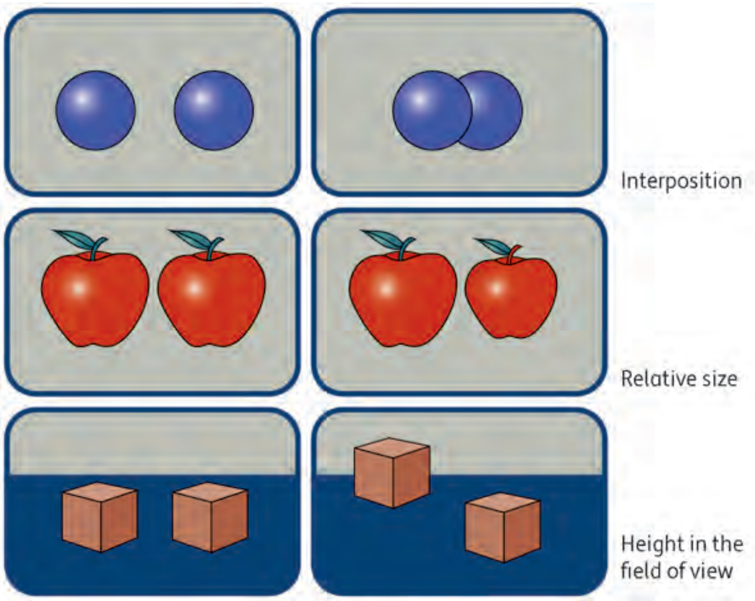
Monocular cues
Depth cues that require information from only one eye

- *Interposition* When one object partially blocks our view of another, we perceive the partially obscured object as more distant.
- *Familiar size* When we see a familiar object, we perceive it as near or distant based on the size of its retinal image. Familiar objects that cast small retinal images are perceived as distant, while familiar objects that make large retinal images are perceived as near.
- *Relative size* If we assume that two objects are similar in size, we perceive the object with the larger retinal image as being closer.
- *Height in the field of view* When we see objects, those closer to the horizon are perceived as farther away. This means that objects on the ground (below the horizon) are perceived as farther away when higher in our field of view, while aerial objects (above the horizon) are perceived as farther away when lower in our field of view. This depth cue is also called *relative elevation* or *relative height.*
- *Texture gradients* When we see a change in the surface texture of objects from coarse, distinct features to fine, indistinct features, we perceive increasing distance.
- *Atmospheric blur* When we see objects that appear hazy, we perceive them as farther away than sharp, clear objects. This cue is also called *atmospheric perspective* or *aerial perspective.*
- *Linear perspective* When we see the converging of what we assume are parallel lines, we perceive this convergence as indicating increasing distance.
- *Light and shadow* When objects reflect more light to our eyes than other objects, we perceive the brighter objects as closer to us. Further, when we see different degrees of light and shadow on a single object, this provides clues

about the object's orientation relative to us and its three-dimensional shape. This cue is also called *relative brightness.*

- *Motion parallax* When we move our head sideways, objects at different distances appear to move in different directions and at different speeds.

Figure 4-16 Monocular Cues
Monocular cues are depth cues that require information from only one eye. Close one eye and test this depth perception principle for yourself.



The monocular cue of *motion parallax* deals with movement (Ichikawa & Saida, 2002). *Parallax* means a change in position, so motion parallax is a change in the position of an object caused by motion. It was Wertheimer's attention to this perceptual phenomenon that led to the founding of Gestalt psychology. The next time you ride in a car, bus, or train, experience what Wertheimer experienced by focusing on a distant object to your side. Notice how the speed and direction of motion depend on distance. Closer objects appear to speed by in the opposite direction of your own movement, while farther objects seem to move more slowly and in your same direction. It is this motion parallax that causes many children to believe that the moon or clouds they see through their side windows are actually following them.

The eye sees only what the mind is prepared to comprehend.

—Henri Bergson, French philosopher, 1859–1941

When artists use monocular cues to create a three-dimensional look in their paintings, the monocular cues are called *pictorial cues* (Zimmer, 2006). Prior to the Renaissance, which occurred in Europe from the 14th through the 16th centuries, artists did not understand how to use the full range of monocular cues. As a result, their paintings often looked two-dimensional and unrealistic. Figure 4–18 depicts a painting by the 20th-century Indiana artist Norman Badgley Wilson that utilizes several pictorial cues to convey varying degrees of depth in a country scene.

What we see depends mainly on what we look for.

—Sir John Lubbock, English naturalist, 1834–1913

Figure 4-17 **The Monocular Cues of Texture Gradients, Atmospheric Blur, Linear Perspective, and Light and Shadow**

(a) Due to texture gradients, objects are perceived to be more distant as their surface texture becomes less distinct. (b) Due to atmospheric blur, objects that appear hazy are judged to be farther away than sharp, clear objects. (c) Due to linear perspective, we perceive the converging of seemingly parallel lines as indicating increasing distance. (d) The relative brightness cue suggests that when an object reflects more light to our eyes than another object, the brighter object must be closer.

Franzoi

(a)

Franzoi

(b)

Franzoi

(c)

Franzoi

(d)

Figure 4-18 **Monocular Cues in a Painting**

Several monocular cues are evident in this painting by Indiana artist Norman Badgley Wilson. Can you identify where Wilson has used the monocular cues of interposition, familiar size, texture gradients, and atmospheric blur to depict three dimensions on the flat surface of his canvas?

Norman Badgley Wilson, *Cattle in a Landscape*, 1930, oil on canvas, 24 × 36 inches

Perceptual Constancy

Thus far, you have learned how we organize sensations into meaningful shapes and patterns, and how we also organize them in space. A third aspect of perceptual organization involves **perceptual constancy**, which is the tendency to perceive objects as relatively stable despite continually changing sensory information. Once we form a stable perception of an object, we can recognize it from almost any distance, angle, and level of illumination.

Perceptual constancy The tendency to perceive objects as relatively stable despite continually changing sensory information

There are various forms of perceptual constancy. *Color constancy* is the tendency to perceive objects as having consistent color under different conditions of illumination (Lotto & Purves, 2002). Research indicates that color constancy works best when an object is surrounded by objects of many colors, suggesting that our brain perceives color partly based on computations of the light reflected by an object relative to the light reflected by surrounding objects (Pokorny et al., 1991). *Size constancy* is the tendency to perceive objects as stable in size despite changes in the size of their retinal images when we view them from different distances. This form of perceptual constancy explains why you don't perceive people approaching you from a distance as little people who are mysteriously growing in stature before your eyes. Likewise, *shape constancy* is the tendency to perceive an object as the same shape no matter from what angle we view it. Thus, when you look at your hand, this book, or a door from different angles, you still perceive it as retaining its original shape despite changes in the shape of its retinal image.

4.5b Perceptual Sets Shape Interpretations of Sensory Stimuli

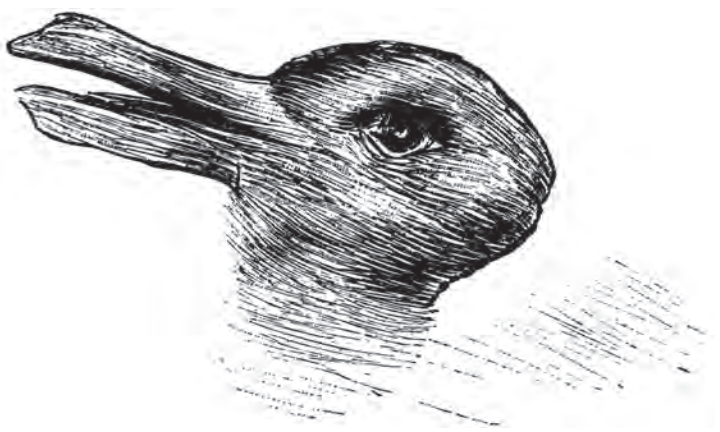
Just as expectations can influence whether we detect the presence of a stimulus (refer back to Section 4.1a), the expectations we bring to a situation can also influence *how* we perceive the stimulus object. These expectations, known as **perceptual sets**, create a tendency to interpret sensory information in a particular way due to top-down processing. For example, look at the drawing of the duck in Figure 4–19 and then read the figure caption. Based on your initial expectation of seeing a duck, you most likely organized the stimuli in this drawing so that your expectation was realized. Now ask a friend to look at this same drawing (cover up the caption) but tell them to "look at the rabbit." This is a demonstration of how people can develop different perceptions of the same stimuli based on the situational contexts that create different perceptual sets.

Perceptual sets Expectations that create a tendency to interpret sensory information in a particular way

Figure 4–19 What Kind of a Duck Is This?

Now that you have seen the duck, look again at this drawing, but now see the rabbit.

From Fliegende Blätter, 1892, via Wikimedia



Perceptual set can also be influenced by culture. For example, look at Figure 4–20(a). Most of you will see a rather confusing pattern of black shapes that may look somewhat like a boot. However, when you look at Figure 4–20(b), most of you readily perceive the word FLY in the white spaces. Your experience with the English language causes you to focus attention on the white spaces of Figure 4–20(b), while the black regions serve as background. Yet, if you were Chinese, you would readily perceive the white spaces in Figure 4–20(a) as depicting the Chinese calligraphic character for the word FLY, and it would be Figure 4–20(b) that would likely look confusing (Coren et al., 1987).

(a)

(b)

Figure 4-20 Cultural Influence on Perception
(a) Why does this figure appear to be a confusing pattern of black figures to most English-speaking Westerners, but not to people who are familiar with Chinese?
(b) Why is the exact opposite probably true for this figure?

Perceptual sets can certainly influence how we interpret stimuli in our world, as was demonstrated in our chapter-opening wine expert's story. Similarly, as a cost-saving measure during White House parties, former President Richard Nixon occasionally instructed waiters to refill empty bottles of fine and expensive wine with cheaper and lower-quality brands. Nixon was counting on the expensive bottle's label to create a perceptual set of fine taste in his guests. Later brain scan studies found that when people tasted $5 wine but were told that it cost $45, the area of their brains responsible for pleasant experiences became more active and they rated the wine tastier than when they drank the same wine but were told its true $5 price (Kringelbach et al., 2003). These findings demonstrate that expectations, or top-down processing, can influence taste experience and associated neural activity. The psychological phenomenon of perceptual set is yet another illustration that what we perceive is much more than just a matter of detecting sensory stimuli in the world, or bottom-up processing—perception also has to do with what's going on in our minds, or top-down processing.

4.5c Inattention Can Cause Us to Not Perceive a Highly Visible Object

A frequently reported phenomenon in traffic accident reports involving an automobile and a motorcycle is the car driver claiming that they "looked but failed to see" the motorcyclist before turning in front of them. Because motorcycles are much less commonly seen on our roads than cars or trucks, such accidents—as well as car-deer accidents—may often be caused by **inattentional blindness**, which is the failure to notice a fully visible, but unexpected object because attention was engaged on another task, event, or object (Mack & Rock, 1998). The experience of looking without seeing something directly in our field of vision is most likely to occur during moments of intense concentration on other stimuli. During these moments, even though our eyes are open and the object before us is imaged on our retinas, we seem not to perceive it.

Inattentional blindness
The failure to notice a fully visible, but unexpected object because attention was engaged on another task, event, or object

Inattentional blindness is another example of how perception is much more than just a matter of detecting sensory stimuli in the world, or bottom-up processing. In one dramatic demonstration of inattentional blindness, researchers asked participants to watch a video of people passing basketballs and counting the passes made by players wearing white shirts while ignoring the passes made by players wearing black shirts (Simons & Chabris, 1999). As participants watched the video and attentively counted the passes made by the players wearing white, a person in a gorilla suit entered the scene, walked between the players passing the basketballs, stopped and faced the camera, thumped its chest, and then exited the scene. Immediately after viewing the video and giving their "passing count," participants were asked if they had seen the gorilla. Approximately half of them said "no" and were astounded when the video was replayed so they could clearly see that the gorilla had been present while they were focused on the basketball passes (see a video of this study at http://www.dansimons.com/videos.html). In another study, a research confederate approached people on a public street and asked them for directions (Simons & Levin, 1998). While these unsuspecting individuals were answering the confederate's query, two workers carrying a large door passed between them. During the few moments in which the participant's view was obscured, a second confederate stepped in to replace the original confederate. Only half the participants noticed the change.


Adobe Stock

How might inattentional blindness partly explain the high motorcycle accident rate involving other motor vehicles?

Inattentional blindness highlights how our perceptions are influenced by *selective attention*, which is the focused awareness on a single stimulus to the exclusion of all others (see Chapter 5, Section 5.1a). In our everyday living, it is often critically important for us to remain focused on important aspects of our world without distraction from irrelevant objects and events. Only when those unattended aspects of our world are both unexpected and important does inattentional blindness pose problems for us (Simons, 2007). This and other research demonstrate that we often are unable to perceive unexpected objects to which we aren't paying attention, and it raises a host of related questions. For example, how much visual input can we encode and consciously—and unconsciously—perceive? What brings some visual objects to conscious awareness, while others remain unnoticed? As scientists address these questions in their research, the insights they gain will not only increase our understanding of how the visual system works, it will also hopefully yield practical benefits for human performance in areas such as driving and aviation where inattentional blindness can be fatal.

However, no two people see the external world in exactly the same way. To every separate person a thing is what he thinks it is—in other words, not a thing, but a think.

—Penelope Fitzgerald, British author, 1916–2000

4.5d Perceptual Illusions Represent a Misperception of Physical Reality

Because perception depends on how the perceiver interprets sensory stimuli, errors or misperceptions are bound to occur (Glover & Dixon, 2002). For example, have you ever been sitting behind the driver's wheel of a parked car when the car parked next to you began to back up, and you mistakenly perceived your car moving forward? I know that when this happens to me, I slam on my brakes before realizing that I have just experienced a **perceptual illusion** called **induced movement**. The reason we sometimes experience perceptual illusions is because we misapply one or more of the perceptual principles previously examined in this chapter (see Section 4.5a). In the case of induced movement, it is the misapplication of the principle of motion parallax. That is, instead of your movement forward causing close objects to appear as though they are moving backward, the movement backward of the car close to you makes you feel like you are moving forward.

Adobe Stock

The ancient Greeks built the Parthenon in Athens to look perfectly symmetrical, but it is not. The designers understood and used some basic principles of visual illusions. If it had been built with perfect right angles, it would have looked crooked and ready to fall down.

Because vision is our dominant sense, we know more about *visual* illusions than any other sensory misperceptions. Thus, in this section, the type of perceptual illusions we will focus on will be mostly of the visual variety. Yet, let me mention one *auditory* illusion I am hearing right now as I type this sentence. As mentioned previously, I have an antique clock in my den. Although I know it is making a steady click-click-click-click sound as the pendulum swings back and forth, what I more often hear is an accented CLICK-click-CLICK-click. The reason for this auditory illusion is that people tend to group the steady clicks of a clock into patterns of two clicks, with one of the clicks—usually the first—being misperceived as slightly louder than the other.

Perceptual illusion
A misperception of physical reality, often due to the misapplication of perceptual principles

Induced movement
The illusory movement of a stationary object caused by the movement of another nearby object

Exploring Culture & Diversity 4–1

Do Perceptual Illusions Differ Cross-Culturally?

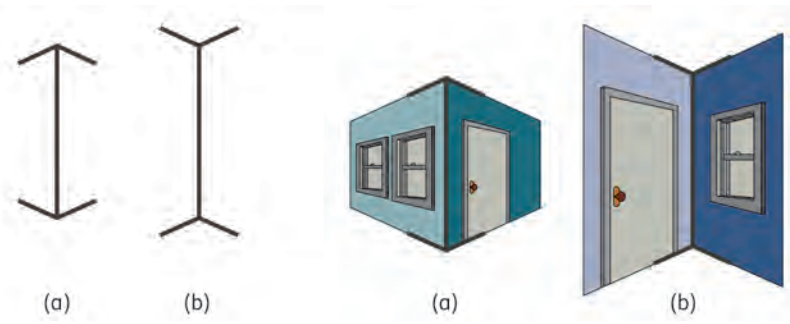
The most famous and extensively studied illusion is the **Müller-Lyer illusion**, shown in Figure 4–21 (van Doorn et al., 2007). Notice that the vertical line b to the right appears longer than line a to the left. Yet, if you measure the lines with a ruler, you will find that they are equal in length. The generally accepted explanation for this illusion is that it is due to the misapplication of size constancy (Gregory, 1998). That is, because figure a bears a likeness to the outside corner of a building and figure b resembles the inside corner of a room, the vertical line b appears farther away than the vertical line a. As a result of this distance cue, the application of size constancy enlarges the perceived length of b relative to a. Interestingly, cross-cultural research indicates that the Müller-Lyer illusion is most likely to occur in cultures where

Müller–Lyer illusion
A perceptual illusion in which the perceived length of a line is influenced by placing inward- or outward-facing wings on the ends of the line

straight lines, right angles, and rectangles are common design elements in buildings (Segall et al., 1966, 1990). People who live in curved buildings without straight lines and right angles, such as the Zulu of southeastern Africa, are much less susceptible to this perceptual illusion.

Figure 4-21 The Müller-Lyer Illusion

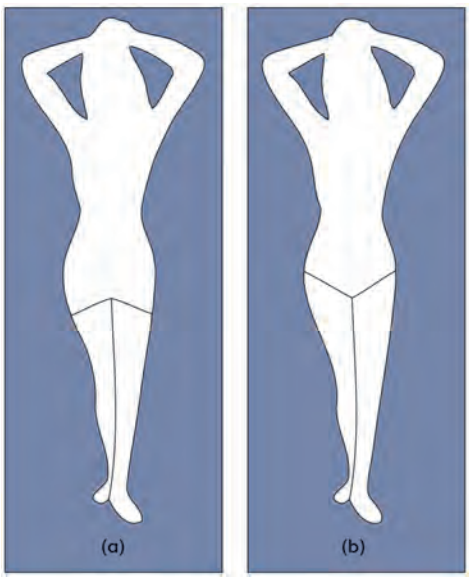
In the Müller-Lyer illusion, lines of equal length are perceived as unequal. Research indicates that this illusion is more commonly experienced in cultures where straight lines, right angles, and rectangles are common building-design elements. What monocular distance cue is misapplied in this illusion?



The Japanese psychologist Kazunori Morikawa (2003) demonstrated that the popularity of high-cut bathing suits is at least partly because they make a woman's legs look longer than a conventional bathing suit. This fashion effect is simply an application of the Müller-Lyer illusion. How so? Figure 4–22a depicts the "low-cut" look of a conventional bathing suit, whereas Figure 4–22b depicts the "high-cut" look. Don't the legs in figure b look longer, even though we know they are not?

Figure 4-22 High-Cut Bathing Suits and the Müller-Lyer Illusion

Fashion designers rely on the Müller-Lyer illusion to make women's legs appear longer, and thus more attractive, when they wear high-cut bathing suits (b) rather than low-cut bathing suits (a). Is it possible that this misperception of these two women's leg lengths will occur more often in cultures where straight lines, right angles, and rectangles are common building-design elements?



Just as in the Müller-Lyer illusion, the misperception of distance cues by people in carpentered cultures causes the perceptual illusion of the Ames Room. Designed by Adelbert Ames and depicted in Figure 4–23, this room is built with a trapezoidal rear wall, different-sized windows, and a sloping floor and ceiling. When viewed through a peephole with one eye, this room appears to have a normal rectangular shape. The person standing to the right (the near corner) appears disproportionately large because we judge their

(continues)

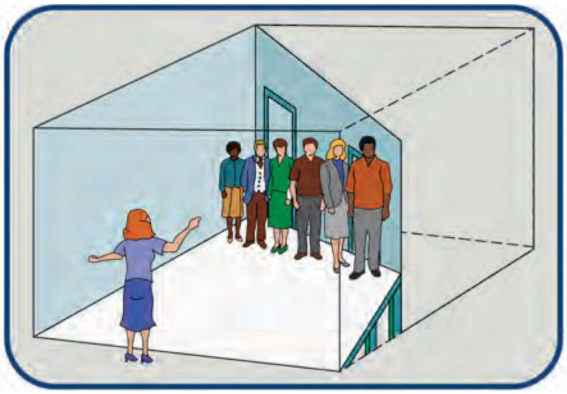
(continued)

size based on the incorrect assumption that the person is the same distance away as the person in the far-left corner. Even more interesting is what we mistakenly perceive when people in the room walk to the opposite corner. When they cross the room from right to left they appear to shrink before our very eyes, while they are transformed from "little people" to giants as they move from left to right!

Figure 4-23 The Ames Room

(a) Why does the person in the right corner of the Ames Room look like a giant? (b) This perceptual illusion is created by having viewers look into the room through a peephole, with one eye. When viewed through the peephole, this room looks like a normal rectangular room—despite the fact that this room has a trapezoidal rear wall, a left window that is larger than the right window, and a sloping floor and ceiling. This illusion occurs because people on the right fill more of the space between the floor and ceiling, and because peephole viewers assume that when two objects are the same distance from them, the object that produces the larger image on their retinas is larger in size than the object that produces a smaller retinal image.

Mark McKenna

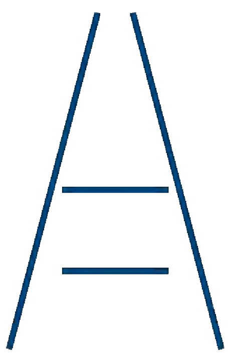


Another perceptual illusion caused by the misapplication of size constancy is the **Ponzo illusion** depicted in Figure 4–24. Most people see the line on top as longer than the one on the bottom (Oyama & Goto, 2007). As in the Müller-Lyer illusion, these two lines cast the same-sized retinal image; thus, the illusion occurs due to the top line appearing farther away than the bottom line because people misapply the monocular distance cue of linear perspective. This illusion is also less likely to be experienced by people who live in cultures where they aren't exposed to many straight lines and right angles (Deregowski, 1989; Segall et al., 1966).

Ponzo illusion
A perception illusion in which the perceived lengths of horizontal lines are influenced by their placement between vertical converging lines that serve as distance cues

Figure 4-24 The Ponzo Illusion

Although the two horizontal lines are the same length, our experience tells us that a more distant object can create the same-sized retinal image only if it is larger. What monocular distance cue is being misapplied here?



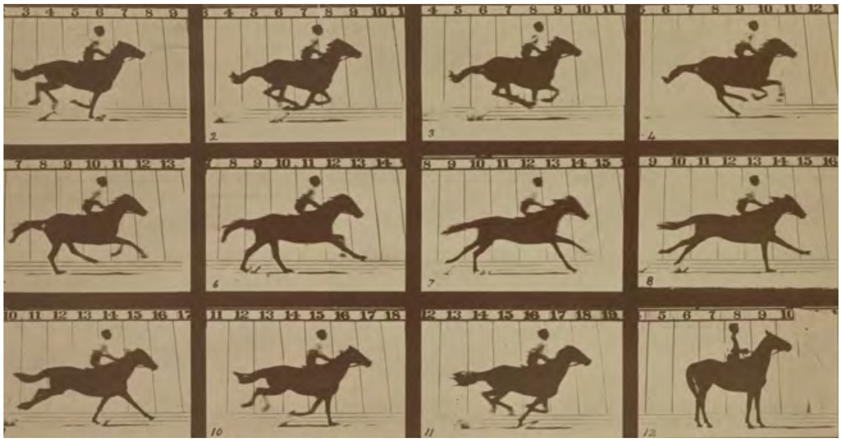
The most important visual illusion you experience when watching movies and playing video games is **stroboscopic movement**, the illusion of movement produced by a rapid pattern of stimulation on different parts of the retina (Anstis, 1978). In motion pictures, stroboscopic movement is created by rapidly passing a series of still pictures (or film frames) past a light source, which projects these images onto a screen. As we watch these rapidly changing images, the memory of each lasts just long enough in our minds until the next one appears (see Figure 4–25). For this illusion of movement to occur, a film frame must replace the previous one 24 times per second. During the early days of motion pictures, the frame rate was only 16 per second, resulting in jerky and disjointed movement and a noticeable flickering of light. In television and video games, the static frames change about 30 times per second, resulting in the perception of fluid movement.

Stroboscopic movement
The illusion of movement produced by a rapid pattern of stimulation on different parts of the retina

Figure 4–25 Stroboscopic Movement

Motion picture film consists of a series of still photographs. Presenting the pictures one at a time, in quick succession, creates the illusion of movement. Why do silent movies from the 1920s have a noticeable flickering of light and jerky images, while the movement seen in contemporary movies is fluid and realistic in appearance?

Source: "The Horse in Motion," by Eadweard Muybridge, public domain, via Wikimedia.



When stroboscopic movement is combined with the 19th-century technology of stereoscope photography, the visual illusion offered by 3-D movies is created (McCarthy, 1992). Early black-and-white 3-D movies from the 1950s were filmed from two slightly different angles, and the two images were later projected onto the theater screen with different-colored filters (red or blue) placed in front of each projector (McGee, 1989). So that each eye could receive a different view of the same scene, moviegoers wore special glasses with one red and one blue lens. The red lens washed out the red image, and the blue lens washed out the blue image. As previously described (see Section 4.5a), as their brains merged these two images into one, applying the cue of retinal disparity, the audience experienced three-dimensional movie vision. Later 3-D movies used different types of polarized light that allowed color to be depicted.

The modern-day version of the 3-D movie is the *virtual environment,* in which a person can experience 3-D images and sounds while wearing a head visor (Aznar-Casanova et al., 2008). The visor sends clear, full wraparound 3-D images to each eye, and the ears receive digital stereo sound. The images and sounds transmitted by the visor are controlled by a computer that takes into account the head movements of the wearer. Thus, whenever the wearer's head turns, the scene shifts accordingly. As discussed in Chapter 1, Section 1.3e, psychologists are beginning to use virtual environment technology in their research to increase the realism of laboratory experiments.

Likewise, some clinical psychologists employ this technology when treating clients who suffer from certain phobic disorders (see Chapter 11, Section 11.2a).

Outside of psychology, virtual environment visors and helmets are used to train airline pilots, police officers, surgeons, and soldiers in their various environments and are quickly becoming an integral part of the equipment used by gamers. One troubling fact about most virtual-environment computer games is that they involve violence. As noted in Chapter 1, Section 1.3e, psychological research suggests that watching aggression on television and in movies appears to increase people's own aggressive tendencies. Yet, when people play virtual-environment computer games, they are not merely observing violence—they are actively participating in simulated aggression. What effect does this more active participation in violent media events have on people's later aggression? Despite denials from the video-game industry, a meta-analysis of 33 videogame studies involving over 3,000 participants found that high levels of video-game violence are associated with heightened aggression in the real world among young adults and children (Anderson & Bushman, 2001; Barlett et al., 2008).

Art has a double face, of expression and illusion, just like science has a double face: the reality of error and the phantom of truth.

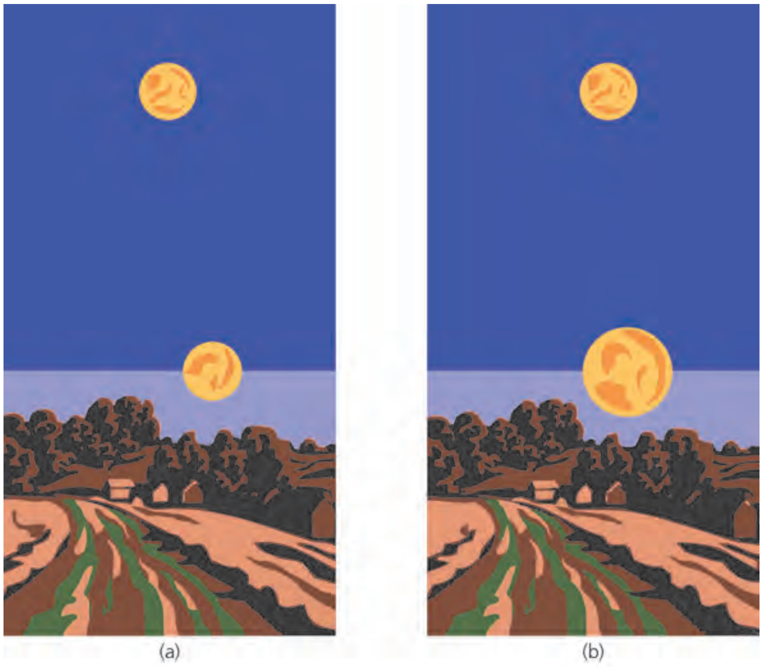
—René Daumal, French poet, 1908–1944

Moon illusion
A perceptual illusion in which the moon appears to be larger when near the horizon than when high in the sky

Finally, one last illusion that is affected by the perception of depth is the **moon illusion**, in which the moon appears to be about 1.5 times larger when near the horizon than when high in the sky (the same illusion also occurs for the sun). To verify that this experience is really an illusion, take a sheet of paper and roll it up into a narrow tube. As the moon rises from the horizon at night point your tube at the moon's image and adjust the tube's size until it's a little larger than the moon's diameter and then tape the tube so its size stays the same. In a few hours when the moon is higher in the sky and appears smaller to you (as represented in Figure 4–26[b]), look at it through the tube and you will see that it fills the same space. Of course, you know that the moon does not actually shrink as it rises in the sky, and looking through the tube confirms that the retinal size of the horizon moon and zenith moon is exactly the same, as represented by Figure 4–26(a). The Earth's atmosphere does not magnify the visual appearance of the horizon moon, so what causes this illusion?

Figure 4-26 The Moon Illusion

(a) This is a representation of a time-lapse photograph of the horizon moon and zenith moon. As you can see, the two moon images have the same diameter. (b) This is a representation of what most of us perceive as our moon illusion experience. That is, when we watch the moon rise in the night sky, it appears to be about 1½ times larger when near the horizon than when high in the sky. Do you think this same illusion also occurs for the sun?



One of the oldest and best-known explanations of the moon illusion is the *apparent-distance theory,* which contends that the illusion is caused by the two monocular depth cues of interposition and height in the field of view, combined with the misapplication of the principle of size constancy. According to this theory, when we see the moon near the horizon, it is often partially covered by buildings or trees that provide distance cues (interposition) that the moon is relatively far away. These distance cues are absent when the moon is high on the horizon because it is almost always unobstructed. Regarding height in the field of view, when the moon is closer to the horizon, we perceive it as farther away than when it is higher in our visual field. Thus, apparent-distance theory states that these two monocular cues cause us to mistakenly perceive the horizon moon as farther away than the moon that is high in the sky. If we perceive the horizon moon as farther away than the zenith moon, we implicitly conclude that this "distant low moon" must be larger than the "near high moon" (Kaufman & Rock, 1962). The problem with apparent-distance theory, however, is that when people are asked to judge which moon appears to be closer (Kim, 2008), most report that the horizon moon looks closer, not farther away! Of course, this directly contradicts apparent-distance theory.

So, is there any solution to the moon illusion puzzle? Not yet. Some scientists believe that the primary cause of this illusion is the moon's appearance near objects of known size (Hershenson, 2003). According to this explanation, when seen near the horizon next to trees, buildings, and mountains, the size of the moon in the sky appears rather large in relation to these known-size objects. In contrast, when seen high overhead, the moon doesn't seem very big because there is nothing with which to compare it. As you might expect, this explanation also has its critics, and they offer their own solutions to this perceptual puzzle. And so it goes. The most accurate statement I can make to you regarding the moon illusion is that it is a very complicated illusion, and there is widespread disagreement as to its causes (Acosta, 2004).

4.5e Certain Aspects of Perception Are Innate, and Others Are Learned

The principles of Gestalt psychology describe how we transform sensory information into meaningful perceptions. Gestalt psychologists believe that we are born with these principles for organizing sensory information. Yet, to what extent is perception based on inborn abilities versus experience-based learning?

The Visual Cliff

To study the ability to perceive depth, Eleanor Gibson and Richard Walk (1960) designed the *visual cliff.* This apparatus consists of a glass-covered tabletop with a "shallow" checkerboard on one end and a "deep" checkerboard on the other end that appears to drop off like a cliff (see Figure 4–27). Infants between ages 6 months and 14 months were placed on the middle of this table, and their mothers were instructed to try to coax them into crawling to one side or the other. Although the mothers had little problem getting their children to crawl toward them on the shallow end, most refused to crawl past the visual cliff onto the deep end (Walk & Gibson, 1961). It's possible that by the time they learned to crawl, these children had also learned to perceive depth, yet newborn animals that can walk the day they're born—such as lambs, chicks, kittens, pigs, and rats—also avoid the deep end of the visual cliff (Walk, 1981). In addition, later studies using the visual cliff found that when younger noncrawling infants were physically moved from the shallow end of the table to the deep end, their heart rates slowed down, which is a typical reaction when people try to orient themselves in new situations (Campos et al., 1970). In other words, although these younger babies may not have known precisely how to react, they did *perceive* something different between the shallow and deep ends of the table. Together, these findings suggest that infants develop depth perception shortly after birth, but that fear and avoidance of dangerous depths may develop only after they learn to crawl and obtain first-hand experience with the dangers of height.

Figure 4-27 The Visual Cliff

The visual cliff consists of a glass-covered tabletop with a "shallow" checkerboard on one end and a "deep" checkerboard on the other end that appears to drop off like a cliff. Most 6-month-old infants won't crawl across the "deep" side.

Newly "Sighted" People and Animals

Further evidence that some perceptual abilities are inborn comes from case histories of people who have gained sight after a lifetime of blindness. Most gained their vision by having *cataracts*—clouded lenses that allow only diffused light to enter the eye—surgically removed. Following this procedure, these newly sighted individuals could distinguish figure from ground, scan objects, perceive colors, and follow moving objects with their eyes (Gregory, 1998). Unfortunately, they often could not recognize objects until they touched them.

Seeking to study this same phenomenon under more controlled conditions, Torsten Wiesel (1982) either stitched closed the eyelids of newborn kittens and monkeys or placed goggles over their eyes that enabled them to see only diffused light. Following infancy, when these visual impairments were removed, the animals exhibited perceptual limitations similar to those observed in the human cataract patients. Further studies with cats found that the first 3 months of life are a critical period in the development of their ability to detect horizontal and vertical lines (Hirsch & Spinelli, 1970; Mitchell, 1980). If kittens don't get the necessary exposure to these visual stimuli, they experience a permanent deficit in visual perception even after years of living in a normal environment. Together, these studies suggest that although certain aspects of visual perception may be inborn, others require experience-based learning during critical periods in infancy. If this critical period is missed, certain perceptual deficits cannot be corrected through later learning.

Review

- *Form perception* is the process by which sensations are organized into meaningful shapes and patterns.
- *Figure-ground relationship* is a Gestalt principle stating that when people focus on an object or "figure" in their perceptual field, they automatically distinguish it from its surroundings.
- *Depth perception* is the ability to perceive objects three-dimensionally.
- *Perceptual constancy* is the tendency to perceive objects as relatively stable despite continually changing sensory information.
- *Perceptual set* refers to the expectations an observer brings to a situation that influence what is perceived.
- *Inattentional blindness* is the failure to notice a fully visible, but unexpected object because attention was engaged on something else in the visual field.
- *Perceptual illusion* is a misperception of physical reality due to the misapplication of perceptual principles.
- Certain aspects of visual perception may be inborn, whereas others require experience-based learning during critical periods in infancy.

Psychological Applications

Can You Improve Your Memory and Self-Esteem Using Subliminal Perception?

As discussed earlier in Section 4.1b, there are many events that we do not consciously experience because they are below our absolute threshold. Although we are not consciously aware of these stimuli, can they still influence our behavior? Stimulation just below the absolute threshold of conscious awareness is known as subliminal stimulation. **Subliminal perception** is the processing of such information (Ruys & Stapel, 2008). Many astounding claims have been made over the years about the powerful influence that subliminal messages can have on our minds and actions, especially consumers' purchasing decisions, yet are any of these claims supported by scientific research?

Numerous studies have found that people can respond to stimuli without being aware that they are doing so (Eimer & Schlaghecken, 2002; Katkin et al., 2001), but there is no convincing evidence that subliminal messages influence consumers' behavior (Trappey, 1996; Zher-Wen & Yu, 2023). Yet what about people who have used subliminal messaging programs to increase their self-esteem or improve their memory and swear that their lives have been changed? Isn't this evidence that subliminal messages can be effective at least some of the time?

This was the question that Anthony Greenwald and his colleagues (1991) were interested in answering when they conducted a study of such self-help programs. Participants were first pretested for their level of self-esteem and memory-recall ability and then given an audiotape containing various pieces of classical music. The tape manufacturers claimed that embedded within these self-help tapes were subliminal messages designed either to increase self-esteem (for example, "I have high self-worth and high self-esteem") or to increase memory (for example, "My ability to remember and recall is increasing daily"). Half the tapes were purposely mislabeled by the researchers, leading the participants who received them to believe they had a memory tape when they really had a self-esteem tape, or vice versa. The rest of the tapes, with correct labels, were distributed to the remaining participants. During the next 5 weeks, these volunteers listened at home daily to their respective tapes. After this exposure period, they again were given self-esteem and memory tests and were also asked whether they believed the tapes had been effective. The

Subliminal perception
The processing of information that is just below the absolute threshold of conscious awareness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Although subliminal self-help programs do not improve memory or increase self-esteem, they continue to do a brisk business. Why do you think people believe in their effectiveness?

test results indicated no self-esteem or memory increases; the subliminal tapes were utterly ineffective. Despite these null findings, participants who thought they had received the self-esteem tape tended to believe their self-esteem had increased, and those who thought they had received the memory tape believed their memory had improved. This was true even if they had received a mislabeled tape!

These results, combined with other subliminal program studies, suggest that whatever benefits people derive from such self-help products have little to do with the content of the subliminal messages (Froufe & Schwartz, 2001; Moore, 1995). Instead, people's expectations (the **placebo effect**), combined with their economic and psychological investment ("I invested a lot of time and money in this product; it must be good!"), appear to be the sole influence operating here.

Before we dismiss the possibility that subliminal perception can influence people's everyday attitudes and behavior, we should consider that there are some studies, conducted under carefully controlled laboratory conditions, that have successfully manipulated people's attitudes and behavior using subliminal stimuli (Weisbuch et al., 2003). For example, in a series of experiments, participants who were repeatedly exposed to subliminal stimuli (abstract geometric figures or people's faces) later expressed greater liking for those stimuli (Bornstein et al., 1987). In another study, participants who were subliminally exposed to achievement-oriented words (strive, succeed, master) while completing a "word search" puzzle were more likely to continue working on the puzzle task when signaled to stop than those in the control group (Bargh & Chartrand, 1999). These findings suggest that it may be possible for a stimulus subliminally embedded in an advertisement to influence buyers' preferences. Additional research suggests that advertisers may be able to subliminally persuade people who are already motivated to purchase specific products over others (Karremans et al., 2006).

Placebo effect
A situation in which people experience some change or improvement from an empty, fake, or ineffectual treatment

The caveat to this possibility is that there are some important differences between the laboratory environment where these results were obtained and the real world where people would normally receive subliminal messages. In the carefully controlled settings where these subliminal effects have been found, participants paid a great deal of attention to the experimental stimuli. In watching the average media advertisement, people are considerably less attentive. Due to the viewer's wandering eye, it is much less likely that a subliminal stimulus embedded in an ad would be unconsciously processed. A second reason to doubt that these effects would occur outside the lab is that the duration of most of these subliminal effects appears to be very short, perhaps lasting only a few seconds. If the subliminal effects last only a short time, they are unlikely to influence product purchases. Thus, although it is not beyond the realm of possibility that practitioners could at some time in the future develop clever subliminal techniques that influence the thinking and behavior of the general public, there are no known effective techniques at the present time. Future research will determine the actual potential use—and abuse—of subliminal procedures in persuasion.

Chapter Review

Suggested Websites

Sensation and Perception Jeopardy

https://bvtlab.com/3J7vs

This website, JeopardyLabs, was created by Matt Johnson, while he was an undergrad at Washington State University, Vancouver. The link here for JeopardyLabs tests your knowledge of sensation and perception using the *Jeopardy!* game show format. JeopardyLabs is not affiliated with *Jeopardy!*® or Sony Pictures Digital Inc.

Visual Phenomena & Optical Illusions with Explanations by Michael Bach

https://michaelbach.de/ot/

This huge collection of non-scary optical illusions and fascinating visual phenomena emphasizes interactive exploration, beauty, and scientific explanation.

Dan Simons

http://www.dansimons.com/videos.html

This site contains the video of the inattentional blindness where researchers asked participants to watch a video of people passing basketballs and counting the passes made by players wearing white shirts while ignoring the passes made by players wearing black shirts.

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Review Questions

1. Which of the following statements is true?
   a. To determine absolute threshold, a stimulus must be detectable 90% of the time.
   b. We have many thresholds for a given sense.
   c. Our sense of taste is more sensitive than hearing.
   d. Sensory adaptation occurs with vision without any special equipment.
   e. None of the above
2. Which of the following types of energy can our eyes detect?
   a. radio
   b. ultraviolet and infrared
   c. X-ray radiation
   d. None of the above
   e. *a* and *c*
3. Pupil size is affected by ______.
   a. light
   b. psychological arousal
   c. interest
   d. All of the above
   e. *a* and *b*
4. Which of the following animals have all-rod eyes?
   a. lizards and chipmunks
   b. rats
   c. bears
   d. owls
   e. *b* and *d*
5. Which of the following statements is true?
   a. Visual information in the right visual field goes to the left hemisphere of the brain.
   b. Visual information in the left visual field goes to the right hemisphere of the brain.
   c. Axons from the right eye are all connected to the right hemisphere of the brain.
   d. The optic nerve is the retina's area of central focus.
   e. *a* and *b*
6. Which of the following is true of color?
   a. Color is energy.
   b. Color is created by our nervous system.
   c. Color is the same for humans and animals.
   d. *a* and *b*
   e. All of the above
7. Which theory of vision best explains most of the visual processing occurring in the eye?
   a. trichromatic theory
   b. opponent-process theory
   c. depth perception theory
   d. frequency theory
   e. None of the above
8. The main parts of the inner ear include which of the following?
   a. oval window, cochlea, and organ of Corti
   b. hammer, anvil, and stirrup
   c. pinna, cochlea, and basilar membrane
   d. basilar membrane, oval window, and hammer
   e. None of the above
9. What theory best explains how we can hear sounds at frequencies between 1,000 and 5,000 Hz?
   a. volley theory
   b. place theory
   c. frequency theory
   d. pitch theory
   e. None of the above
10. Which of the following statements is true?
    a. Sensitivity to sweet and salty substances is strongest along the sides of the tongue.
    b. If your L-fibers are destroyed by amputation, you will be insensitive to pain.
    c. The inner ear is responsible only for our sense of hearing.
    d. Our tongue is the largest sensory organ.
    e. None of the above
11. What is the height of a sound wave called?
    a. Its threshold
    b. Its frequency
    c. Its complexity
    d. Its refraction
    e. None of the above

12. Which of the areas of the skin has the greatest concentration of receptors?
    a. fingers, lips, face, tongue, and genitals
    b. fingers, lips, bottom of feet, and genitals
    c. toes, elbows, knees, and eyes
    d. tongue, knees, wrists, and neck
    e. None of the above
13. On which of the following principles is Gestalt psychology based?
    a. Our mind responds to individual sensations.
    b. Our mind actively organizes stimuli into a whole.
    c. motion parallax
    d. *a* and *b*
    e. None of the above
14. Depth perception depends on which of the following?
    a. binocular cues
    b. monocular cues
    c. perceptual set
    d. absolute threshold
    e. Both *a* and *b*
15. To fool the brain into seeing in three dimensions, 3-D movies rely on which of the following?
    a. monocular cues
    b. retinal disparity
    c. amplitude
    d. *a* and *b*
    e. None of the above
16. How have scientists tried to determine what aspects of perception are innate?
    a. by studying human infants
    b. by studying newborn animals
    c. by studying blind people whose eyesight was surgically restored
    d. All of the above
    e. *a* and *c* only
17. Which of the following statements is true?
    a. As we age our sense of smell remains remarkably stable.
    b. Presbyosmia is more common in women than in men and appears to occur during menopause.
    c. Anosmia is a relatively common olfactory problem, affecting 20% of adolescents and 50% of adults.
    d. As many as 80% of people diagnosed with the COVID-19 virus experienced a temporary loss of smell.
    e. None of the above are true

Answers: 1. b 2. d 3. d 4. e 5. e 6. b 7. a 8. a 9. a 10. e 11. e 12. a 13. b 14. e 15. b 16. d 17. d

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