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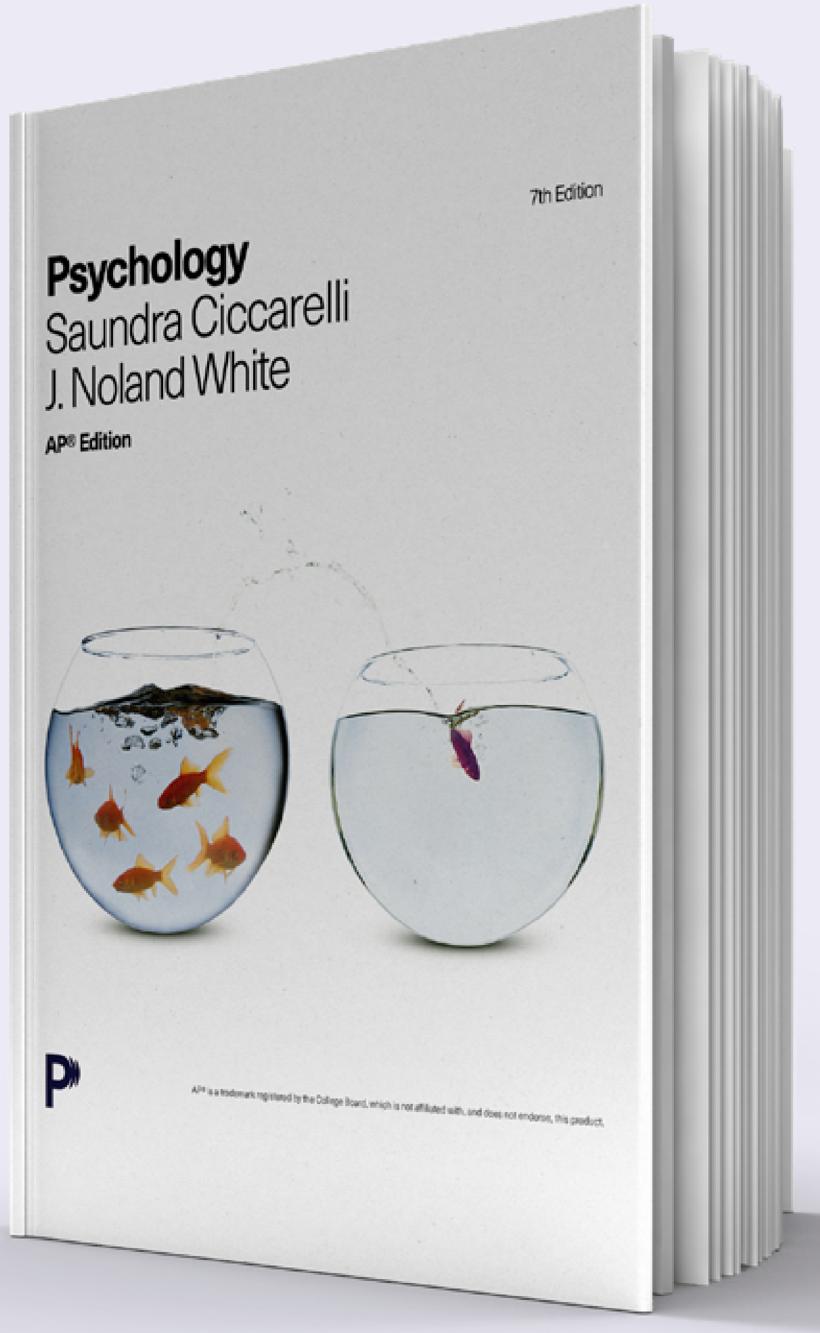
Inside:

Chapter 3:

Sensation and Perception



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About the Author

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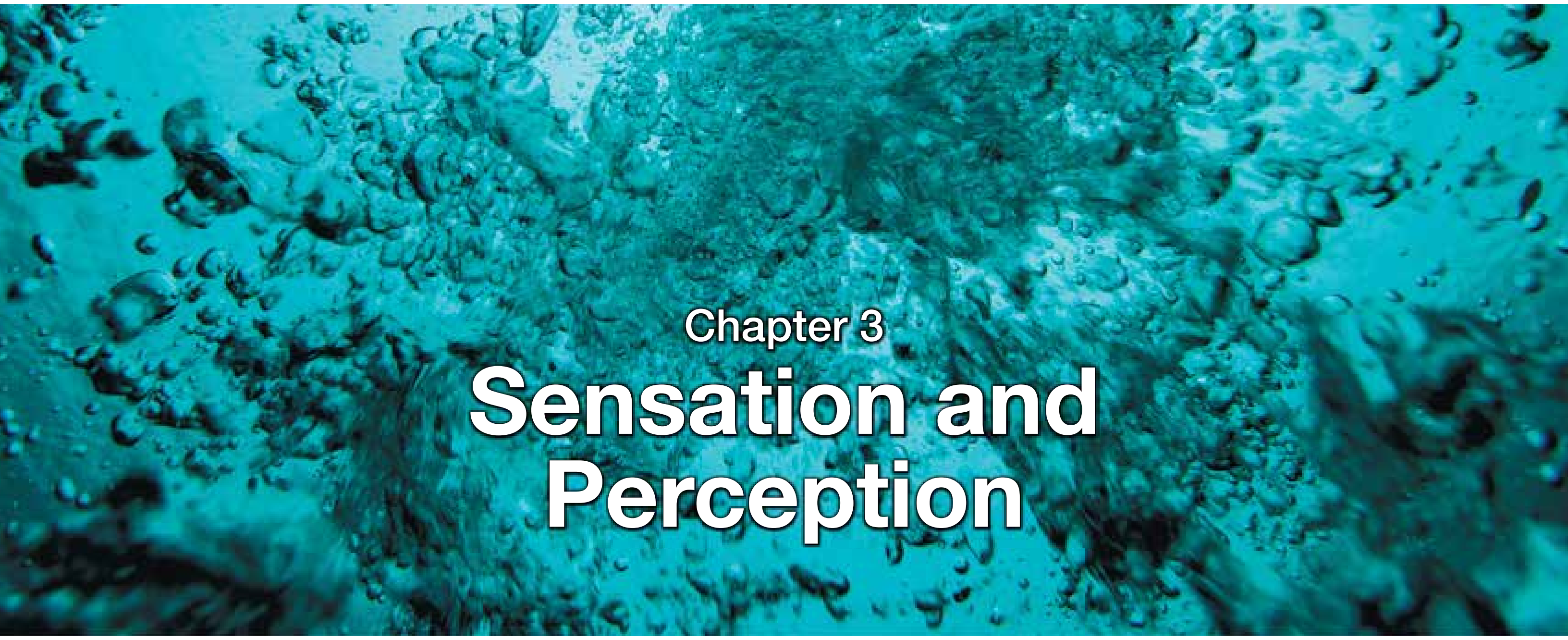


Chapter 3
Sensation and Perception

In your words

Which of your sensory abilities do you rely on most during a typical day? Are certain senses more important than others, depending on the social context or setting?

After you have thought about these questions, watch the video in **Revel** to see how other students would answer them.

Why study sensation and perception?

Without sensations to tell us what is outside our own mental world, we would live entirely in our own minds, separate from one another and unable to find food or any other basics that sustain life. Sensations are the mind's window to the world that exists around us. Without perception, we would be unable to understand what all those sensations mean—perception is the process of interpreting the sensations we experience so that we can act upon them.

AP® Learning Objectives (AP® LO)

1.6.A: Explain how the process of sensation is related to behavior and mental processes.

1.6.B: Explain how the structures and functions of the visual sensory system relate to behavior and mental processes.

1.6.C: Explain how the structures and functions of the auditory sensory system relate to behavior and mental processes.

1.6.D: Explain how the structures and functions of the chemical sensory systems relate to behavior and mental processes.

1.6.E: Explain how the structures and functions of the touch sensory system relate to behavior and mental processes.

1.6.F: Explain how the structures and functions of the pain sensory system relate to behavior and mental processes.

1.6.G: Explain how the structures and functions that maintain balance (vestibular) and body movement (kinesthetic) relate to behavior and mental processes.

2.1.A: Explain how internal and external factors influence perception.

2.1.B: Explain how visual perceptual processes produce correct or incorrect interpretations of stimuli.

AP® Science Practices (AP® SP)

1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.
1.B: Explain how cultural norms, expectations, and circumstances, as well as cognitive biases apply to behavior and mental processes.
2.B: Evaluate the appropriate use of research design elements in experimental methodology.
3.A: Identify psychology-related concepts in descriptions or representations of data.
3.B: Calculate and interpret measures of central tendency, variation, and percentile rank in a given data set.
3.C: Interpret quantitative or qualitative inferential data from a given table, graph, chart, figure, or diagram.
4.A: Propose a defensible claim.
4.B: Provide reasoning that is grounded in scientifically derived evidence to support, refute, or modify an established or provided claim, policy, or norm.

Learning Objectives

3.1 Describe how we get information from the outside world into our brains.
3.2 Describe the difference and absolute thresholds.
3.3 Explain why some sensory information is ignored.
3.4 Describe how light travels through the various parts of the eye.
3.5 Explain how light information reaches the visual cortex.
3.6 Compare and contrast two major theories of color vision, and explain how color-deficient vision occurs.
3.7 Explain the nature of sound, and describe how it travels through the various parts of the ear.
3.8 Summarize three theories of how the brain processes information about pitch.
3.9 Describe how we determine the loudness and location of sounds.
3.10 Identify types of hearing loss and treatment options for each.
3.11 Explain how the sense of taste works.
3.12 Explain how the sense of smell works.
3.13 Describe how we experience the sensations of touch, pressure, temperature, and pain.
3.14 Describe the systems that tell us about balance and position and movement of our bodies.
3.15 Describe how perceptual constancies and the Gestalt principles account for common perceptual experiences.
3.16 Explain how we perceive depth using both monocular and binocular cues.
3.17 Identify some common visual illusions and the factors that influence our perception of them.
3.18 Describe how mindfulness and paying attention to our senses, thoughts, and feelings can impact perceptions, personal experiences, and overall sense of well-being.

Integrative themes in psychological science highlighted in this chapter

Integrative Theme A Psychological science relies on empirical evidence and adapts as new data develop.

Integrative Theme B Psychology explains general principles that govern behavior while recognizing individual differences.

Integrative Theme C Psychological, biological, social, and cultural factors influence behavior and mental processes.

Integrative Theme E Our perceptions and biases filter our experiences of the world through an imperfect personal lens.

3.1–3.3 The ABCs of Sensation

Information about the world has to have a way to get into the brain, where it can be used to determine actions and responses. The way into the brain is through the sensory organs and the process of sensation.

3.1 Transduction

3.1 Describe how we get information from the outside world into our brains.

AP® LO 1.6.A: Explain how the process of sensation is related to behavior and mental processes.

Sensation occurs when special receptors in the sense organs—the eyes, ears, nose, skin, and taste buds—are activated, allowing various forms of outside stimuli to become neural signals. This process of converting outside stimuli, such as light, into neural activity occurs at the level of these special receptors, or *sensory receptors*, and is called **transduction**.

The *sensory receptors* are specialized forms of neurons, the cells that make up the nervous system. Instead of receiving neurotransmitters from other cells, these receptor cells are stimulated by different kinds of energy—for example, the receptors in the eyes are stimulated by light, whereas the receptors in the ears are activated by vibrations. Touch receptors are stimulated by pressure or temperature, and the receptors for taste and smell are triggered by chemical substances. Each receptor type transduces the physical information into electrical information in different ways, which then either depolarizes or hyperpolarizes the cell, causing it to fire more or to fire less based on the timing and intensity of information it is detecting from the environment (Gardner & Gardner, 2021). While our sensory systems work independently, they also work together and may influence each other through *sensory interaction*. For example, consider how the integration of sight and touch assists us with tasks requiring hand-eye coordination or how foods taste different when a cold impairs our sense of smell. See Learning Objective 3.11.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

In some people, the sensory information gets processed in unusual, but fascinating ways. Some people experience colors and shapes as taste, smells as colors, and words and sounds as colors. Individuals like this have a condition known as **synesthesia**, or *synaesthesia*, which literally means "joined sensation." Studies suggest at least 4 to 5 percent of the population may experience some form of synesthesia, with nearly equivalent representation across females and males (Simner & Carmichael, 2015; Simner et al., 2006). Although the causes of synesthesia are still being investigated, it appears that in some forms, signals that come from the sensory organs, such as the eyes or the ears, either go to places in the brain where they weren't originally meant to be or they are processed differently (Ward, 2013). Research suggests some aspects are universal—many people with grapheme-color synesthesia (where colors are triggered by letters and/or digits) report that the first grapheme is red (see **Figure 3.1**; Root et al., 2018). There is also research support for individuals with grapheme-color synesthesia having some level of improved memory for certain stimuli, perhaps facilitated by enhanced processing (Lunke & Meier, 2020; Rothen et al., 2020; Ward, 2013). See Learning Objective 6.1. Other research suggests that synesthesia is not purely a condition that people are born with.

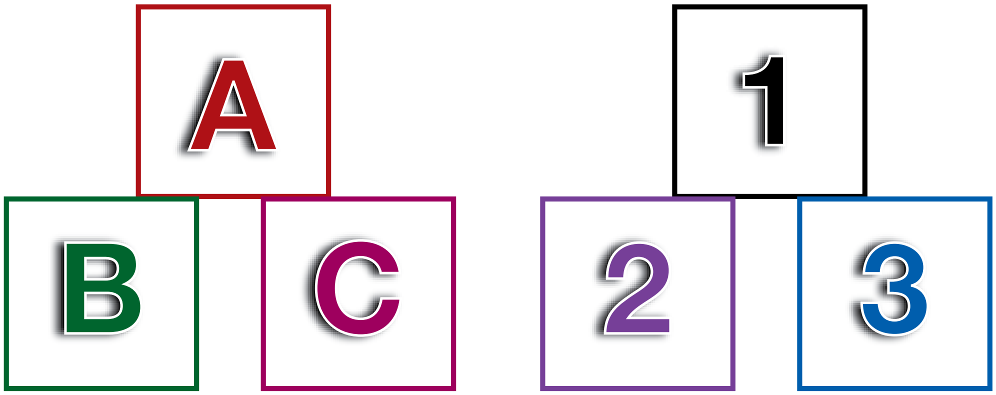
sensation
the process that occurs when specialized receptors in the sense organs are activated, allowing various forms of outside stimuli to become neural signals; see AP® LO EK 1.6.A.1**.

transduction
the process of converting outside stimuli, such as light, into neural activity.

synesthesia
condition in which the signals from the various sensory organs are processed differently, resulting in the sense information being interpreted as more than one sensation; see AP® LO EK 1.6.A.3.

**Terms that are related to specific AP® Psychology Learning Objective Essential Knowledge statements (AP® LO EK) are noted at the end of their definition.

Figure 3.1 Grapheme-Color Synesthesia



Both alphabetical letters and numerical digits are graphemes. In grapheme-color synesthesia, individuals consistently perceive specific letters and numbers as having associated colors, as illustrated in the figure. Putting aside the immediate experience, how might having synesthesia impact someone's memory?

For example, some forms of synesthesia may be acquired, as they can be brought on by sensory loss or through pharmacological means, and some synesthesia-like experiences can be learned (Bor et al., 2014; Ward, 2013). We hope you recognize that the experience of synesthesia is one example of Integrative Theme B: *Psychology explains general principles that govern behavior while recognizing individual differences*.

3.2 Sensory Thresholds

3.2 Describe the difference and absolute thresholds.

AP® LO 1.6.A: Explain how the process of sensation is related to behavior and mental processes.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

Ernst Weber (1795–1878) did studies trying to determine the smallest difference between two weights that could be detected. His research led to the formulation known as Weber's law of **just noticeable differences (JND**, or the **difference threshold)**. A JND is the smallest difference between two stimuli that is detectable 50 percent of the time. Weber's law simply means that whatever the difference between stimuli might be, it is always a *constant*. If to notice a difference in the amount of sugar a person would need to add to a cup of coffee already sweetened with 5 teaspoons is 1 teaspoon, then the percentage of change needed to detect a just noticeable difference is one fifth, or 20 percent. So, if the coffee has 10 teaspoons of sugar in it, the person would have to add another 20 percent, or 2 teaspoons, to be able to taste the difference half of the time. Most people would not typically drink a cup of coffee with 10 teaspoons of sugar in it, let alone 12 teaspoons, but you get the point. To see an application with visual stimuli, participate in the *Weber's Law* experiment simulation in **Revel**.

Gustav Fechner (1801–1887) expanded on Weber's work by studying something he called the **absolute threshold** (Fechner, 1860). An absolute threshold is the lowest level of stimulation that a person can consciously detect 50 percent of the time the stimulation is present. (Remember, the JND is detecting a difference *between two* stimuli.) For example, assuming a very quiet room and normal hearing, how far away can someone sit and you might still hear the tick of their mechanical (analog) watch on half of the trials? For some examples of absolute thresholds for various senses, see **Table 3.1**.

just noticeable difference (JND or the difference threshold)
the smallest difference between two stimuli that is detectable 50 percent of the time; see AP® LO EK 1.6.A.2.

absolute threshold
the lowest level of stimulation that a person can consciously detect 50 percent of the time the stimulation is present; see AP® LO EK 1.6.A.1.

Table 3.1 Examples of Absolute Thresholds

Sense	Threshold
Sight	A candle flame at 30 miles on a clear, dark night
Hearing	The tick of a mechanical (analog) watch 20 feet away in a quiet room
Smell	One drop of perfume diffused throughout a three-room apartment
Taste	1 teaspoon of sugar in 2 gallons of water
Touch	A bee's wing falling on the cheek from 1 centimeter above

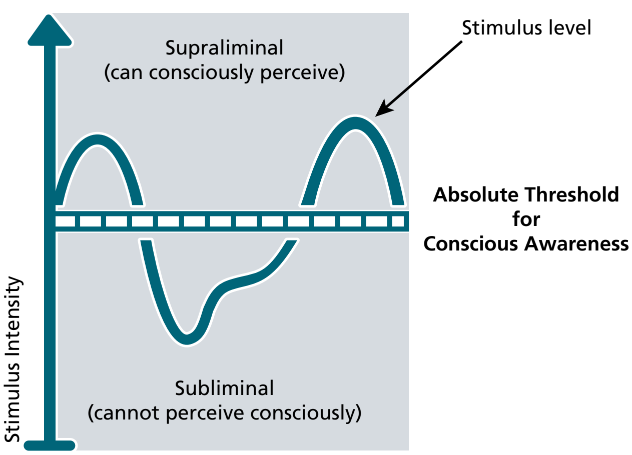
I've heard about people possibly being influenced by stuff in movies and on television without being aware of it. Is that true?

Stimuli above the absolute threshold are *supraliminal stimuli*. The prefix *supra* means "above" and the root word *limin* means "threshold," so *supralimin* means "above the threshold." In contrast, stimuli below the level of conscious awareness are called *subliminal stimuli*. The prefix *sub* means "below," so *sublimin* means "below the threshold." These stimuli are just strong enough to activate the sensory receptors but not strong enough, or are presented too quickly, for people to be consciously aware of them (see **Figure 3.2**). Many people believe these stimuli act on the unconscious mind, influencing behavior in a process called *subliminal perception*.

AP® SP 3.A: Identify psychology-related concepts in descriptions or representations of data.

At one time, many people believed that a market researcher named James Vicary had demonstrated the power of subliminal perception in advertising. In 1957, Vicary claimed that over a 6-week period, 45,699 patrons at a movie theater in Fort Lee, New Jersey, were shown two advertising messages, *Eat Popcorn* and *Drink Coca-Cola*, while they watched the film *Picnic*. According to Vicary, these messages were flashed for 3 milliseconds once every 5 seconds. Vicary claimed that over the 6-week period the sales of popcorn rose 57.7 percent and the sales of Coca-Cola rose 18.1 percent. It was 5 years before Vicary finally admitted that he had never conducted a real study (Merikle, 2000; Pratkanis, 1992). Furthermore, researchers have gathered scientific evidence that subliminal perception does not work in advertising (Bargh et al., 1996; Broyles, 2006; Moore, 1988; Pratkanis & Greenwald, 1988; Trappey, 1996; Vokey & Read, 1985). The collection of scientific evidence and changes in the way people think about the possible influences of subliminal perception in advertising is an excellent example of Integrative Theme A: *Psychological science relies on empirical evidence and adapts as new data develop.* And while the interest in the possibility of such an approach in advertising is appealing to some, and fascinating for many, this is another example where the basic tenets of critical thinking should come to mind. See Learning Objective 1.5. Before you look, though, use this opportunity to test your retrieval. Can you remember the four basic criteria of critical thinking we highlighted in Chapter One?

Figure 3.2 Supraliminal and Subliminal Stimuli

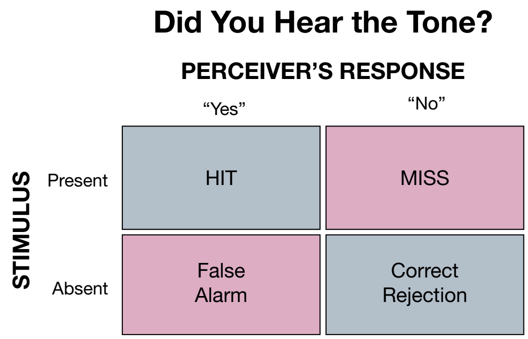


AP® SP 2.B: Evaluate the appropriate use of research design elements in experimental methodology.

This is not to say that subliminal perception does not exist—there is a growing body of evidence that we process some stimuli without conscious awareness, especially stimuli that are fearful or threatening (LeDoux & Phelps, 2008; Mudrik & Deouell, 2022;

Öhman, 2008; Rubianes et al., 2025; Song et al., 2023). In this effort, researchers have used *event-related potentials* (ERPs), skin conductance, and functional magnetic resonance imaging (fMRI) to verify the existence of subliminal perception and associated learning in the laboratory (King et al., 2016; March et al., 2022; Schröeder et al., 2021; Victor et al., 2017). See Learning Objective 2.5. The stimuli used in these studies are detectable by our sensory systems but below the level of full conscious perception. These participants, who are experiencing *subliminal priming,* are not aware or conscious that they have been exposed to the stimuli due to masking or manipulation of attention. Furthermore, the stimuli typically influence automatic reactions (such as an increase in facial tension) rather than direct voluntary behaviors (such as going to buy something suggested by advertising). However, the results of other research suggest the rare exception might be in situations where individuals are subliminally primed toward something that is directly related to a pre-existing goal and their pre-existing intentions (Elgendi et al., 2018). For example, individuals who were primed with the brand name of an iced tea reported a greater intention to choose and drink that brand of tea, but only if they were already thirsty (Karremans et al., 2006).

Figure 3.3 Signal Detection Theory



Another useful way of analyzing what stimuli we respond to is based on signal detection theory. **Signal detection theory** is used to compare our judgments, or the decisions we make, under uncertain conditions. The ability to detect any physical stimulus is based on how strong it is and how mentally and physically prepared the individual is. For example, a stimulus can be either present or absent. In turn, an individual can either detect a stimulus when present, a "hit," or say it is not there, a "miss." They can also falsely report a stimulus as present when it actually isn't, a "false alarm," or correctly state it isn't there, a "correct rejection." The theory was originally developed to help address issues associated with research participants guessing during experiments and is a way to measure accuracy (Green & Swets, 1966; Macmillan & Creelman, 1991).

signal detection theory
provides a method for assessing the accuracy of judgments or decisions under uncertain conditions; used in perception research and other areas. An individual's correct "hits" and rejections are compared against their "misses" and "false alarms."

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

You can use signal detection theory to understand possible outcomes when a health care professional views an x-ray or CT scan for a bone fracture, or an MRI to aid in diagnosing a brain tumor. See Learning Objective 2.5. You, too, can apply signal detection theory to understand your experience if you have ever had your hearing tested. When the audiologist was playing the tones for you, which were presented at different frequencies and loudness levels, did you ever think you heard something but were wrong (a false alarm) and for others correctly identified when a tone was presented (a hit)? See **Figure 3.3**.

3.3 Habituation and Sensory Adaptation

3.3 Explain why some sensory information is ignored.

AP® LO 1.6.A: Explain how the process of sensation is related to behavior and mental processes.
AP® LO 3.7.A: Explain how classical conditioning applies to behavior and mental processes.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

FXQuadro/Shutterstock

This person does not feel the piercings on their ears and lips because sensory adaptation allows them to ignore a constant, unchanging stimulation from the metal rings. What else are they wearing that would cause sensory adaptation?

Some of the lower centers of the brain filter sensory stimulation and "ignore" or prevent conscious attention to stimuli that do not change. The brain is primarily interested in changes in information. That's why people don't really "hear" the noise of the air conditioner unless it suddenly cuts off or the noise made in some classrooms unless it gets very quiet or someone else directs their attention toward it. Although they actually are *hearing* it, they aren't paying attention to it. This is called **habituation**, and it is the way the brain deals with unchanging information from the environment. In Chapter Five, we will talk about about a type of learning called *classical conditioning*, one of the important features is that a stimulus being conditioned is usually something that stands out from other stimuli. See Learning Objective 5.2. If a human or non-human animal is pre-exposed to a stimulus and they become too accustomed (habituated) to it, the conditioning process can be less effective or more difficult.

Sometimes I can smell the odor of the garbage can in the kitchen when I first come home, but after a while the smell seems to go away—is this also habituation?

Although different from habituation, **sensory adaptation** is another process by which constant, unchanging information from the sensory receptors is effectively ignored. In habituation, the sensory receptors are still responding to stimulation, but the lower centers of the brain are not sending the signals from those receptors to the cortex. The process of sensory adaptation differs because the receptor cells *themselves* become less responsive to an unchanging stimulus—garbage odors included—and the receptors no longer send signals to the brain.

For example, when you eat, the food you put in your mouth tastes strong at first, but as you keep eating the same thing, the taste does fade somewhat, doesn't it? Generally speaking, all of our senses are subject to sensory adaptation.

You might think, then, that if you stare at something long enough, it would also disappear, but the eyes are a little different. Even though the sensory receptors in the back of the eyes adapt to and become less responsive to a constant visual stimulus, under ordinary circumstances, the eyes are never entirely still. There's a constant involuntary movement of the eyes, tiny little vibrations called "microsaccades," that people don't consciously notice. These movements keep the eyes from adapting to what they see. (That's a good thing because otherwise many of us would no doubt experience a temporary loss of vision from staring off into space.) In contrast, saccades are rapid, voluntary or reflexive simultaneous movements of the eyes between fixation points.

habituation

tendency of the brain to stop attending to constant, unchanging information; see AP® LO EK 3.7.A.5.

sensory adaptation

tendency of sensory receptor cells to become less responsive to a stimulus that is unchanging; see AP® LO EK 1.6.A.2.

Concept Map L.O. 3.1, 3.2, 3.3

The ABCs of Sensation

sensation
process by which information from the outside world enters the brain

- related to the activation of receptors in the various sense organs and transduction of that information into neural signals
- related to changes in physical stimuli
  - detected by sensory receptors
  - influenced by both absolute and difference thresholds; responses can also be examined through signal detection theory
  - sometimes "ignored" through sensory adaptation or cognitive habituation

Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. ________ involves the detection of physical stimuli from our environment and is made possible by the activation of specific receptor cells.

a. Sensation
b. Perception
c. Sublimination
d. Adaptation

2. Kate is having her hearing tested and the audiologist is playing tones of different frequencies and systematically varying the volume of each tone. Kate is certain that she hears the tones in some trials, but she questions if she heard a tone in others. It is likely that the audiologist is trying to determine Kate's ________ for each frequency tested.

a. activation gradient
b. difference threshold
c. absolute threshold
d. gestalt level

3. After being in class for a while, ________ is a likely explanation for not hearing the sound of the fan in the LCD projector because the lower centers of the brain stop sending signals about the sound.

a. accommodation
b. habituation
c. adaptation
d. sublimation

4. You are drinking a strong cup of coffee that is particularly bitter. After a while, your taste receptors stop sending messages about the bitter flavor. What has happened?

a. perceptual defense
b. subliminal perception
c. habituation
d. sensory adaptation

3.4–3.6 The Science of Seeing

I've heard that light is waves, but I've also heard that light is made of particles—which is it?

Light is a complicated phenomenon. Although scientists have long argued over the nature of light, they finally have agreed that light has the properties of both waves and particles. The following section gives a brief history of how scientists have tried to "shed light" on the mystery of light.

3.4 Light and the Eye

3.4 Describe how light travels through the various parts of the eye.

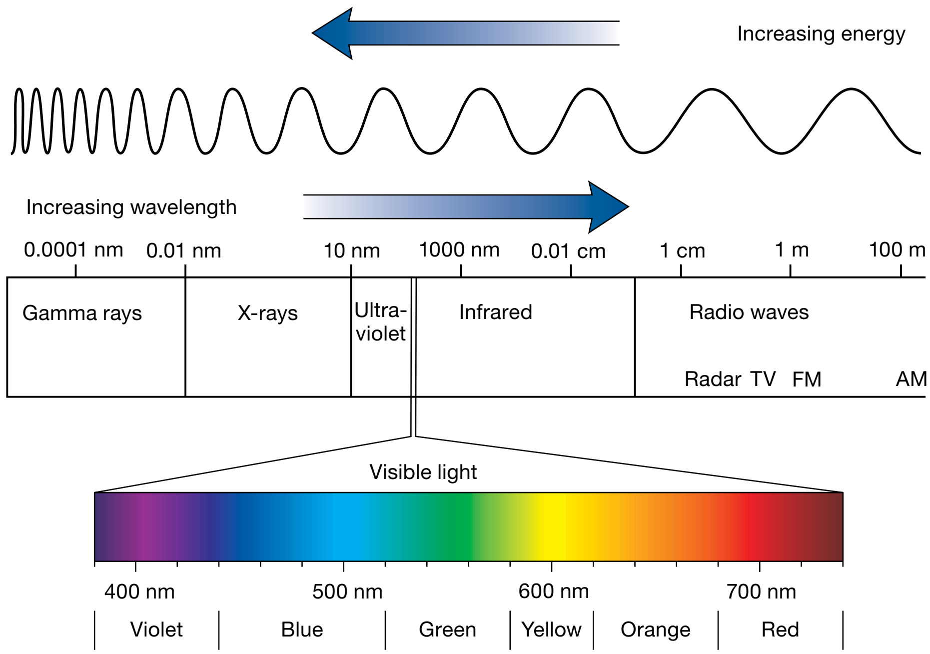
AP® LO 1.6.B: Explain how the structures and functions of the visual sensory system relate to behavior and mental processes.

It was Albert Einstein who first proposed that light is actually tiny "packets" of waves. These "wave packets" are called *photons* and have specific wavelengths associated with them (Lehnert, 2007; van der Merwe & Garuccio, 1994).

When people experience the physical properties of light, they are not really aware of its dual, wavelike and particle-like, nature. With regard to its psychological properties, there are three aspects to our perception of light: *brightness*, *color*, and *saturation*.

Brightness is determined by the amplitude of the wave—how high or how low the wave actually is. The higher the wave, the brighter the light appears to be. Low waves are dimmer. *Color*, or hue, is largely determined by the length of the wave. Short wavelengths (measured in nanometers) are found at the blue end of the *visible spectrum* (the portion of the whole spectrum of light visible to the human eye; see **Figure 3.4**), whereas longer wavelengths are found at the red end. For more information, watch the video *The Visual Spectrum* in **Revel**.

Figure 3.4 The Visible Spectrum



See the interactive version of this figure in **Revel**.

Saturation refers to the purity of the color people perceive: A highly saturated red, for example, would contain only red wavelengths, whereas a less-saturated red might contain a mixture of wavelengths. For example, when a child is using the red paint from a set of poster paints, the paint on the paper will look like a pure red, but if the child mixes in some white paint, the paint will look pink. The hue is still red, but it will be less of a saturated red because of the presence of white wavelengths. Mixing in black or gray would also lessen the saturation. (Note that when combining different colors, light works differently than pigments or paint. We will look at this distinction when we examine perception of color.)

THE STRUCTURE OF THE EYE The best way to talk about how the eye processes light is to talk about what happens to an image being viewed as the photons of light from that image travel through the eye.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

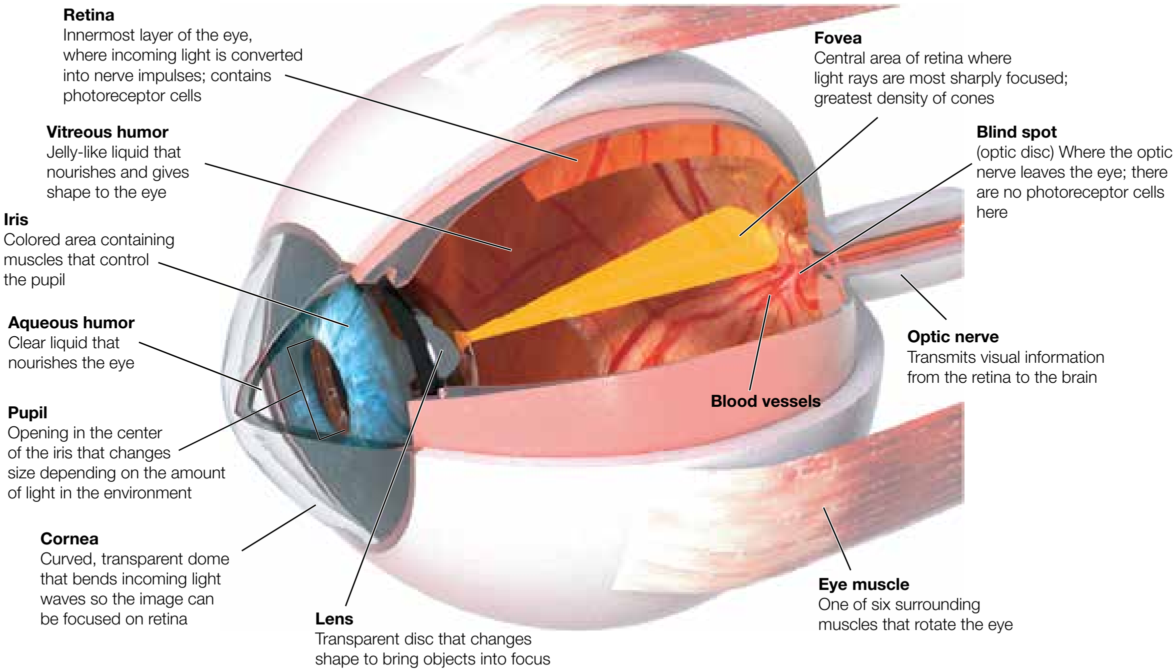
Light enters the eye directly from a source (such as the sun) or indirectly by reflecting off of an object. Refer to **Figure 3.5.** To see clearly, a single point of light from a source or reflected from an object must travel through the structures of the eye and end up on the retina as a single point. Light bends as it passes through substances of different densities, through a process known as refraction. For example, have you ever looked at a drinking straw in a glass of water through the side of the glass? It appears that the straw bends, or is broken, at the surface of the water. That optical illusion is due to the refraction of light. The structures of the eye play a vital role in both collecting and focusing light so we can see clearly. To follow the path of an image as it travels through the eye, watch the video *The Structure of the Eye* in **Revel**.

Noland White

This photo illustrates an optical illusion caused by the refraction of light. The straw is not really broken, although it appears that way.

The surface of the eye is covered in a clear membrane called the *cornea*. The cornea not only protects the eye but also is the structure that focuses most of the light coming

Figure 3.5 The Structure of the Eye



Light enters the eye through the cornea and pupil. The iris controls the size of the pupil. From the pupil, light passes through the lens to the retina, where it is transformed into nerve impulses. The nerve impulses travel to the brain along the optic nerve. See the interactive version of this figure in **Revel**.

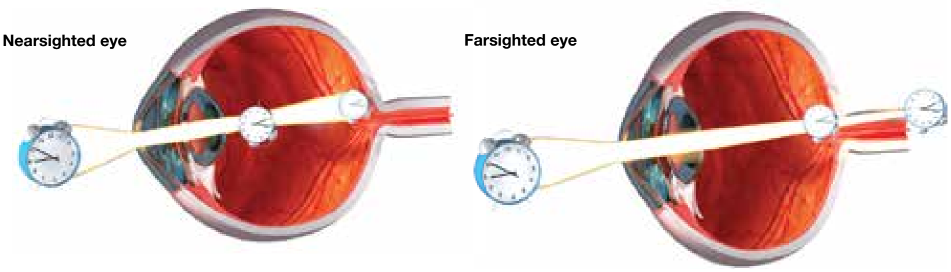
into the eye. The cornea has a fixed curvature, like a camera that has no option to adjust the focus. However, this curvature can be changed somewhat through vision-improving techniques that change the shape of the cornea. For example, ophthalmologists, physicians who specialize in medical and surgical treatment of eye problems, can use both *photorefractive keratectomy (PRK)* and *laser-assisted in situ keratomileusis (LASIK)* procedures to remove small portions of the cornea, changing its curvature and thus the focus in the eye. The next visual layer is a clear, watery fluid called the *aqueous humor*. This fluid is continually replenished and supplies nourishment to the eye. The light from the visual image then enters the interior of the eye through a hole, called the *pupil*, in a round muscle called the *iris* (the colored part of the eye). The iris can change the size of the pupil, letting more or less light into the eye. That also helps focus the image; people try to do the same thing by squinting.

Behind the iris, suspended by muscles, is another clear structure called the *lens*. The flexible lens finishes the focusing process begun by the cornea. In a process called **visual accommodation**, the lens changes its shape from thick to thin, enabling it to focus on objects that are close or far away. The variation in thickness allows the lens to project a sharp image on the retina. People lose this ability as the lens hardens through aging (a disorder called *presbyopia*). Although people try to compensate* for their inability to focus on things close to them, eventually they usually need bifocals because their arms just aren't long enough anymore. In nearsightedness, or *myopia*, visual accommodation may occur, but the shape of the eye causes the focal point to fall short of the retina. In farsightedness, or *hyperopia*, the focus point is beyond the retina (see **Figure 3.6**). Glasses, contacts, or corrective surgery like LASIK or PRK can correct these issues.

visual accommodation
the change in the thickness of the lens as the eye focuses on objects that are far away or close; see AP® LO EK 1.6.B.2.

*compensate: to correct for an error or defect.

Figure 3.6 Nearsightedness and Farsightedness



Source: Adapted from St. Luke's Cataract & Laser Institute.

Noland White

Compared to the center image, which approximates normal vision, the first image simulates the experience of tunnel vision, and the last image simulates the experience of macular degeneration.

Low vision is a vision impairment that cannot be corrected with regular corrective lenses and interferes with daily life, often measured as 20/70 or lower visual acuity, meaning that what someone with 20/20 vision (unimpaired) sees at 70 feet is only visible at 20 feet for the individual with low vision (American Foundation for the Blind, 2023). Someone "legally blind" in the United States has a visual acuity of 20/200 or less with the best correction with regular lenses, or they experience tunnel vision with a restricted visual field of 20 degrees or less. About 85 percent of individuals with either low vision or legal blindness can still perceive light. In comparison, only about 15 percent of individuals experience *total blindness* and cannot perceive any light or forms (American Foundation for the Blind, 2023). Depending on the context, visual acuity is typically measured with Snellen or *logMAR* charts (Azzam & Ronquillo, 2022). You can see examples of the Snellen eye chart and the logMAR eye chart in **Revel**.

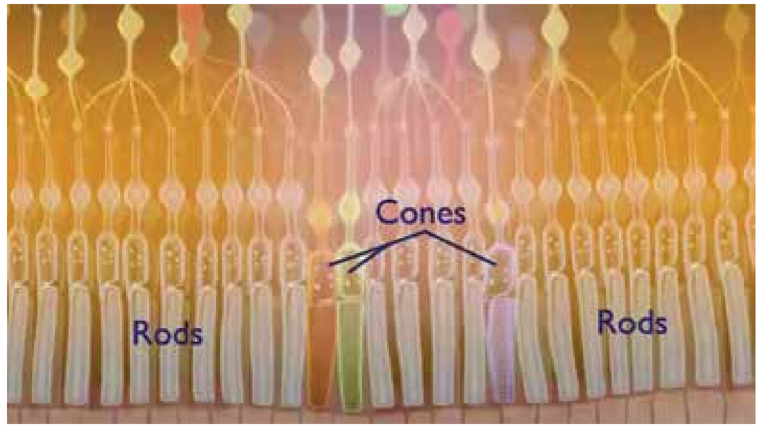
Retinal diseases can cause vision changes depending on which part of the retina is affected. *Diabetic retinopathy*, caused by damaged vessels in the back of the eye and swelling of the retina, leads to lower visual acuity and seeing cobweb-like streaks and dark floating spots, or "floaters" (Mayo Foundation for Medical Education and Research, 2022b; National Eye Institute, 2022). Diabetic retinopathy can also cause changes to the periphery of the retina where the rods are located, resulting in tunnel vision or a loss of peripheral vision (Cleveland Clinic, 2022). Individuals with *glaucoma*, or damage to the optic nerve, can also experience tunnel vision. *Age-related macular degeneration* (AMD) affects the *macula*, the area of the retina surrounding the fovea, resulting in central vision loss, making tasks like recognizing faces, reading, and driving more difficult (Mayo Foundation for Medical Education and Research, 2022a; National Eye Institute, 2021). See photos for examples of how these visual changes might be experienced.

Remember that the visual impairments discussed in this section affect an individual's ability to detect visual stimuli. There are some conditions or disorders where the eyes work perfectly well. Still, the individual's experience is dramatically affected by either the disruption of visual information getting to specific areas of the brain or there are brain areas not working as they should. *Agnosia* is a neurological condition in which a person cannot recognize or interpret sensory information despite their basic sensory abilities remaining intact and functioning as they should. For example, **prosopagnosia**, also known as "face blindness," is a visual agnosia in which an individual can see and detect the visual features of a face, but is unable to recognize them. Still, they are unable to recognize their own faces. So, instead of a sensory impairment, the impairment occurs at the perceptual level, where the brain processes and interprets the visual sensory information. The majority of cases of prosopagnosia are *developmental* in that people were either born with the condition due to genetic or other influences (also called *congenital* prosopagnosia), or they experienced brain damage shortly before or after birth. For others, it is *acquired*, or the result of damage to visual areas of the brain. The *fusiform gyrus*, which spans the bottom surface of the temporal and occipital lobes, and the right *fusiform facial area* (FFA), in particular, seem to play a critical role (Damasio et al., 2000; Mesulam, 1998). The FFA is part

prosopagnosia
a type of visual agnosia characterized by an impaired ability to perceive and recognize faces, while the ability to recognize other objects remains largely intact; see AP® LO EK 1.6.B.5.

of the visual association cortex, not the primary visual cortex. See Learning Objectives 2.8, 2.9. In contrast, consider the experience of *blindsight*, where some individuals with damage to the primary visual cortex, or V1, lack visual awareness. In blindsight, individuals report they cannot see and are, therefore, "consciously blind" but can respond to some types of visually guided information (LeDoux et al., 2020; Leopold, 2012).

Once past the lens, light passes through a large, open space filled with a clear, jelly-like fluid called the *vitreous humor*. This fluid, like the aqueous humor, also nourishes the eye and gives it shape.



Light passes through the ganglion and bipolar cells until it reaches and stimulates the retina's rods and cones.

THE TRANSDUCTION OF LIGHT The final stop for light within the eye is the *retina*, a light-sensitive area at the back of the eye containing three layers: ganglion cells, bipolar cells, and the **rods** and **cones**, special receptor cells (*photoreceptors*) that respond to the various wavelengths of light. The video in **Revel**, *Rods and Cones*, provides an overview of this process.

While the retina is responsible for absorbing and processing light information, the rods and the cones are the business end of the retina—the part that actually receives the photons of light and turns them into neural signals for the brain, sending them first to the *bipolar cells* (a type of interneuron; called bipolar or "two-ended" because they have a single dendrite at one end and a single axon on the other; see Learning Objective 2.1) and then to the retinal *ganglion cells* whose axons form the optic nerve.

The rods and cones are responsible for different aspects of vision. There are 6 million cones in each eye, and while they are located all over the retina, cones are more concentrated at its very center (the area called the *fovea*) where there are no rods. Some cones have a private line to the optic nerve (one bipolar cell for each cone). This means that the cones are the receptors for visual acuity. Cones require a lot more light to function than the rods do and work best in bright light, which is also when people see things most clearly. Cones are also sensitive to different wavelengths of light, so they are responsible for color vision.

Rods are found over the entire retina, except for the *fovea.* They are concentrated in the periphery and are responsible for peripheral vision. They are sensitive to changes in brightness but only for a narrow band of wavelengths, so they see in black and white and shades of gray. Many rods connect to a single bipolar cell. If only one rod in a region is stimulated, the brain perceives the whole area as stimulated. But because the brain doesn't know exactly what part of the region is actually sending the message, visual acuity is quite low. That's why things tend to appear less distinct and dark or grayish in low light levels, such as at twilight or in a dimly lit room.

And because rods work well in low levels of light, they are also the cells that allow the eyes to fully adapt to low light. **Dark adaptation** occurs as the eye recovers its ability to see when going from a brightly lit state to a dark state. (The light-sensitive pigments that allow us to see are able to regenerate or "recharge" in the dark.) Both cones and rods are involved in dark adaptation, with the cones adapting faster but only allowing for a few minutes of vision in dimly lit conditions. The rods adapt more slowly, but since they require less light than the cones, they will continue to adapt to lower light levels. When going from bright to dark, the brighter the pre-darkness light was, the longer it takes the cones and rods to adapt to the new lower levels of light (Bartlett, 1965). This is why the bright headlights of an oncoming car can leave a person less able to see for a while after that car has passed. Fortunately, this is usually a temporary condition because the bright light was on so briefly. The cones adapt first, followed by the rods readapting to the dark night. Full dark adaptation, which occurs when going from more constant light to darkness, such as turning out one's bedroom lights, takes about 30 minutes. As people

rods
visual sensory receptors found at the back of the retina, responsible for noncolor sensitivity to low levels of light; see AP® LO EK 1.6.B.3.

cones
visual sensory receptors found at the back of the retina, responsible for color vision and sharpness of vision.

dark adaptation
the recovery of the eye's sensitivity to visual stimuli in darkness after exposure to bright lights; see AP® LO EK 1.6.B.3.

light adaptation

the recovery of the eye's sensitivity to visual stimuli in light after exposure to darkness; see AP® LO EK 1.6.B.3.

blind spot

area in the retina where the axons of the retinal ganglion cells exit the eye to form the optic nerve; insensitive to light; see AP® LO EK 1.6.B.1.

get older this process takes longer, causing many older persons to be less able to see at night and in darkened rooms (Klaver et al., 1998). This age-related change can cause *night blindness*, in which a person has difficulty seeing well enough to drive at night or get around in a darkened room or house. When going from a darkened room to one that is brightly lit, the opposite process occurs. The cones have to adapt to the increased level of light, and they accomplish this **light adaptation** much more quickly than the rods adapt to darkness—it takes a few seconds at most (Hood, 1998).

Night blindness is often one of the first signs of vitamin A deficiency (a health care provider can perform tests to check levels.) For example, low vitamin A levels can occur following gastrointestinal (GI) surgeries, such as bariatric procedures for weight loss, or with some GI issues, chronic health conditions, or restrictive eating. Some research indicates that taking supplemental vitamin A can reverse or relieve this symptom in some cases (Garza et al., 2022; Jacobson et al., 1995; Kishimoto et al., 2021). Left untreated, deficiencies in vitamin A can cause damage to photoreceptors and eventual blindness (Meister & Tessier-Lavigne, 2021). Vitamin A deficiency due to malnutrition or disease is a public health problem in more than half of all countries, as it is the leading, but preventable, cause of childhood blindness (World Health Organization, 2025). This is a concern primarily in developing countries rather than developed ones, with those in Southeast Asia and Africa being major areas of concern. Of those who become blind, approximately half die within a year (World Health Organization, 2025).

Lastly, the eyes don't adapt to constant stimuli under normal circumstances because of saccadic movements. But if people stare with one eye at one spot long enough, small objects that slowly cross their visual field may at one point disappear briefly because there is a "hole" in the retina—the place where all the axons of those ganglion cells leave the retina to become the optic nerve, the *optic disk*. There are no rods or cones here, so this is referred to as the **blind spot**. You can demonstrate the blind spot for yourself by following the directions in **Figure 3.7**.

Figure 3.7 The Blind Spot

Hold the image in front of you. Close your right eye and stare at the picture of the dog with your left eye. Slowly bring the image closer to your face. The picture of the cat will disappear at some point because the light from the picture of the cat is falling on your blind spot. If you cannot seem to find your blind spot, try moving the image more slowly.

3.5 The Visual Pathway

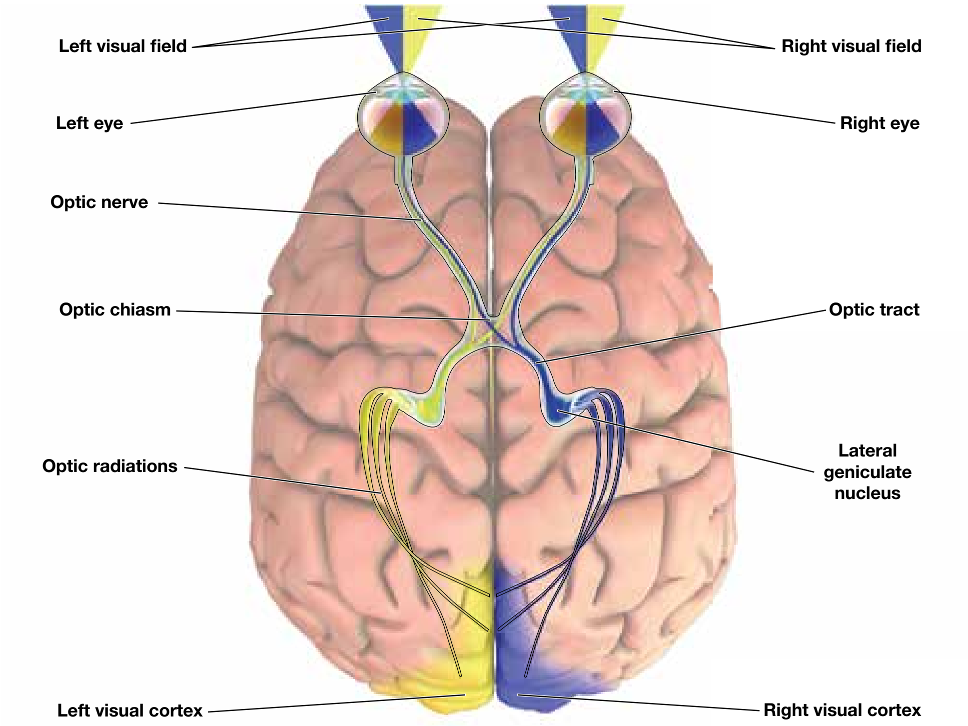
3.5 Explain how light information reaches the visual cortex.

AP® LO 1.6.B: Explain how the structures and functions of the visual sensory system relate to behavior and mental processes.

You may want to first look at **Figure 3.8** for a moment before reading this section. Light entering the eyes can be separated into the left and right visual fields. Light from the right visual field falls on the left side of each eye's retina; light from the left visual field falls on the right side of each retina. Light travels in a straight line through the cornea and lens, resulting in the image projected on the retina actually being upside down and reversed from left to right as compared to the visual fields. Thank goodness our brains can compensate for this!

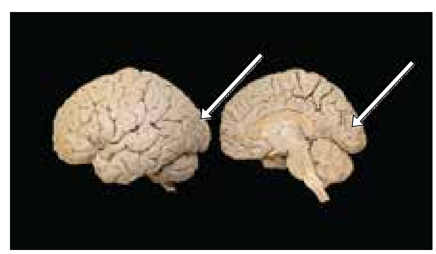
The areas of the retina can be divided into halves, with the halves toward the temples of the head referred to as the temporal retinas and the halves toward the center, or nose, called the nasal retinas. Look at Figure 3.8 again. Notice that the information from the left visual field (falling on the right side of each retina) goes to the right visual cortex, while the

Figure 3.8 Crossing of the Optic Nerve



Light falling on the left side of each eye's retina (from the right visual field, shown in yellow) will stimulate a neural message that will travel along the optic nerve to the thalamus and then on to the visual cortex in the occipital lobe of the left hemisphere. Notice that the message from the temporal half of the left retina goes to the left occipital lobe, while the message from the nasal half of the right retina crosses over to the left hemisphere (the optic chiasm is the point of crossover). The optic nerve tissue from both eyes joins together to form the left optic tract before going on to the lateral geniculate nucleus of the thalamus, the optic radiations, and then the left occipital lobe. For the left visual field (shown in blue), the messages from both right sides of the retinas will travel along the right optic tract to the right visual cortex in the same manner.

information from the right visual field (falling on the left side of each retina) goes to the left visual cortex. This is because the axons from the temporal halves of each retina project to the visual cortex on the same side of the brain, while the axons from the nasal halves cross over to the visual cortex on the opposite side of the brain. The optic chiasm is the point of crossover.



Noland White and Walter Isaac

Primary and secondary visual cortex are found in the occipital lobe. Arrows point to the occipital lobe in these external and medial views of the brain.

3.6 Perception of Color

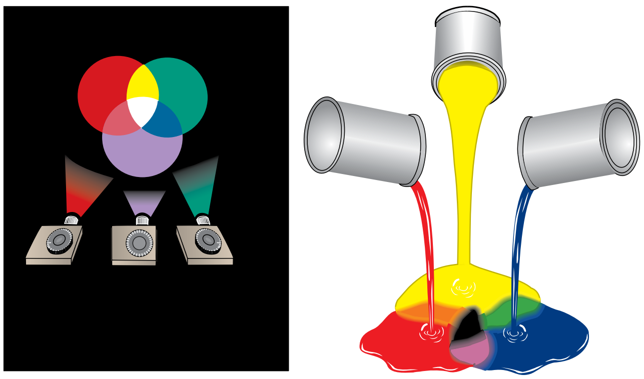
3.6 Compare and contrast two major theories of color vision, and explain how color-deficient vision occurs.

AP® LO 1.6.B: Explain how the structures and functions of the visual sensory system relate to behavior and mental processes.

Earlier you said the cones are used in color vision. There are so many colors in the world—are there cones that detect each color? Or do all cones detect all colors?

Although experts in the visual system have been studying color and its nature for many years, at this point in time there is an ongoing theoretical discussion about the role the cones and other brain areas play in the perception of color.

Figure 3.9 Mixing Light



The mixing of direct light is different than the mixing of reflected light. The mixing of red, blue, and green light is additive, resulting in white light. The mixing of multiple colors of paint (reflected light) is subtractive, resulting in a dark gray or black color.

TRICHROMATIC THEORY Two theories about how people see colors were originally proposed in the 1800s. The first is called the **trichromatic ("three colors") theory**. First proposed by Thomas Young in 1802 and later modified by Hermann von Helmholtz in 1852, this theory proposed three types of cones: red cones, blue cones, and green cones, one for each of the three primary colors of light.

Most people probably think that the primary colors are red, yellow, and blue, but these are the primary colors when talking about *painting*—not when talking about *light*. Paints *reflect* light, and the way reflected light mixes is different from the way direct light mixes. For example, if an artist were to blend red, yellow, and blue paints together, the result would be a mess—a black mess. The mixing of paint (reflected light) is subtractive, removing more light as you mix in more colors. As all of the colors are mixed, more light waves are absorbed and we see black. But if the artist were to blend a red, green, and blue light together by focusing lights of those three colors on one common spot, the result would be white, not black (see **Figure 3.9**). The mixing of direct light is additive, resulting in lighter colors, more light, and when mixing red, blue, and green, we see white, the reflection of the entire visual spectrum.

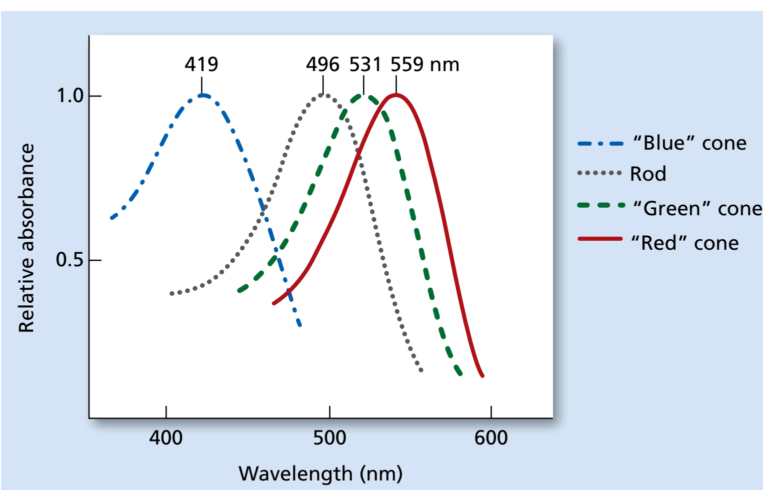
trichromatic ("three colors") theory

theory of color vision that proposes three types of cones: red, blue, and green; see AP® LO EK 1.6.B.4.

In the trichromatic theory, different shades of colors correspond to different amounts of light received by each of these three types of cones. These cones then fire their message to the brain's vision centers. The combination of cones and the rate at which they are firing determine the color that will be seen. For example, if the red and green cones are firing in response to a stimulus at fast enough rates, the color the person sees is yellow. If the red and blue cones are firing fast enough, the result is magenta. If the blue and green cones are firing fast enough, a kind of cyan color (blue-green) appears.

Paul K. Brown and George Wald (1964) identified three types of cones in the retina, each sensitive to a range of wavelengths, measured in nanometers (nm), and a peak sensitivity that roughly corresponds to three different colors (although hues/colors can vary depending on brightness and saturation). The peak wavelength of light the cones seem to be most sensitive to turns out to be just a little different from Young and von Helmholtz's original three corresponding colors: Short-wavelength cones detect what we see as blue-violet (about 420 nm), medium-wavelength cones detect what we see as green (about 530 nm), and long-wavelength cones detect what we see as green-yellow (about 560 nm). Interestingly, none of the cones identified by Brown and Wald have a peak sensitivity to light where most of us see red (around 630 nm). Keep in mind, though, each cone responds to light across a range of wavelengths, not just its wavelength of peak sensitivity. Depending on the intensity of the light, both the medium- and long-wavelength cones respond to light that appears red, as shown in **Figure 3.10** (see the interactive version of this figure in **Revel**).

Figure 3.10 Absorbance of Light from Rods and Cones



OPPONENT-PROCESS THEORY The trichromatic theory would, at first glance, seem to be more than adequate to explain how people perceive color. But there's an interesting phenomenon that this theory cannot explain. If a person stares at a picture of the American flag for a little while—say, a minute—and then looks away to a blank white wall or sheet of paper, that person will see an afterimage of the flag. **Afterimages** occur when a visual sensation persists for a brief time even after the original stimulus is removed. The person would also notice rather quickly that the colors of the flag in the afterimage are all wrong—green for red, black for white, and yellow for blue. If you follow the directions for **Figure 3.11**, in which the flag is yellow, green, and black, you should see a flag with the usual red, white, and blue.

afterimages
images that occur when a visual sensation persists for a brief time even after the original stimulus is removed.

Hey, now the afterimage of the flag has normal colors! Why does this happen?

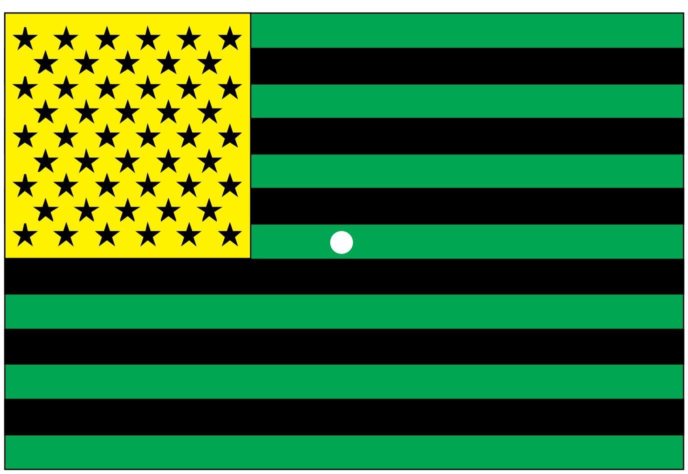
The phenomenon of the color afterimage is explained by the second theory of color perception, called the **opponent-process theory** (De Valois & De Valois, 1993; Hurvich & Jameson, 1957), based on an idea first suggested by Edwald Hering in 1874 (Finger, 1994). In opponent-process theory, there are four primary colors: red, green, blue, and yellow. The colors are arranged in pairs, with each member of the pair as opponents. Red is paired with its opponent green, and blue is paired with its opponent yellow. If one member of a pair is strongly stimulated, the other member is inhibited and cannot be working—so there are no reddish-greens or bluish-yellows.

opponent-process theory
theory of color vision that proposes visual neurons (or groups of neurons) are stimulated by light of one color and inhibited by light of another color.

So how can this kind of pairing cause a color afterimage? From the level of the bipolar and ganglion cells in the retina, all the way through the thalamus, and on to the visual cortical areas in the brain, some neurons (or groups of neurons) are stimulated by light from one part of the visual spectrum and inhibited by light from a different part of the spectrum. For example, let's say we have a red-green ganglion cell in the retina whose baseline activity is rather weak when we expose it to white light. However, the cell's activity is increased by red light, so we experience the color red. If we stimulate the cell with red light for a long enough period of time, the cell becomes fatigued. If we then swap out the red light with white light, the fatigued cell responds even less than the original baseline. Now we experience the color green, because green is associated with a decrease in the responsiveness of this cell.

So which theory is the right one? Both theories play a part in color vision. Trichromatic theory can explain what is happening with the raw stimuli, the actual detection of various wavelengths of light. Opponent-process theory can explain afterimages and other aspects of visual perception that occur after the initial detection of light from our environment. In addition to the retinal bipolar and ganglion cells, opponent-process cells are contained inside the thalamus in an area called the lateral geniculate nucleus

Figure 3.11 Color Afterimage



Stare at the white dot in the center of this oddly colored flag for about 30 seconds. Now look at a white piece of paper or a white wall. Notice that the colors are now the normal, expected colors of the American flag. They are also the primary colors that are opposites of the colors in the picture and provide for the opponent-process theory of color vision. See the interactive version of this figure in **Revel**.

(LGN). The LGN is part of the pathway that visual information takes to the occipital lobe. It is when the cones in the retina send signals through the retinal bipolar and ganglion cells that we see the red versus green pairings and blue versus yellow pairings. Together with the retinal cells, the cells in the LGN appear to be the ones responsible for opponent-processing of color vision and the afterimage effect.

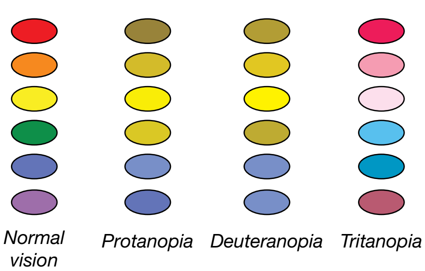
So which theory accounts for color blindness? I've heard there are two kinds of color blindness, when you can't tell red from green and when you can't tell blue from yellow.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

COLOR VISION DEFICIENCY From the mention of red-green and yellow-blue color blindness, one might think that the opponent-process theory explains this phenomena. But in reality, color vision deficiency, also called *color-deficient vision* or "color blindness", is caused by defective cones in the retina of the eye. Most people who experience color vision deficiency, have two types of cones working and can see many colors.

There are really three kinds of color vision deficiency. In a very rare type, *achromatopsia* or *monochromatic vision*, people have cones, but they are not functioning correctly as the result of one or more genetic mutations. Essentially, everything looks the same to the brain—black, white, and shades of gray. The other types of color vision deficiency, or *dichromatic vision*, are caused by the same kind of problem—having one cone that does not work properly. So instead of experiencing the world with normal vision based on combinations of three cones or colors—trichromatic vision—individuals with dichromatic vision experience the world with essentially combinations of two cones or colors. Red-green color deficiency (as in *protanopia* or *deuteranopia*) is due to red or green cones not functioning correctly. In both of these, the individual confuses reds and greens, seeing the world primarily in blues, yellows, and shades of gray. In one real-world example, a November 2015 professional American football game had one team in all green uniforms and the other in all red uniforms. The combination caused problems for some viewers, who were unable to tell the teams apart! An actual lack of functioning blue cones is much less common and causes blue-yellow color deficiency (*tritanopia*). These individuals see the world primarily in reds, greens, and shades of gray. To get an idea of what it might be like for someone who experiences color vision deficiency, look at **Figure 3.12**.

Figure 3.12 Types of Color Vision Deficiency



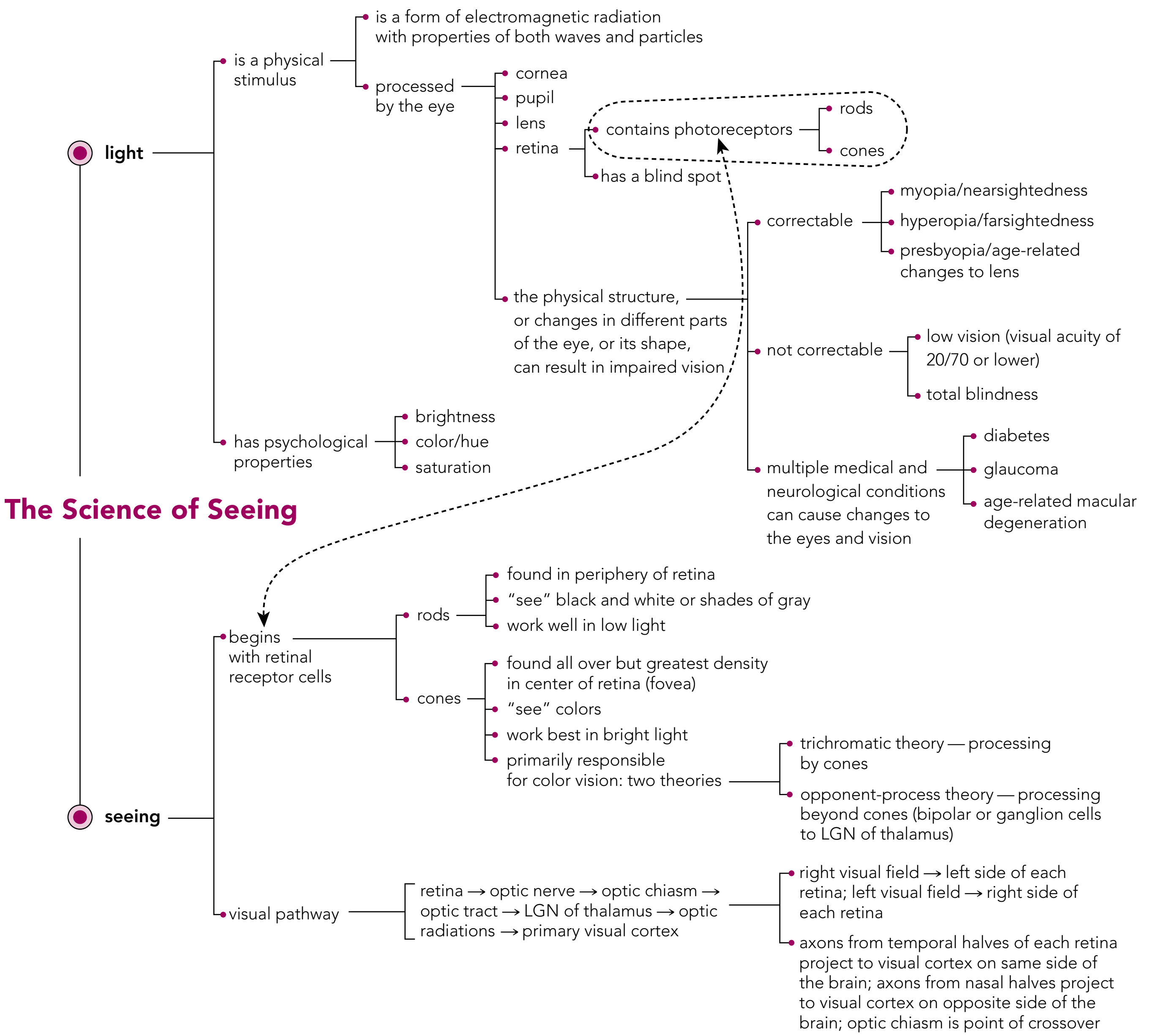
Compare the colors perceived by someone with normal color vision on the left with three types of color vision deficiency. Protanopia is linked to red cone cells not working properly, deuteranopia is caused by deficient functioning of green cone cells, and tritanopia is tied to a lack of functioning blue cone cells.

Source: Timonina/Shutterstock

Why are most of the people with color vision deficiency male?

Color-deficient vision can be *congenital*, present at birth, or *acquired*, developing or originating after birth. Color vision deficiencies involving one set of cones is inherited in a pattern known as *sex-linked inheritance*. The gene for color-deficient vision is *recessive*. To inherit a recessive trait, you normally need two of the genes, one from each birth parent. See Learning Objective 8.3. But the gene for color-deficient vision is attached to a particular chromosome (a package of genes) that helps determine the sex of a person. Males have one X chromosome and one smaller Y chromosome (named for their shapes), whereas females have two X chromosomes. The smaller Y has fewer genes than the larger X, and one of the genes missing is the one that would suppress the gene for color-deficient vision. For a female to be born with color vision deficiency, she must inherit two recessive genes, one from each parent, but a male only needs to inherit *one* recessive gene—the one passed on to him on his female parent's X chromosome. His odds are greater; therefore, more males than females have color-deficient vision.

Concept Map L.O. 3.4, 3.5, 3.6



Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. Which of the following is largely determined by the length of a light wave?

a. color
b. brightness
c. saturation
d. duration

2. Damage to this clear membrane at the front of the eye can severely disturb the eye's ability to focus light.

a. pupil
b. iris
c. cornea
d. retina

3. In farsightedness, also known as ________, the focal point is ________ the retina.

a. hyperopia, beyond

b. presbyopia, above

c. myopia, below

d. presbyopia, in front of

4. Sabreen stares at a fixed spot in her bedroom using only one eye. After a while, what might happen to her vision?

a. Objects will become more distorted the longer she looks at them.

b. Any object that she focuses on will begin to rotate, first clockwise, then counterclockwise.

c. Objects will become more focused the longer she looks at them.

d. Any small object that crosses her visual field very slowly may at one point briefly disappear.

5. What are the three primary colors as proposed by the trichromatic theory?

a. red, yellow, blue

b. red, green, blue

c. white, black, brown

d. white, black, red

6. Which theory of color vision accounts for afterimages?

a. color-deficient vision

b. trichromatic theory

c. opponent-process theory

d. monochrome color blindness

3.7–3.10 The Hearing Sense: Can You Hear Me Now?

If light works like waves, then do sound waves have similar properties?

Both the seeing and hearing senses rely on waves. But the similarity ends there, as the physical properties of sound are different from those of light.

3.7 Sound Waves and the Ear

3.7 Explain the nature of sound, and describe how it travels through the various parts of the ear.

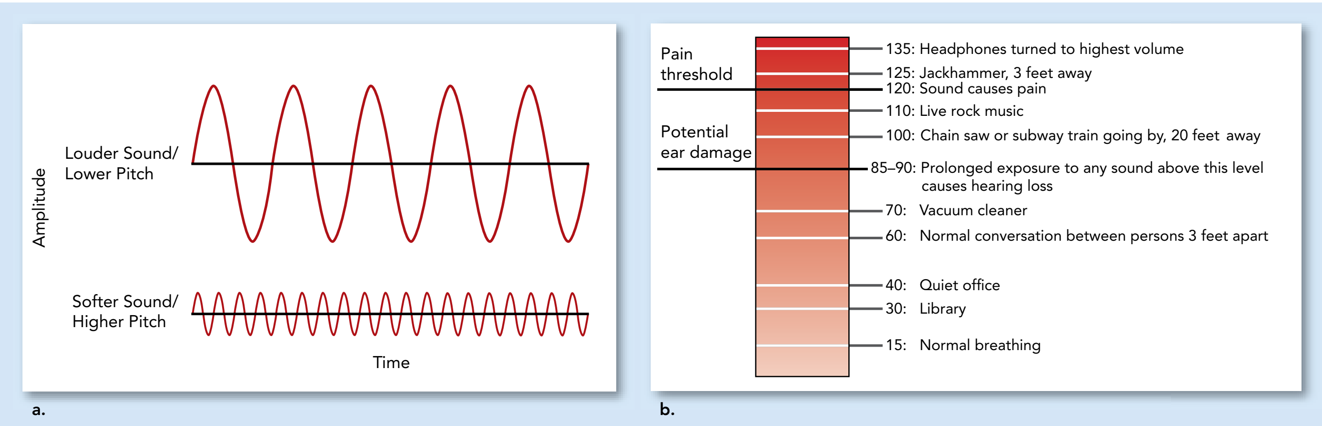
AP® LO 1.6.C: Explain how the structures and functions of the auditory sensory system relate to behavior and mental processes.

Sound waves do not come in little packets the way light comes in photons. Sound waves are simply the vibrations of the molecules of air that surround us. Sound waves do have the same properties of light waves though—wavelength, amplitude, and purity. Wavelengths are interpreted by the brain as frequency or *pitch* (high, medium, or low). Amplitude is interpreted as *volume*, how soft or loud a sound is (see **Figure 3.13**). Finally, what would correspond to saturation or purity in light is called *timbre* in sound, a richness in the tone of the sound. And just as people rarely see pure colors in the world around us, they also seldom hear pure sounds. The everyday noises that surround people do not allow them to hear many pure tones.

Just as a person's vision is limited by the visible spectrum of light, a person is also limited in the range of frequencies they can hear. Frequency is measured in cycles (waves) per second, or **hertz (Hz)**. Human limits are between 20 and 20,000 Hz, with the most sensitivity from about 2,000 to 4,000 Hz—very important for conversational speech. (In comparison, dogs can hear between 50 and 60,000 Hz, and dolphins can hear up to 200,000 Hz.) To hear the higher and lower frequencies of a piece of music on their iPhone, for example, a person would need to increase the amplitude or volume—which explains why some people like to "crank it up."

hertz (Hz)
cycles or waves per second, a measurement of frequency.

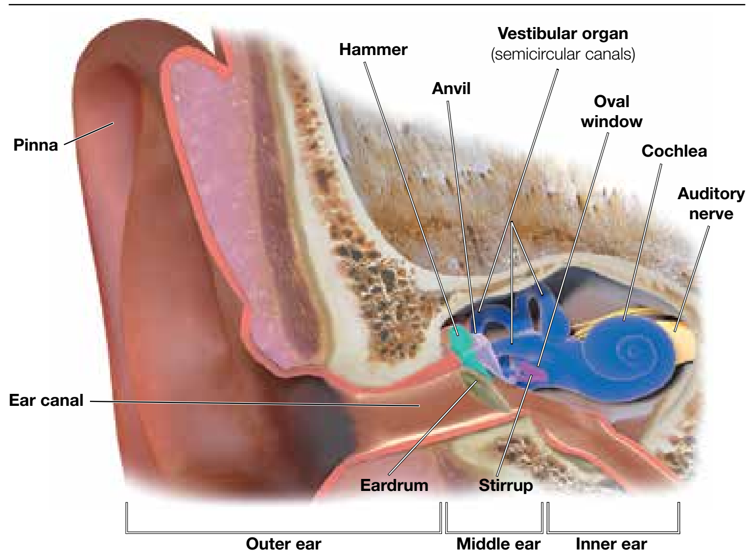
Figure 3.13 Sound Waves and Decibels



(a) Two sound waves. The higher the wave, the louder the sound; the lower the wave, the softer the sound. If the waves are close together in time (high frequency), the pitch will be perceived as a high pitch. Waves that are farther apart (low frequency) will be perceived as having a lower pitch. (b) Decibels of various stimuli. A *decibel* is a unit of measure for loudness. Psychologists study the effects that noise has on stress, learning, performance, aggression, and psychological and physical well-being.

THE STRUCTURE OF THE EAR: FOLLOW THE VIBES The ear is a series of structures, each of which plays a part in the sense of hearing, as shown in **Figure 3.14** (see the interactive version of this figure in **Revel**).

Figure 3.14 The Structure of the Ear



THE OUTER EAR The **pinna** is the visible, external part of the ear that serves as a kind of concentrator, funneling* the sound waves from the outside into the structure of the ear. The pinna is also the entrance to the **auditory canal** (or ear canal), the short tunnel that runs down to the *tympanic membrane*, or eardrum. When sound waves hit the eardrum, they cause three tiny bones in the middle ear to vibrate.

THE MIDDLE EAR: HAMMER, ANVIL, AND STIRRUP The three tiny bones in the middle ear are known as the hammer (*malleus*), anvil (*incus*), and stirrup (*stapes*), each name stemming from the shape of the respective bone. Collectively, they are referred to as the *ossicles* and they are the smallest bones in the human body. The vibration of these three bones amplifies the vibrations from the eardrum. The stirrup, the last bone in the chain, causes a membrane covering the opening of the inner ear to vibrate. This membrane is called the *oval window*, and its vibrations set off another chain reaction within the inner ear.

THE TRANSDUCTION OF SOUND In our previous discussion of vision, we discussed the special role the retina and the photoreceptors play in the transduction of light. In hearing, specific structures in the inner ear are involved in the transduction of sounds; they are the *hair cells* found on the *organ of Corti*.

The inner ear is a snail-shaped structure called the **cochlea**, which is filled with fluid. When the oval window vibrates, it causes the fluid in the cochlea to vibrate. This fluid surrounds a membrane running through the middle of the cochlea called the *basilar membrane*.

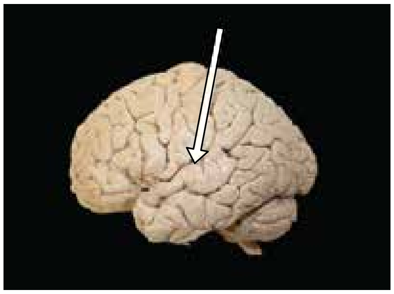
The basilar membrane is the resting place of the organ of Corti, which contains the receptor cells for the sense of hearing. When the basilar membrane vibrates, it vibrates

auditory canal
short tunnel that runs from the pinna to the eardrum.

pinna
the visible part of the ear.

cochlea
snail-shaped structure of the inner ear that is filled with fluid.

*funneling: moving to a focal point.



Noland White and Walter Isaac

The primary auditory cortex is found on the superior temporal gyrus in the temporal lobe.

the organ of Corti, causing it to brush against a membrane above it. On the organ of Corti are special cells called hair cells, which are the receptors for sound. When these auditory receptors or hair cells are bent up against the other membrane, it causes them to send a neural message through the **auditory nerve** (which contains the axons of all the receptor neurons) and into the brain, where after passing through the thalamus, the auditory cortex will interpret the sounds (the transformation of the vibrations of sound into neural messages is transduction). The louder the sound in the outside world, the stronger the vibrations that stimulate more of those hair cells—which the brain interprets as loudness.

I think I have it straight—but all of that just explains how soft and loud sounds get to the brain from the outside. How do we hear different kinds of sounds, like high pitches and low pitches?

3.8 Perceiving Pitch

3.8 Summarize three theories of how the brain processes information about pitch.

AP® LO 1.6.C: Explain how the structures and functions of the auditory sensory system relate to behavior and mental processes.

Pitch refers to how high or low a sound is. For example, the bass beats in the music pounding through the wall of your apartment from the neighbors next door are low pitch, whereas the scream of a 2-year-old child is a very high pitch. *Very* high. There are three primary theories about how the brain receives information about pitch.

PLACE THEORY The oldest of the three theories, **place theory**, is based on an idea proposed in 1863 by Hermann von Helmholtz and elaborated on and modified by Georg von Békésy, beginning with experiments first published in 1928 (Békésy, 1960). In this theory, the pitch a person hears depends on the vibration of frequencies that occur along the basilar membrane, which correspond to where the hair cells that are stimulated are located on the organ of Corti. For example, if the person is hearing a high-pitched sound, the basilar membrane near the oval window will vibrate, and the corresponding hair cells near the oval window will be stimulated. However, if the sound is low pitched, the furthest parts of the basilar membrane will vibrate, accompanied by stimulation of the hair cells located farther away on the organ of Corti. This frequency-to-place mapping is known as *tonotopic mapping, tonotopic organization*, or *tonotopic representation*.

FREQUENCY THEORY **Frequency theory**, developed by Ernest Rutherford in 1886, and later elaborated on by Wever & Bray (1930, 1937), states that pitch is related to how fast the basilar membrane vibrates. The faster this membrane vibrates, the higher the pitch; the slower it vibrates, the lower the pitch. In this theory, all of the auditory neurons would be firing at the same time. In other words, in this theory, pitch is determined by a sound's *temporal code*, or coding, by the basilar membrane.

So which of these first two theories is right? It turns out that both are right—up to a point. For place theory to be correct, the basilar membrane has to vibrate unevenly—which it does when the frequency of the sound is *above* 1,000 Hz. For frequency theory to be correct, the neurons associated with the hair cells would have to fire as fast as the basilar membrane vibrates. This only works up to 1,000 Hz, because neurons don't appear to fire at exactly the same time and rate when frequencies are faster than 1,000 times per second. Not to mention the maximum firing rate for neurons is approximately 1,000 times per second due to the refractory period. See Learning Objective 2.2.

VOLLEY PRINCIPLE Frequency theory works for low pitches, and place theory works for moderate to high pitches. Is there another explanation? Yes, and it is a third theory, developed by Ernest Wever and Charles Bray, called the **volley principle** (Wever, 1949;

auditory nerve
bundle of axons from the hair cells in the inner ear.

pitch
psychological experience of sound that corresponds to the frequency of the sound waves; higher frequencies are perceived as higher pitches; see AP® LO EK 1.6.C.1.

place theory
theory of pitch that states that different pitches are experienced by the stimulation of hair cells in different locations on the organ of Corti; see AP® LO EK 1.6.C.2.

frequency theory
theory of pitch that states that pitch is related to the speed of vibrations in the basilar membrane; see AP® LO EK 1.6.C.2.

volley principle
theory of pitch that states that frequencies from about 400 Hz to 4,000 Hz cause the hair cells (auditory neurons) to fire in a volley pattern, or take turns in firing; see AP® LO EK 1.6.C.2.

Wever & Bray, 1930, 1937), which appears to account for pitches from about 400 Hz up to about 4,000 Hz. In this explanation, groups of auditory neurons take turns firing in a process called *volleying*. If a person hears a tone of about 3,000 Hz, it means that three groups of neurons have taken turns sending the message to the brain—the first group for the first 1,000 Hz, the second group for the next 1,000 Hz, and so on.

3.9 Loudness and Localization of Sound

3.9 Describe how we determine the loudness and location of sounds.

AP® LO 1.6.C: Explain how the structures and functions of the auditory sensory system relate to behavior and mental processes.

In addition to pitch, the activity of hair cells in the cochlea and their location on the basilar membrane provide information about the loudness of sounds (Gardner & Gardner, 2021; Oertel & Wang, 2021). For low-frequency sounds, where rate coding conveys pitch information, the number of active hair cells indicates sound intensity. However, for moderate and high-frequency sounds, where pitch is based on place coding (where on the basilar membrane hair cells are activated), loudness is conveyed by the firing rate of hair cells.

localization
our ability to pinpoint the physical or spatial location of a sensory stimulus; see AP® LO EK 1.6.C.3.

What about sound **localization** (i.e., how do we figure out where the sounds around us are coming from)? We tend to do a pretty good job of determining the source of a sound to the left or right of us, and tend to do so by the differences in both the intensity and timing of the sound arriving at each ear. We generally use timing information with lower frequencies and intensity differences for higher frequencies. If a sound is coming from our left, it will reach our left ear before it does our right ear, and the opposite is true for a sound coming from the right. Also, note that a sound from the left will be more intense in our left ear than our right, and vice versa if it comes from the right. If a sound is coming from straight ahead, it will reach both ears simultaneously. Furthermore, the shape and folds of our outer ear affect the frequency or timbre of sounds, which also helps us determine if sounds are coming from in front of us or behind us. Timbre also assists us in determining where in the vertical plane (above or below our outer ears) a sound is coming from (Oertel & Wang, 2021).

Think about it: Why is sound localization important? For instance, when navigating traffic or crossing a busy street, how do detecting and pinpointing sounds help you to do so safely? Or at home, how do you use sounds to locate an earbud or AirPod® that has exploded from the case you dropped on the floor? Or to determine if Rhea, the cat, just jumped down from the kitchen counter or the dining room table (neither of which she was supposed to be on)?

3.10 Types of Hearing Loss

3.10 Identify types of hearing loss and treatment options for each.

AP® LO 1.6.C: Explain how the structures and functions of the auditory sensory system relate to behavior and mental processes.

Hearing loss refers to difficulties in hearing. A person can be *hard of hearing*, with mild-to-moderate or possibly severe hearing loss, or *deaf*, with profound loss or very little to no functional hearing. Hearing loss can come on suddenly or gradually. Also, people can be born deaf or hard of hearing, and their experience of hearing may not be "lost" versus what has been their personal experience all of their lives. Treatments and assistive devices for hearing loss will vary according to the reason for the loss.

CONDUCTIVE HEARING LOSS *Conductive hearing loss* refers to problems with the mechanics of the outer or middle ear and means that sound vibrations cannot be passed from the eardrum to the cochlea. The cause might be a damaged eardrum or damage to the bones of the middle ear (usually from an infection). In this kind of hearing loss, the causes can often be treated, for example, hearing aids may be of some use in restoring hearing.

SENSORINEURAL HEARING LOSS In *sensorineural hearing loss*, the problem lies either in the inner ear or in the auditory pathways and cortical areas of the brain. This is the most common type of permanent hearing loss. Normal aging causes loss of hair cells in the cochlea, and exposure to loud noises can damage hair cells. *Tinnitus* is a fancy word for an extremely annoying ringing in one's ears, and it can also be caused by infections or loud noises—including loud music in headphones. Prolonged exposure to loud noises further leads to permanent damage and hearing loss, so you might want to turn the volume down!

Because the damage is to the nerves or the brain, sensorineural hearing loss cannot typically be helped with ordinary hearing aids, which are basically sound amplifiers, or the hearing aids are not enough. A technique for restoring some hearing to those with irreversible nerve hearing impairment makes use of an electronic device called a *cochlear implant*. This device has an external speech processor, consisting of a microphone to capture sound and a processor that converts sounds to digital signals. The speech processor is often worn as an earpiece on one or both ears, much like a Bluetooth® headset. Some processors connect to phones and other devices, with some using those devices as external microphones, or so device-specific apps can be used to modify volume and other processor settings. The digital signals from the sound processor are converted into electrical stimuli by the internal implant, when then sends the information to a series of electrodes implanted directly into the cochlea, allowing transduction to take place and stimulating the auditory nerve. The brain then processes the electrode information as sound. In any case, if you or someone you care about experiences hearing loss, get help or assistance, as recent evidence supports that hearing loss has a significant relationship to dementia, and among different modifiable risk factors for dementia, hearing loss is one of the greatest (Johnson et al., 2021; Livingston et al., 2020; Livingston et al., 2024; Readman et al., 2025; H. F. Wang et al., 2022). See Learning Objective 6.14.

Kathy deWitt/Alamy Stock Photo

In a cochlear implant, a microphone picks up sound from the surrounding environment. A speech processor attached to the implant selects and arranges the sound picked up by the microphone. The implant itself is a transmitter and receiver, converting the signals received from the speech processor into electrical impulses and transmitting them to the electrode array in the cochlea.

THINKING CRITICALLY 3.1

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

How might someone who has been deaf since birth react to suddenly being able to hear?

Concept Map L.O. 3.7, 3.8, 3.9, 3.10

The Hearing Sense

- **sound**
  - is a physical stimulus
    - composed of sound waves
      - have wavelengths and wavelike properties that can be measured
      - result of vibrations of air molecules
    - processed by the ear
      - **outer ear (pinna)**
        - the timing and intensity of sounds reaching the outer ear aid in determining their horizontal location
        - the shape and folds of our outer ear influence timbre, which helps us locate sounds vertically and determine whether they come from in front of or behind us
      - **middle ear**
      - **inner ear**
    - processing can be impaired; hearing aids may help with conductive issues whereas cochlear implants may be used with sensorineural hearing loss
  - has psychological properties
    - **frequency** or **pitch** — shorter wavelengths = more waves per second = higher frequencies — theories of pitch perception
      - place theory
      - frequency theory
      - volley theory
    - **volume** — larger wave amplitudes associated with louder volume — the loudness of low-frequency sounds is indicated by rate coding, while place coding conveys this information for moderate to high-frequency sounds.
    - **timbre** — increase in number of sounds results in greater richness

Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. Frank is a mixed martial arts fighter, and he has experienced significant repeated trauma to both ears, resulting in what is often called "cauliflower ear." He is experiencing hearing loss, especially of higher frequencies, and difficulty with sound localization. What structure in each of Frank's ears is affected?

a. the pinna **c.** the organ of Corti
b. the oval window **d.** the cochlea

2. In which part of the ear might you find the oval window?

a. Between the outer ear and middle ear.
b. Between the ossicles.
c. The oval window is not a structure of the ear.
d. Between the middle ear and inner ear.

3. Which theory cannot adequately account for pitches above 1,000 Hz?

a. place **c.** volley
b. frequency **d.** adaptive

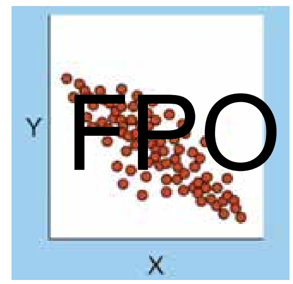
4. Hasan has conductive hearing loss due to minor damage to the bones in his middle ear. What treatment might help restore his hearing?

a. a hearing aid **b.** a cochlear implant
c. an ocular prosthetic **d.** a scleral lens

5. Alice's experiences are consistent with the most common type of permanent hearing loss. Which kind of hearing loss will likely be diagnosed?

a. conductive hearing loss
b. psychological hearing loss
c. sensorineural hearing loss
d. frequency-based hearing loss

6. A health psychologist conducted a study to examine the relationship between average daily exposure to loud noises and hearing sensitivity in adults aged 30–60. The results are shown in the graph, with Y indicating sensitivity or ability to detect quiet sounds (increasing bottom to top), and X indicating minutes of daily exposure to loud sounds (increasing left to right). Which of the following best describes the relationship between noise exposure and hearing sensitivity?



a. no correlation **c.** negative correlation
b. positive correlation **d.** perfect correlation

3.11–3.12 Chemical Senses: It Tastes Good and Smells Even Better

The sense of taste (taste in food, not taste in clothing or friends) and the sense of smell are very closely related. As Dr. Alan Hirsch, a researcher on smell and taste, explains in the video *Smell and Taste* video in **Revel**, about 90 percent of what we deem taste is really smell.

More on that later; for now, let's start with the taste buds.

3.11 Gustation: How We Taste the World

3.11 Explain how the sense of taste works.

AP® LO 1.6.D: Explain how the structures and functions of the chemical sensory systems relate to behavior and mental processes.

Our food preferences, or aversions, start to form very early in life. Taste is one of our earliest developed senses. Research suggests developing babies are exposed to substances the mother inhales or digests, and these impart flavor to the amniotic fluid, which the baby also ingests. Along with exposure to different flavors early in life after we are born, these experiences may affect food choices and nutritional status, that is, picking certain foods over others, for a long time to come (Beauchamp & Mennella, 2011; Mennella & Trabulsi, 2012).

TASTE BUDS *Taste buds* are the common name for the location of taste receptor cells, special kinds of neurons found in the mouth that are responsible for the sense of taste, or

gustation
the sensation of a taste; see AP® LO EK 1.6.D.2.

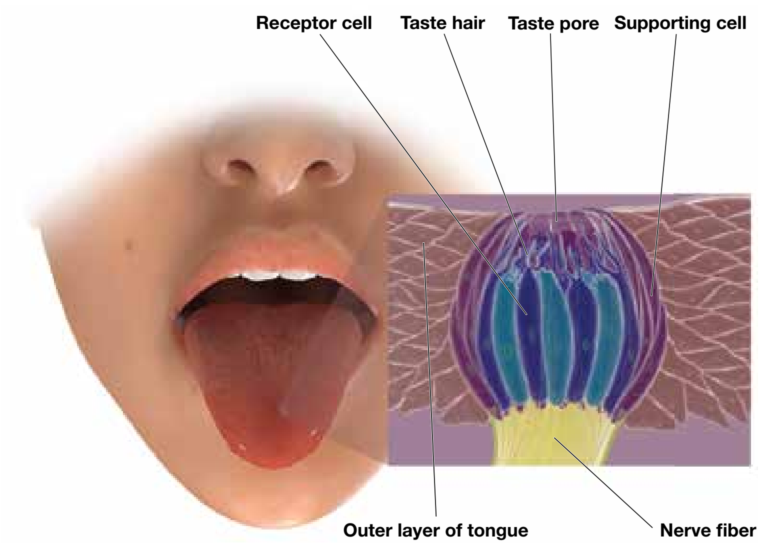
gustation. Most taste buds are located on the tongue, but there are a few on the roof of the mouth, the cheeks, under the tongue, and in the throat. How sensitive people are to various tastes depends on how many taste buds they have; some people have an average density of taste buds on their tongues, whereas others have the lowest density and others the highest density. The latter are called "supertasters" and make up about 25% of the population, requiring far less seasoning in their food than those with fewer taste buds (Bartoshuk, 1993). About half of us have an average amount and are classified as "medium tasters." In contrast, the other 25% with the lowest density of taste buds are classified as "non-tasters" and are much less sensitive to flavors. Just as with our discussion of synesthesia, we hope you recognize that the experience of being a non-taster, medium taster, or supertaster is another example of Integrative Theme B: *Psychology explains general principles that govern behavior while recognizing individual differences*.

So taste buds are those little bumps I can see when I look closely at my tongue?

No, those "bumps" are called *papillae*, and the taste buds line the walls of these papillae. See **Figure 3.15**, and the video *The Tongue and Taste Buds* in **Revel**.

Each taste bud has about 20 receptors that are very similar to the receptor sites on receiving neurons at the synapse. See Learning Objective 2.3. In fact, the receptors on taste buds work exactly like receptor sites on neurons—they receive molecules of various substances that fit into the receptor like a key into a lock. Taste is often called a chemical sense because it works with the molecules of foods people eat in the same way the neural receptors work with neurotransmitters. When the molecules (dissolved in saliva) fit into the receptors, a signal is fired to the brain, which then interprets the taste sensation.

Figure 3.15 The Tongue and Taste Buds



Taste buds are located inside the papillae of the tongue and are composed of small cells that send signals to the brain when stimulated by molecules of food. See the interactive version of this figure in **Revel**.

What happens to the taste buds when I burn my tongue? Do they repair themselves? I know when I have burned my tongue, I can't taste much for a while, but the taste comes back.

In general, the taste receptors get such a workout that they have to be replaced every 10 to 14 days (McLaughlin & Margolskee, 1994). And when the tongue is burned, the damaged cells no longer work. As time goes on, those cells get replaced and the taste sense comes back.

THE FIVE BASIC TASTES In 1916, German psychologist Hans Henning proposed that there are four primary tastes: sweet, sour, salty, and bitter. Lindemann (1996) supported the idea of a fifth kind of taste receptor that detects a pleasant "brothy" taste associated with foods like chicken soup, tuna, kelp, cheese, and soy products, among others. Lindemann proposed that this fifth taste be called *umami*, a Japanese word first coined in 1908 by Dr. Kikunae Ikeda of Tokyo Imperial University to describe the taste. Dr. Ikeda had succeeded in isolating the substance in kelp that generated the sensation of umami—glutamate (Beyreuther et al., 2007). See Learning Objective 2.3. Glutamate not only exists in the foods listed earlier but is also present in human breast milk and is the reason that the seasoning MSG—monosodium *glutamate*—adds a pleasant flavor to foods. Although not yet widely accepted, researchers have suggested there may be yet another basic taste. The proposed name for this potential sixth taste is *oleogustus*, the taste of fatty acids in the foods we eat, and researchers have investigated how different fat profiles can affect the taste of foods like milk, dark chocolate, and potato chips (Jaime-Lara et al., 2023; C. Lin et al., 2020; Running et al., 2015, 2017).

Although researchers used to believe that certain tastes were located on certain places on the tongue, it is now known that all of the taste sensations are processed all over the tongue (Bartoshuk, 1993). The taste information is sent to the gustatory cortex, found in the front part of the *insula* and the *frontal operculum* (see **Figure 3.16**.) These areas are involved in the conscious perception of taste, whereas the texture, or "mouth-feel," of foods is processed in the somatosensory cortex of the parietal lobe (Buck & Bargmann, 2013; Pritchard, 2012; Shepherd, 2012). The cortical taste areas also project to the orbitofrontal cortex and the limbic system, namely the amygdala and anterior cingulate cortex, which helps explain why tastes can be used for both positive and negative reinforcement (Pritchard, 2012; Rolls, 2016, 2023). It also appears that an individual's perception of taste intensity may be regulated in part by the amygdala (Veldhuizen et al., 2020). See Learning Objectives 2.7 and 5.5.

Figure 3.16 The Gustatory Cortex

The gustatory cortex is found in the anterior insula and frontal operculum. The insula is an area of cortex covered by folds of overlying cortex, and each fold is an operculum. In the coronal section (see Figure 2.5) of a human brain, the gustatory cortex is found in the regions colored a light red.

Source: Noland White

The five taste sensations work together, along with the sense of smell and the texture, temperature, and "heat" of foods, to produce thousands of taste sensations, which are further affected by our culture, personal expectations, and past learning experiences. For example, boiled peanuts are not an uncommon snack in parts of the southern United States, but the idea of a warm, soft and mushy, slightly salty peanut may not be appealing in other parts of the country. Males and females respond differently to taste, and there are differences in perceived taste intensity among different ethnic groups (Bartoshuk et al., 1994; Williams et al., 2016). Our taste preferences are influenced by genetics (C. Lin et al., 2020). Furthermore, we are influenced by the eating behaviors and taste preferences of those around us. For example, mothers in Poland who preferred fattier tastes were more likely to have children who were overweight or obese (Sobek & Dabrowski, 2022).

AP® SP 1.B: Explain how cultural norms, expectations, and circumstances, as well as cognitive biases apply to behavior and mental processes.

AP® SP 3.A: Identify psychology-related concepts in descriptions or representations of data.

More broadly speaking, you tend to find spicier food in hotter climates or countries, such as Thailand or Ghana, as compared to cooler ones, say Norway or Finland. Besides enhancing flavor, there have been a variety of hypotheses offered as to why spicier foods are found in hotter climates. One, the adaptive cuisine hypothesis, is that there is a greater risk of food spoilage in warmer climates, and ingredients such as garlic, onions, chili, vinegar, and alcohol have microbial properties that help protect against pathogens that cause food poisoning and foodborne illnesses (Billing & Sherman, 1998; Bromham et al., 2021; Gharib, 2019; Sherman & Billing, 1999). However, a recent evaluation of a global dataset of almost 34,000 recipes across 70 cuisines and 93 spices found little evidence to support this hypothesis or that spice use was associated with climate temperature. Further, different patterns of spice use could not be accounted for by the variety of local cultures, spices, or plants native to the region (Bromham et al., 2021). Instead of temperature or risk of infection, patterns of spice use appear to be better explained by socioeconomic variables related to global patterns of poverty and health (Bromham et al., 2021).

AP® SP 2.B: Evaluate the appropriate use of research design elements in experimental methodology.

This is a good example of some of the points made in Chapter One related to the scientific method. See Learning Objective 1.6. As a science, psychology involves regular evaluation and re-evaluation of established beliefs, hypotheses, and theories. When we make observations, record data, or develop new ways of looking at new or previous data, it allows scientists the opportunity to possibly revise or replace previous ways of thinking with novel ones. As the science of behavior and mental processes, working with populations of human and nonhuman animals where culture and context will seemingly always play important roles, we have to be prepared for and possibly even excited that the potential of such revisions in thinking may exist! Do these points remind you of Integrative Theme A and Integrative Theme C?

Returning to how things taste for us as individuals, have you ever noticed that food tastes very bland when you have a cold? Everything becomes muted because you can taste only sweet, salty, bitter, sour, and umami—and because your nose is stuffed up, you don't get all the enhanced variations of those tastes that come from the sense of smell.

3.12 The Sense of Scents: Olfaction

3.12 Explain how the sense of smell works.

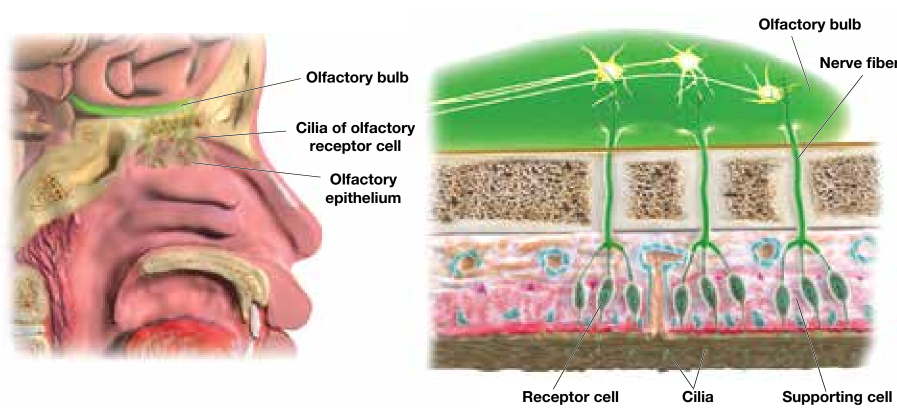
AP® LO 1.6.D: Explain how the structures and functions of the chemical sensory systems relate to behavior and mental processes.

Like the sense of taste, the sense of smell is a chemical sense. The ability to smell odors is called **olfaction**, or the **olfactory sense**.

The outer part of the nose serves the same purpose for odors that the pinna and ear canal serve for sounds: Both are merely ways to collect the sensory information and get it to the part of the body that will translate it into neural signals.

The part of the olfactory system that transduces odors—turns odors into signals the brain can understand—is located at the top of the nasal passages. This area of olfactory receptor cells is only about an inch square in each cavity yet contains about 10 million olfactory receptors. See **Figure 3.17** and *The Olfactory Receptors* video in **Revel**.

Figure 3.17 The Olfactory Receptors



(Left) A cross-section of the nose and mouth. This drawing shows the nerve fibers inside the nasal cavity that carry information about smell directly to the olfactory bulb just under the frontal lobe of the brain (shown in green). (Right) A diagram of the cells in the nose that process smell. The olfactory bulb is on top. Notice the cilia, tiny hairlike cells that project into the nasal cavity. These are the receptors for the sense of smell. See the interactive version of this figure in **Revel**.

OLFACTORY RECEPTOR CELLS The *olfactory receptor cells* each have about a half dozen to a dozen little "hairs," called *cilia*, that project into the cavity. Like taste buds, there are receptor sites on these hair cells that send signals to the brain when stimulated by the molecules of substances that are in the air moving past them.

Wait a minute—you mean that when I can smell something like a skunk, there are little particles of skunk odor IN my nose?

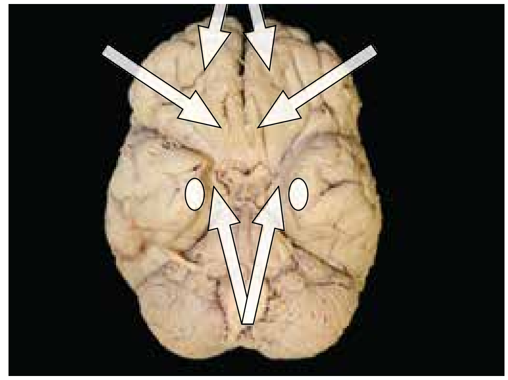
Yes. When a person is sniffing something, the sniffing serves to move molecules of whatever the person is trying to smell into the nose and into the nasal cavities. That's okay when it's the smell of baking bread, apple pie, flowers, and the like, but when it's skunk, rotten eggs, dead animals—well, try not to think about it too much.

olfaction (olfactory sense)
the sensation of smell; see AP® LO EK 1.6.D.1.

olfactory bulbs
two bulb-like projections of the brain located just above the sinus cavity and just below the frontal lobes that receive information from the olfactory receptor cells.

Olfactory receptors are like taste buds in another way, too. Olfactory receptors also have to be replaced as they naturally die off, about every 5 to 8 weeks. Unlike the taste buds, there are many more than five types of olfactory receptors—in fact, there appear to be at least 400 in humans and 1,000 or more in rodents (Buck, 2004; Dikecligil & Gottfried, 2023).

Signals from the olfactory receptors in the nasal cavity do not follow the same path as the signals from all the other senses. Vision, hearing, taste, and touch all pass through the thalamus and then on to the area of the cortex that processes that particular sensory information. But the sense of smell has its own special place in the brain—the olfactory bulbs.



Noland White and Walter Isaac

The olfactory bulbs and other areas of the brain involved in the processing of olfactory information.

THE OLFACTORY BULBS The **olfactory bulbs** are located right on top of the sinus cavity on each side of the brain directly beneath the frontal lobes. (Refer to Figure 3.17.) The olfactory receptors send their neural signals directly up to these bulbs, bypassing the thalamus, the relay center for all other sensory information. The olfactory information is then sent from the olfactory bulbs to higher cortical areas, including the primary olfactory cortex (the *piriform cortex*), the orbitofrontal cortex, and the amygdala (remember from Chapter Two that the orbitofrontal cortex and amygdala play important roles in emotion). See Learning Objectives 2.7 and 2.8.

Concept Map L.O. 3.11, 3.12

The Chemical Senses

- **taste/gustation**
  - made possible largely through the role of taste buds (taste receptor cells)
  - five basic tastes (receptor types)
    - **sweet**
    - **sour**
    - **salty**
    - **bitter**
    - **umami**
  - called a chemical sense because food molecules dissolve in saliva, which then fit into receptor sites
- **smell/olfaction**
  - called a chemical sense because substance molecules are suspended in the air, carried to the nasal cavity, and fit into receptor sites
  - nose serves as a collection device
  - unique in that signals do not first travel to the thalamus before going to the brain

Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. Taste is often called a(n) __________ sense because it works with the molecules of foods that people eat.

a. physical
b. chemical
c. kinesthetic
d. vestibular

2. Research has found that taste information is sent to the ________.

a. insula and frontal operculum
b. pons and medulla
c. suprachiasmatic nucleus
d. cerebellum and parietal lobe

3. How often are olfactory receptors replaced by new olfactory receptors?

a. every 30 days
b. every 12 to 24 hours
c. every 2 to 3 days
d. every 5 to 8 weeks

4. Olfactory receptors project directly to the __________ and are unique in that signals do not first connect to the thalamus.

a. vomeronasal organ
b. olfactory bulbs
c. semicircular canals
d. sinus cavity

3.13–3.14 The Other Senses: What the Body Knows

somesthetic senses
the body senses consisting of the skin senses, the kinesthetic sense, and the vestibular senses.

So far, this chapter has covered vision, hearing, taste, and smell. That leaves touch. What is thought of as the sense of touch is really several sensations, originating in several different places in—and on—the body. It's really more accurate to refer to these as the body senses, or **somesthetic senses**. The first part of that word, *soma*, means "body" (see Learning Objective 2.1); the second part, *esthetic*, means "feeling," hence the name. We will discuss four somesthetic sense systems.

3.13 Somesthetic Senses

3.13 Describe how we experience the sensations of touch, pressure, temperature, and pain.

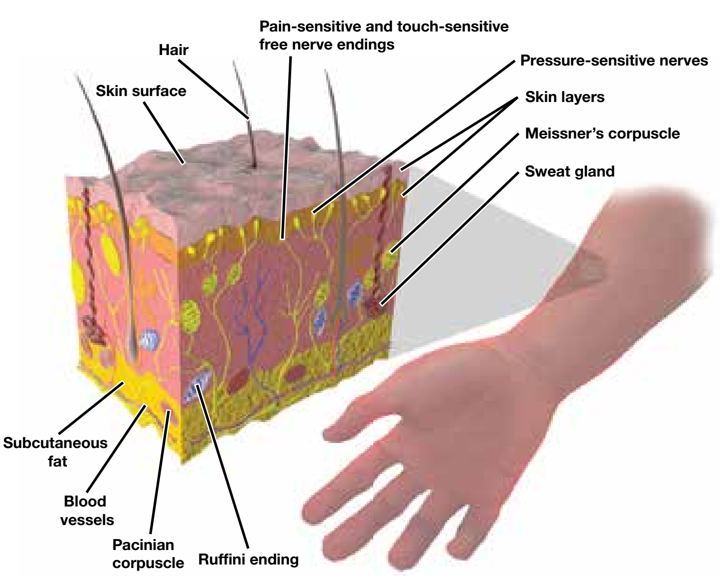
AP® LO 1.6.E: Explain how the structures and functions of the touch sensory system relate to behavior and mental processes.

AP® LO 1.6.F: Explain how the structures and functions of the pain sensory system relate to behavior and mental processes.

Here's a good trivia question: What organ of the body is about 20 square feet in size? The answer is the skin. Skin is an organ. Its purposes include more than simply keeping bodily fluids in and germs out; skin also receives and transmits information from the outside world to the central nervous system (specifically, to the somatosensory cortex). See Learning Objective 2.8 and Figure 2.12. Information about light touch, deeper pressure, hot, cold, and even pain is collected by special receptors in the skin's layers.

TYPES OF SENSORY RECEPTORS IN THE SKIN There are about half a dozen different receptors in the layers of the skin (see **Figure 3.18**). Some of them will respond to only one kind of sensation. For example, the *Pacinian corpuscles* are just beneath the skin and respond to changes in pressure. There are nerve endings that wrap around the ends of the hair follicles, a fact people may be well aware of when they tweeze their eyebrows or when someone pulls their hair. These nerve endings are sensitive to both pain and touch. There are *free nerve endings* just beneath the uppermost layer of the skin that respond to changes in temperature and to pressure—and to pain.

Figure 3.18 Cross Section of the Skin and Its Receptors



The skin comprises several types of cells that process pain, pressure, and temperature. Some cells wrap around hair follicles, some are near the skin's surface, and others are under the top layers of tissue.

How exactly does pain work? Why is it that sometimes I feel pain deep inside? Are there pain receptors there, too?

Yes, there are pain nerve fibers in the internal organs as well as receptors for pressure. How else would people have a stomachache or intestinal* pain—or get that full feeling of pressure when they've eaten too much or their bladder is full?

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

There are actually different types of pain. There are receptors that detect pain (and pressure) in the organs, a type of pain called *visceral pain*. Pain sensations in the skin, muscles, tendons, and joints are carried on relatively larger, myelinated, *A-delta* nerve fibers and are called *somatic pain*.

Somatic pain is the body's warning system that something is being or is about to be damaged and tends to be sharp and fast. Another type of somatic pain is carried on smaller, unmyelinated, C nerve fibers and is slower and more of a general ache. This somatic pain acts as a kind of reminder system, keeping people from further injury by reminding them that the body has already been damaged. For example, if you hit your thumb with a hammer, the immediate pain sensation is of the first kind—sharp, fast, and bright. But later the bruised tissue simply aches, letting you know to take it easy on that thumb.

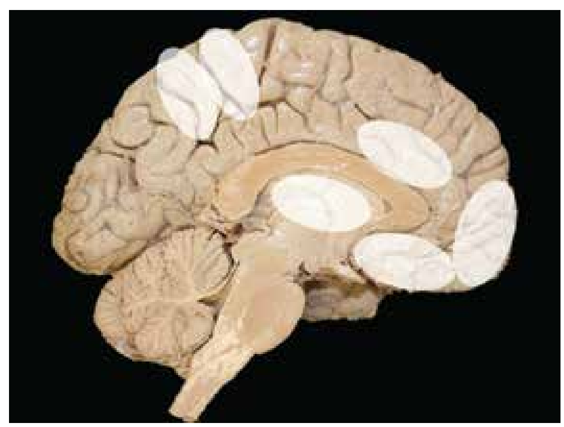
Time to test your recall. What is one of the primary advantages of a neuron having a myelinated axon? Also, think about that question in the context of the A-delta and C nerve fibers. Remember from Chapter Two that a myelinated axon allows for relatively faster conduction of action potentials. See Learning Objective 2.1. Axonal diameter also has an influence, with larger-diameter axons conducting action potentials faster than smaller-diameter axons. The larger, myelinated, A-delta axons conduct action potentials at approximately 5 to 30 meters per second, whereas the smaller, unmyelinated, C axons conduct action potentials more slowly, at less than one meter per second (Basbaum, 2021).

Wavebreakmediamicro/123RF

The fingertips are extremely sensitive to fine differences in texture, allowing readers who are blind or with low vision to distinguish between small dots representing the different letters of the alphabet.

PAIN: GATE-CONTROL THEORY One explanation for how the sensation of pain works is called *gate-control theory*, first proposed by Ronald Melzack and Patrick Wall (1965) and later refined and expanded (Melzack & Wall, 1996). In this theory, the pain signals must pass through a "gate" located in the spinal cord. The activity of the gate can be closed by nonpain signals coming into the spinal cord from the body and by signals coming from the brain. The gate is not a physical structure but instead represents the relative balance in neural activity of cells in the spinal cord that receive information from the body and then send information to the brain. Additional research has revealed that the activity of relay centers in the brain can also be influenced, and the exact locations and mechanisms are still being investigated. The video *Gate-Control Theory* in **Revel** provides a simulation of how pain signals travel along the spinal cord.

Stimulation of the pain receptor cells releases a neurotransmitter and neuromodulator called *substance P* (for peptide, not "pain"). Substance P released into the spinal cord activates other neurons that send their messages through spinal gates (opened by the pain signal). From the spinal cord, the message goes to the brain, activating cells in the thalamus, somatosensory cortex, areas of the frontal lobes, and limbic system. The brain then interprets the pain information and sends signals that either open the spinal gates farther, causing a greater experience of pain, or close them, dampening the pain. Of course, this decision by the brain is influenced by the psychological aspects of the pain-causing stimulus. Anxiety, fear, and helplessness intensify pain, whereas laughter, distraction, and a sense of control can diminish it. This is why people might bruise themselves and not know it if they were concentrating on something else. Pain can also be affected by competing signals from other skin senses, which is why rubbing a sore spot can reduce the feeling of pain.



Noland White and Walter Isaac

Areas of the brain that are involved in the processing of pain information.

Those same psychological aspects can also influence the release of the *endorphins*, the body's natural version of morphine. See Learning Objective 2.3. Endorphins can inhibit the transmission of pain signals in the brain, and in the spinal cord they can inhibit the release of substance P.

I've always heard that females are able to stand more pain than males. Is that true?

---

*intestinal: having to do with the tubes in the body that digest food and process waste material.

AP® SP 2.B: Evaluate the appropriate use of research design elements in experimental methodology.

It depends. Some research has suggested that females report and subjectively feel some types of pain more intensely than males, along with greater subjective functional impairment (Gautschi et al., 2016). However, when objective measures are used, those differences disappear (Gautschi et al., 2016). One systematic review of 10 years of laboratory research suggests there still hasn't been a clear and consistent pattern of sex differences identified, even when using experimental methods that best mimic chronic types of pain (Racine et al., 2012). When differences are present, it appears that social and cognitive factors may help explain at least some reported differences (McGraw, 2016; Racine et al., 2012). For example, when tested on the same pain task, males reported higher levels of both physical and pain task-specific *self-efficacy* (a person's expectancy of how effective their efforts will be; see Learning Objective 12.6) and lower levels of pain overall during the task. In other words, males in this study were found to have a stronger belief than females that they can (or should) tolerate the pain task through their own efforts (Jackson et al., 2002).

Other research is investigating the potential role of brain mechanisms by themselves, versus brain processing being affected by interpersonal and social factors such as chronic stress associated with discrimination, in the experience of certain types of pain across different ethnic groups (Losin et al., 2020). As the authors of the study point out, not only do such studies contribute to the growing area of cultural neuroscience, they may also have critical implications for understanding and addressing inequalities in pain-related health care.

PAIN DISORDERS People may not like pain, but its function as a warning system is vitally important. There are people who are born without the ability to feel pain, rare conditions called *congenital analgesia* and *congenital insensitivity to pain with anhidrosis (CIPA).* Children with these disorders cannot feel pain when they cut or scrape themselves, leading to an increased risk of infection when the cut goes untreated (Mogil, 1999). They fear nothing—which can be a horrifying trial for the parents and teachers of such a child. These disorders affect the neural pathways that carry pain, heat, and cold sensations. Those with CIPA have an additional disruption in the body's heat–cold sensing perspiration system (*anhidrosis*), so that the person is unable to cool off the body by sweating.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

A condition called *phantom limb pain* occurs when a person who has had an arm or leg removed sometimes "feels" pain in the missing limb (Nikolajsen & Jensen, 2001; Woodhouse, 2005). In 2019, the United States Department of Veterans Affairs provided care to over 96,000 veterans with amputations (Webster et al., 2020). As many as 50 to 80 percent of people who have had amputations experience various sensations: burning, shooting pains, or pins-and-needles sensations where the amputated limb used to be. For example, in a nationwide survey of individuals with amputations in Germany, approximately 60 percent of respondents reported phantom limb pain (Diers et al., 2022). Once believed to be a psychological problem, some now believe it is caused by the traumatic injury to the nerves during amputation (Ephraim et al., 2005). Other research suggests it may be due to maladaptive neuroplasticity, or reorganization of some parts of the somatosensory cortex (Flor et al., 1995; Karl et al., 2001; Raffin et al., 2016), and yet others suggest this may not be the cause for the pain, at least not in all individuals (Makin et al., 2015).

THINKING CRITICALLY 3.2

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

What kinds of changes in your life would you have to make if you suddenly could not feel pain?

3.14 Body Movement and Position

3.14 Describe the systems that tell us about balance and position and movement of our bodies.

AP® LO 1.6.G: Explain how the structures and functions that maintain balance (vestibular) and body movement (kinesthetic) relate to behavior and mental processes.

Besides the systems already covered, other senses tell us about our body. *Kinesthesia* and *proprioception*, awareness of body movement and position, are based on somesthetic information. Information affecting our balance comes from the vestibular system, which informs us about head and whole-body movement and position.

KINESTHETIC AND PROPRIOCEPTIVE SENSES Special receptors located in the muscles, tendons, and joints provide information about body movement and the movement and location of the arms, legs, and so forth in relation to one another. Some of these receptors increase awareness of the body's own movements, or **kinesthesia**, from the Greek words *kinein* ("to move") and *aesthesis* ("sensation"). Changes in the skin stretching as body parts move also provide kinesthetic information.

These special receptors also provide proprioceptive information, letting us know where our body parts are and their position in space. This awareness is called **proprioception**. When you close your eyes and raise your hand above your head, you know where your hand is because these receptors, called proprioceptors, tell you about joint movement or the muscles stretching or contracting.

If you have ever gotten sick from traveling in a moving vehicle, it has not been because of these proprioceptors. The culprits are actually special structures in the ear that tell us about the position of the body in relation to the ground and movement of the head that make up the **vestibular sense**—the sense of balance.

THE VESTIBULAR SENSE The name of this particular sense comes from a Latin word that means "entrance" or "chamber." The structures for this sense are located in the innermost chamber of the ear. There are two kinds of vestibular organs, the otolith organs and the semicircular canals.

The *otolith organs* are tiny sacs found just above the cochlea. These sacs contain a gelatin-like fluid within which tiny crystals are suspended (much like pieces of fruit in a bowl of Jell-O). The head moves and the crystals cause the fluid to vibrate, setting off some tiny hairlike receptors on the inner surface of the sac, telling the person that they are moving forward, backward, sideways, or up and down. It's pretty much the way the cochlea works but with movement being the stimulus instead of sound vibrations.

The *semicircular canals* are three somewhat circular tubes that are also filled with fluid that will stimulate hairlike receptors when rotated. Having three tubes allows one to be located in each of the three planes of motion. Remember learning in geometry class about the x-, y-, and z-axes? Those are the three planes through which the body can rotate, and, when it does, it sets off the receptors in these canals. When you spin around and then stop, the fluid in the horizontal canal is still rotating and will make you feel dizzy because your body is telling you that you are still moving, but your eyes are telling you that you have stopped. The horizontal canals are also critical in helping us navigate our environments, as they provide important information about which direction we are facing (Valerio & Taube, 2016).

This disagreement between what the eyes say and what the body says is pretty much what causes *motion sickness*, the tendency to get nauseated when in a moving vehicle, especially one with an irregular movement. Normally, the vestibular sense coordinates with the other senses. But for some people, the information from the eyes may conflict a little too much with the vestibular organs, and dizziness, nausea, and disorientation are the result. This explanation of motion sickness is known as **sensory conflict theory** (Oman, 1990; Reason & Brand, 1975). The dizziness is the most likely cause of the nausea. Many poisons make a

kinesthesia
the awareness of body movement; also called kinesthesis or the kinesthetic sense; see AP® LO EK 1.6.G.2.

proprioception
awareness of where the body and body parts are located in relation to each other in space and to the ground.

vestibular sense
the awareness of the balance, position, and movement of the head and body through space in relation to gravity's pull; see AP® LO EK 1.6.G.1.

sensory conflict theory
an explanation of motion sickness in which the information from the eyes conflicts with the information from the vestibular senses, resulting in dizziness, nausea, and other physical discomfort.

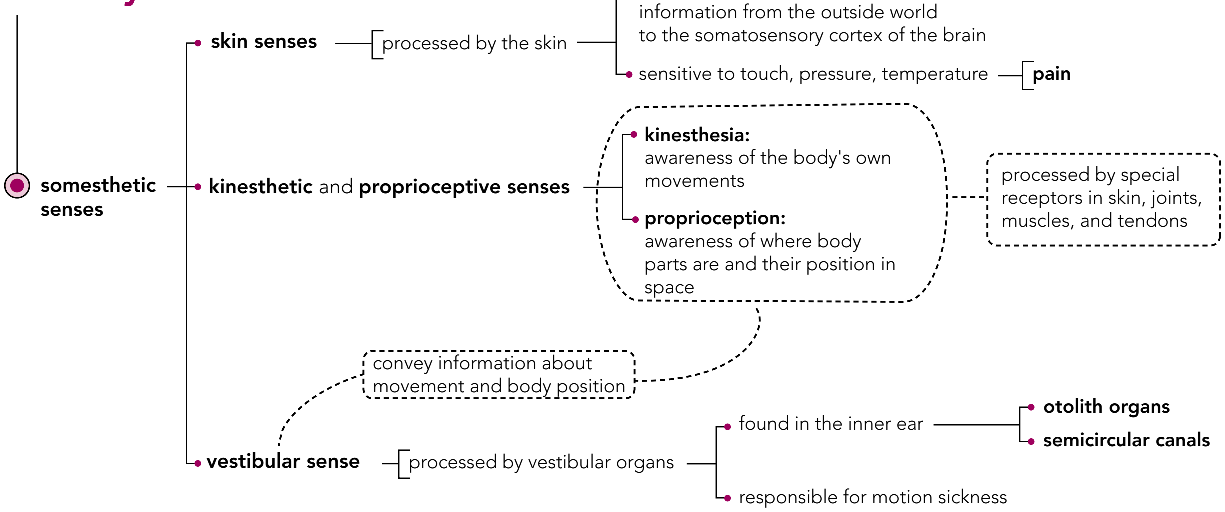
person dizzy, and the most evolutionarily adaptive thing to do is to expel the poison. Even without any poison in a case of motion sickness, the nausea occurs anyway (Treisman, 1977).

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

One way some people overcome motion sickness is to focus on a distant point or object. This provides visual information to the person about how they are moving, bringing the sensory input into agreement with the visual input. This is also how ballerinas and ice skaters manage not to get sick when turning rapidly and repeatedly—they focus their eyes at least once on some fixed object every so many turns.

Concept Map L.O. 3.13, 3.14

The Body Senses



Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. Tactile receptors that are located just beneath the skin and respond to changes in pressure are called _______.
a. Pacinian corpuscles
b. Schwann cells
c. Meissner's corpuscles
d. Amacrine cells

2. In gate-control theory, substance P _______.
a. opens the spinal gates for pain
b. closes the spinal gates for pain
c. creates more gated pain pathways
d. reduces the number of gated pain pathways

3. When you close your eyes and raise your hand above your head, you know where your hand is due to information from _______.
a. Pacinian corpuscles
b. otolith organs
c. proprioceptors
d. semicircular canals

4. Motion sickness often results from conflicting signals sent from the _______ and from the _______.
a. extremities, brain
b. eyes, vestibular organs
c. brain, internal organs
d. sinus cavities, thalamus

perception
the method by which the sensations experienced at any given moment are interpreted and organized in some meaningful fashion.

3.15–3.17 The ABCs of Perception

Perception is the method by which the brain takes all the sensations a person experiences at any given moment and allows them to be interpreted in some meaningful fashion. Perception has some individuality to it. For example, two people might be looking at a cloud, and while one thinks it's shaped like a horse, the other thinks it's more like a cow. They both *see* the same cloud, but they *perceive* that cloud differently.

3.15 How We Organize Our Perceptions

3.15 Describe how perceptual constancies and the Gestalt principles account for common perceptual experiences.

AP® LO 2.1.A: Explain how internal and external factors influence perception.

As individual as perception might be, some similarities exist in how people perceive the world around them. As such, there are some circumstances during which stimuli are seemingly automatically perceived in almost the same way by various individuals.

THE CONSTANCIES: SIZE, SHAPE, AND BRIGHTNESS One form of perceptual constancy* is **size constancy**, the tendency to interpret an object as always being the same size, regardless of its distance from the viewer (or the size of the image it casts on the retina). So if an object normally perceived to be about 6 feet tall appears very small on the retina, it will be interpreted as being very far away.

Another perceptual constancy is the tendency to interpret the shape of an object as constant, even when it changes on the retina. This **shape constancy** is why a person still perceives a coin as a circle even if it is held at an angle that makes it appear to be an oval on the retina. Dinner plates on a table are also seen as round, even though from the angle of viewing they are oval (see **Figure 3.19**).

A third form of perceptual constancy is **brightness constancy**, the tendency to perceive the apparent brightness of an object as the same even when the light conditions change. If a person is wearing black pants and a white shirt, for example, in broad daylight the shirt will appear to be much brighter than the pants. But if the sun is covered by thick clouds, even though the pants and shirt have less light to reflect than previously, the shirt will still appear to be just as much brighter than the pants as before—because the different amount of light reflected from each piece of clothing is still the same difference as before (Zeki, 2001).

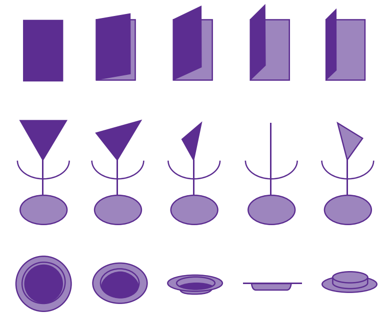
THE GESTALT PRINCIPLES Remember the discussion of the Gestalt theorists in Chapter One? Their original focus on human perception can still be seen in certain basic principles today, including the Gestalt tendency to group objects and perceive whole shapes.

FIGURE–GROUND RELATIONSHIPS Take a look at the drawing of the cube in **Figure 3.20**. Which side of the cube is in the front? Look again—do the planes and corners of the cube seem to shift as you look at it?

This is called the "Necker cube." It has been around officially since 1832, when Louis Albert Necker, a Swiss scientist who was studying the structure of crystals, first drew it in his published papers. The problem with this cube is that there are conflicting sets of depth cues, so the viewer is never really sure which plane or edge is in the back and which is in the front—the visual presentation of the cube seems to keep reversing its planes and edges.

A similar illusion can be seen in **Figure 3.21**. In this picture, the

Figure 3.19 Shape Constancy



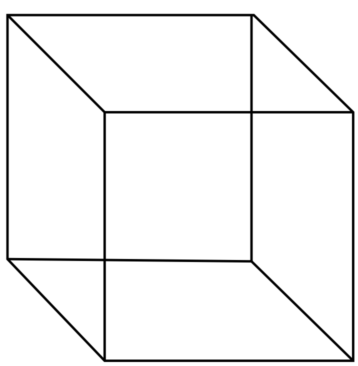
Three examples of shape constancy are shown here. Although when we look at these objects from different angles they cast differently shaped images on our retina, we still experience them as a door, a triangle, and a circle because of shape constancy.

size constancy
the tendency to interpret an object as always being the same actual size, regardless of its distance.

shape constancy
the tendency to interpret the shape of an object as being constant, even when its shape changes on the retina.

brightness constancy
the tendency to perceive the apparent brightness of an object as the same even when the light conditions change.

Figure 3.20 The Necker Cube



This is an example of a reversible figure. It can also be described as an ambiguous figure, since it is not clear which pattern should predominate.

Figure 3.21 Figure–Ground Illusion

YourElechka/Shutterstock

What do you see when you look at this picture? Is it a wine goblet? Or two faces looking at each other? This is an example in which the figure and the ground seem to "switch" each time you look at the picture.

*constancy: something that remains the same; the property of remaining stable and unchanging.

figure–ground relationship
the tendency to perceive objects, or figures, as existing on a background; see AP® LO EK 2.1.A.4

reversible figures
visual illusions in which the figure and ground can be reversed.

proximity
a Gestalt principle of perception; the tendency to perceive objects that are close to each other as part of the same grouping; physical or geographical nearness; see AP® LO EK 2.1.A.4.

similarity
a Gestalt principle of perception; the tendency to perceive things that look similar to each other as being part of the same group; see AP® LO EK 2.1.A.4.

viewer can switch perception back and forth from two faces looking at each other to the outline of a goblet in the middle. Which is the figure in front and which is the background?

Figure–ground relationships refer to the tendency to perceive objects or figures as existing on a background. People seem to have a preference for picking out figures from backgrounds even as early as birth. The illusions in Figures 3.20 and 3.21 are **reversible figures**, in which the figure and the ground seem to switch back and forth.

PROXIMITY Another very simple rule of perception is the tendency to perceive objects that are close to one another as part of the same grouping, a principle called **proximity**, or "nearness" (see **Figure 3.22**).

SIMILARITY **Similarity** refers to the tendency to perceive things that look similar as being part of the same group. When members of a sports team wear uniforms that are all the same color, it allows people viewing the game to perceive them as one group even when they are scattered around the field or court.

CLOSURE **Closure** is the tendency to complete figures that are incomplete. A talented artist can give the impression of an entire face with just a few cleverly placed strokes of the pen or brush—the viewers fill in the details.

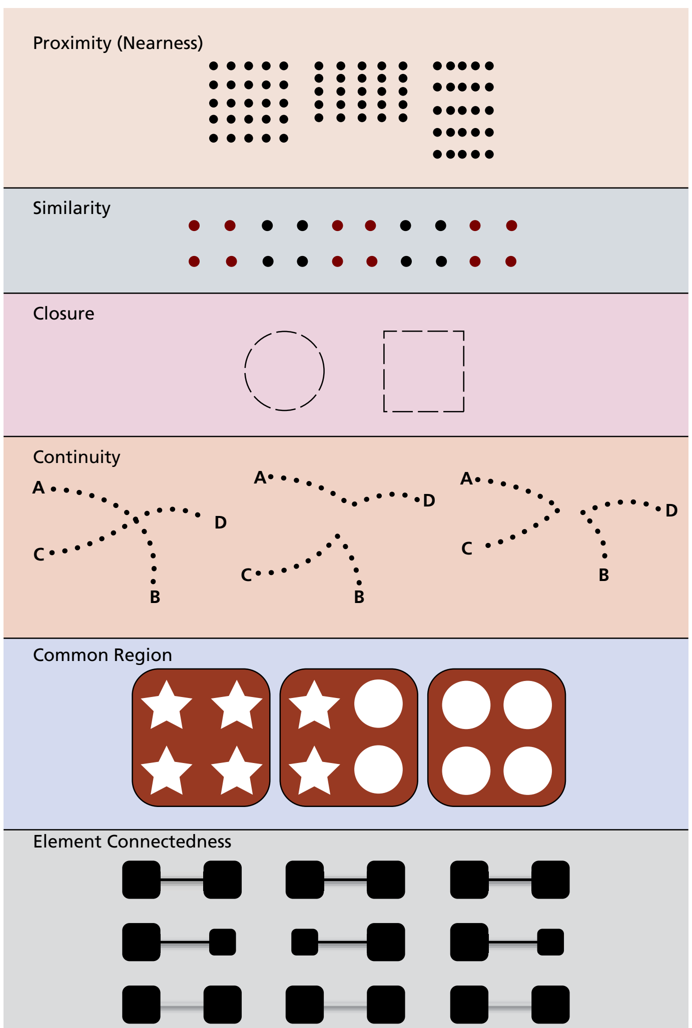


Figure 3.22 Gestalt Principles of Grouping

The Gestalt principles of grouping are shown here. These are the human tendency to organize isolated stimuli into groups on the basis of six characteristics: proximity, similarity, closure, continuity, common region, and elemental connectedness. See the interactive version of this figure in **Revel**.

Proximity: The dots on the left can be seen as horizontal or vertical rows—neither organization dominates. But just by changing the proximity of certain dots, as in the other two examples, we experience the dots as vertical columns (middle) or horizontal rows (right).

Similarity: The similarity of color here makes you perceive these dots as forming black squares and color squares rather than two rows of black and colored dots.

Closure: Even though the lines are broken, we still see these figures as a circle and a square—an example of how we tend to "close" or "fill in" missing parts from what we know of the whole.

Continuity: Because of continuity, we are much more likely to see the figure on the left as being made up of two lines, A to B and C to D, than we are to see it as a figure made up of lines A to D and C to B or A to C and B to D.

Common Region: Similarity would suggest that people see two groups, stars and circles. But the colored backgrounds define a visible common region, and the tendency is to perceive three different groups.

Element Connectedness: Connecting the blocks forms pairs of items, overrides both the principles of proximity and similarity, and as you can see in the bottom set, is not dependent upon items being the same color.

Sources: Based on Palmer, S., & Rock, I. (1994). Rethinking perceptual organization: The role of uniform connectedness. *Psychonomic Bulletin & Review, 1*(1), 29–55. https://doi.org/10.3758/BF03200760

CONTINUITY The principle of **continuity** is easier to see than it is to explain in words. It refers to the tendency to perceive things as simply as possible with a continuous pattern rather than with a complex, broken-up pattern. Look at Figure 3.22 for an example of continuity. Isn't it much easier to see the figure on the left as two wavy lines crossing each other than as the little sections in the diagrams to the right?

CONTIGUITY **Contiguity** isn't shown in Figure 3.22 because it involves not just nearness in space but also nearness in time. Basically, contiguity is the tendency to perceive two things that happen close together in time as related. Usually, the first occurring event is seen as causing the second event. Ventriloquists* make vocalizations without appearing to move their own mouths but move their dummy's mouth instead. The tendency to believe that the dummy is doing the talking is due largely to contiguity.

COMMON REGION AND ELEMENT CONNECTEDNESS There are other principles of perceptual grouping that were not one of the original principles. At least two have been added (and can be seen in Figure 3.22) by Stephen Palmer and colleagues (Palmer, 1992; Palmer & Rock, 1994). In *common region*, the tendency is to perceive objects that are in a common area or region as being in a group. In Figure 3.22, people could perceive the stars as one group and the circles as another on the basis of similarity. But the colored backgrounds so visibly define common regions that people instead perceive three groups—one of which has both stars and circles in it.

In *element connectedness*, the tendency to perceive objects that are connected overrides both elements of similarity and proximity (Brooks, 2015; Palmer & Rock, 1994). See the bottom of Figure 3.22.

closure
a Gestalt principle of perception; the tendency to complete figures that are incomplete; see AP® LO EK 2.1.A.4.

continuity
a Gestalt principle of perception; the tendency to perceive things as simply as possible with a continuous pattern rather than with a complex, broken-up pattern.

contiguity
a Gestalt principle of perception; the tendency to perceive two things that happen close together in time as being related.

3.16 Depth Perception

3.16 Explain how we perceive depth using both monocular and binocular cues.

AP® LO 1.6.B: Explain how the structures and functions of the visual sensory system relate to behavior and mental processes.

AP® LO 2.1.A: Explain how internal and external factors influence perception.

AP® LO 2.1.B: Explain how visual perceptual processes produce correct or incorrect interpretations of stimuli.

The capability to see the world in three dimensions is called **depth perception**. It's a handy ability because without it you would have a hard time judging how far away objects are. How early in life do humans develop depth perception? It seems to develop very early in infancy, if it is not actually present at birth. People who have had sight restored have almost no ability to perceive depth if they were blind from birth. Depth perception, like the constancies, seems to be present in infants at a very young age. See Learning Objective 8.6.

Various cues exist for perceiving depth in the world. Some require the use of only one eye (**monocular cues**) and some are a result of the slightly different visual patterns that exist when the visual fields of both eyes are used (**binocular cues**).

MONOCULAR CUES Monocular cues are often referred to as *pictorial depth cues* because artists can use these cues to give the illusion of depth to paintings and drawings. Examples of these cues are discussed next and can be seen in **Figure 3.23**.

depth perception
the ability to perceive the world in three dimensions.

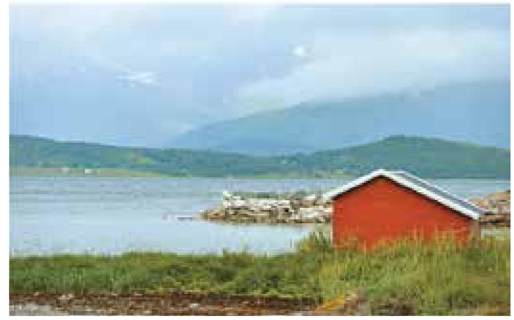
monocular cues (pictorial depth cues)
cues for perceiving depth based on one eye only; see AP® LO EK 2.1.B.2.

binocular cues
cues for perceiving depth based on both eyes; see AP® LO EK 2.1.B.1.

*ventriloquist: an entertainer who, through the use of misdirection and skill, makes other objects, such as a dummy, appear to talk.

Figure 3.23 Examples of Pictorial Depth Cues

a. 

c. 

b. 

d. 

(a) Both the lines of the trees and the sides of the road appear to come together or converge in the distance. This is an example of *linear perspective*. (b) Notice how the larger pebbles in the foreground seem to give way to smaller and smaller pebbles near the middle of the picture. *Texture gradient* causes the viewer to assume that as the texture of the pebbles gets finer, the pebbles are getting farther away. (c) In *aerial* or *atmospheric perspective*, the farther away something is the hazier it appears because of fine particles in the air between the viewer and the object. Notice that the shed and grassy area in the foreground are in sharp focus while the mountain ranges are hazy and indistinct. (d) The depth cue of *relative size* appears in this photograph. Notice that the flowers in the distance appear much smaller than those in the foreground. Relative size causes smaller objects to be perceived as farther away from the viewer.

Sources: a) Grant Faint/The Image Bank/Getty Images; b) Cherrill Rance/Shutterstock; c) Popova Valeriya/Shutterstock; d) Dan Lewis/Shutterstock

linear perspective

monocular depth perception cue; the tendency for parallel lines to appear to converge on each other; see AP® LO EK 2.1.B.2.

relative size

monocular depth perception cue; perception that occurs when objects that a person expects to be of a certain size appear to be small and are, therefore, assumed to be much farther away; see AP® LO EK 2.1.B.2.

1. **Linear perspective:** When looking down a long interstate highway, the two sides of the highway appear to merge together in the distance. This tendency for lines that are actually parallel to *seem* to converge** on each other is called **linear perspective**. It works in pictures because people assume that in the picture, as in real life, the converging lines indicate that the "ends" of the lines are a great distance away from where the people are as they view them.
2. **Relative size:** The principle of size constancy is at work in **relative size**, when objects that people expect to be of a certain size appear to be small and are, therefore, assumed to be much farther away. Movie makers use this principle to make their small models seem gigantic but off in the distance.
3. **Overlap:** If one object seems to be blocking another object, people assume that the blocked object is behind the first one and, therefore, farther away. This cue is also known as **interposition**.

**converge: come together.

4. **Aerial (atmospheric) perspective:** The farther away an object is, the hazier the object will appear to be due to tiny particles of dust, dirt, and other pollutants in the air, a perceptual cue called **aerial (atmospheric) perspective**. This is why distant mountains often look fuzzy, and buildings far in the distance are blurrier than those that are close.
5. **Texture gradient:** If there are any large expanses of pebbles, rocks, or patterned roads (such as a cobblestone street) nearby, go take a look at them one day. The pebbles or bricks close to you are very distinctly textured, but as you look farther off into the distance, their texture becomes smaller and finer. **Texture gradient** is another trick used by artists to give the illusion of depth in a painting.
6. **Motion parallax:** The next time you're in a vehicle, notice how objects outside seem to zip by very fast when they are close, and objects in the distance, such as buildings or mountains, seem to pass by more slowly. This discrepancy in motion of near and far objects is called **motion parallax**.
7. **Accommodation:** A monocular cue that is not one of the pictorial cues, **accommodation** makes use of something that happens inside the eye. The lens of the human eye is flexible and held in place by a series of muscles. The discussion of the eye earlier in this chapter mentioned the process of visual accommodation as the tendency of the lens to change its shape, or thickness, in response to objects near or far away. The brain can use this information about accommodation as a cue for distance. Accommodation is also called a "muscular cue."

BINOCULAR CUES As the name suggests, these cues require the use of two eyes.

1. **Convergence:** Another muscular cue, **convergence**, refers to the rotation of the two eyes in their sockets to focus on a single object. If the object is close, the convergence is pretty great (almost as great as crossing the eyes). If the object is far, the convergence is much less. Hold your finger up in front of your nose, and then move it away and back again. That feeling you get in the muscles of your eyes is convergence (see **Figure 3.24**, left).
2. **Binocular disparity: Binocular disparity** is a scientific way of saying that because the eyes are a few inches apart, they don't see exactly the same image. The brain interprets the images on the retina to determine distance from the eyes. If the two images are very different, the object must be pretty close. If they are almost identical, the object is far enough away to make the retinal disparity very small. You can demonstrate this cue for yourself by holding an object in front of your nose. Close one eye, note where the object is, and then open that eye and close the other. There should be quite a difference in views. But if you do the same thing with an object that is across the room, the image doesn't seem to "jump" or move nearly as much, if at all (see Figure 3.24, right).

In spite of all the cues for perception that exist, even the most sophisticated perceiver can still fail to perceive the world as it actually is, as the next section demonstrates.

3.17 Perceptual Illusions

3.17 Identify some common visual illusions and the factors that influence our perception of them.

AP® LO 2.1.B: Explain how visual perceptual processes produce correct or incorrect interpretations of stimuli.

AP® SP 1.B: Explain how cultural norms, expectations, and circumstances, as well as cognitive biases apply to behavior and mental processes.

You've mentioned the word *illusion* several times. Exactly what are illusions, and why is it so easy to be fooled by them?

interposition
monocular depth perception cue; the assumption that an object that appears to be blocking part of another object is in front of the second object and closer to the viewer; see AP® LO EK 2.1.B.2.

aerial (atmospheric) perspective
monocular depth perception cue; the haziness that surrounds objects that are farther away from the viewer, causing the distance to be perceived as greater.

texture gradient
monocular depth perception cue; the tendency for textured surfaces to appear to become smaller and finer as distance from the viewer increases; see AP® LO EK 2.1.B.2.

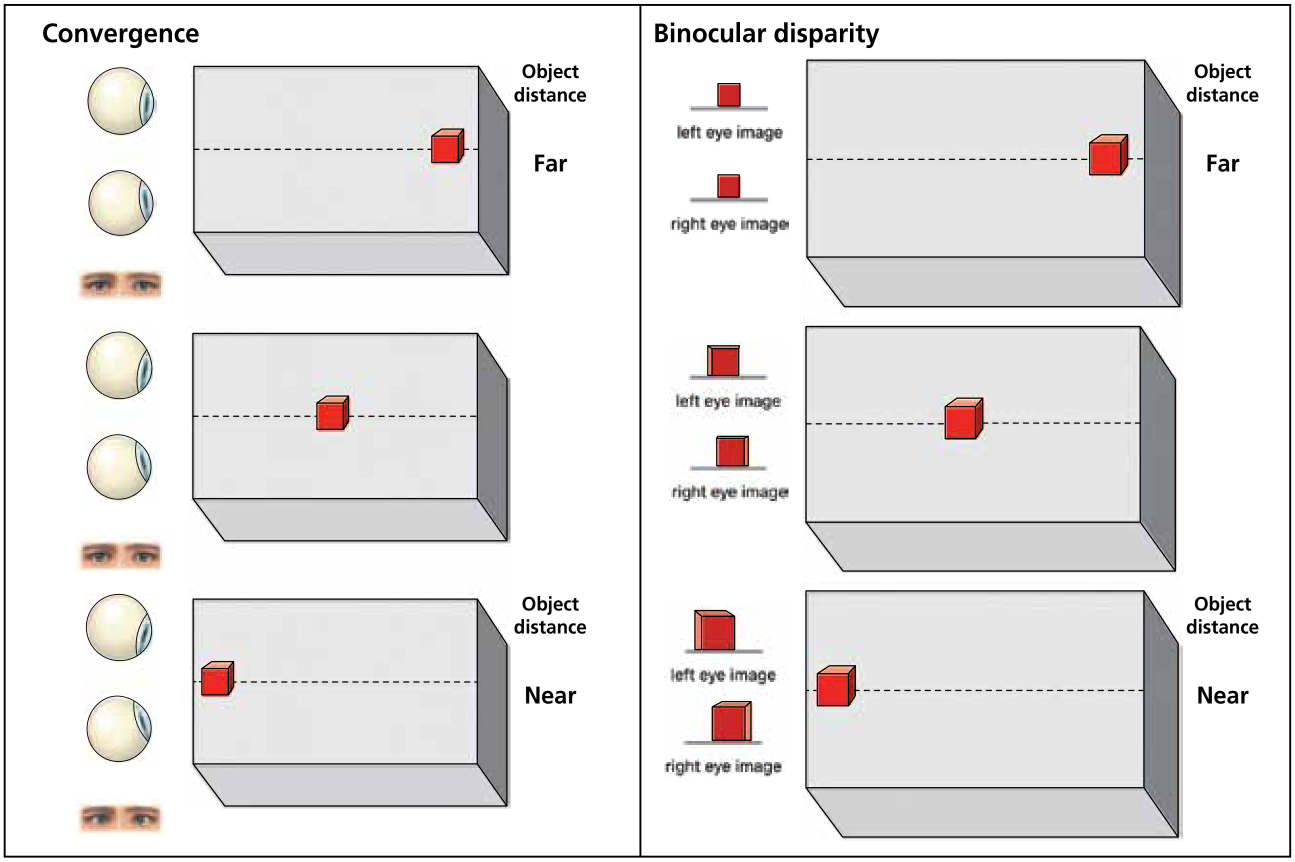
motion parallax
monocular depth perception cue; the perception of motion of objects in which close objects appear to move more quickly than objects that are farther away.

accommodation
as a monocular cue of depth perception; the brain's use of information about the changing thickness of the lens of the eye in response to looking at objects that are close or far away; see AP® LO EK 1.6.B.2.

convergence
binocular depth perception cue; the rotation of the two eyes in their sockets to focus on a single object, resulting in greater convergence for closer objects and lesser convergence if objects are distant; see AP® LO EK 2.1.B.1.

binocular disparity
binocular depth perception cue; the difference in images between the two eyes, which is greater for objects that are close and smaller for distant objects; see AP® LO EK 2.1.B.1.

Figure 3.24 Binocular Cues to Depth Perception



(Left) Convergence is a depth cue that involves the muscles of the eyes. When objects are far away, the eye muscles are more relaxed; when objects are close, the eye muscles move together, or converge. (Right) Binocular disparity. Because your eyes are separated by several centimeters, each eye sees a slightly different image of the object in front of you. In A, the object is far enough away that the difference is small. In B, while the object is closer, there is a greater difference between what each eye sees. The brain interprets this difference as the distance of the object. For an interactive version of this figure, see **Revel**.

An *illusion* is a perception that does not correspond to reality: People *think* they see something when the reality is quite different. Another way of thinking of illusions is as visual stimuli that "fool" the eye. Illusions are not hallucinations: An illusion is a distorted perception of something that is really there, but a hallucination originates in the brain, not in reality. Perceptual illusions are a great example of Integrative Theme E: *Our perceptions and biases filter our experiences of the world through an imperfect personal lens*.

Research involving illusions can be very useful for both psychologists and neuroscientists. These studies often provide valuable information about how the sensory receptors and sense organs work and how humans interpret sensory input.

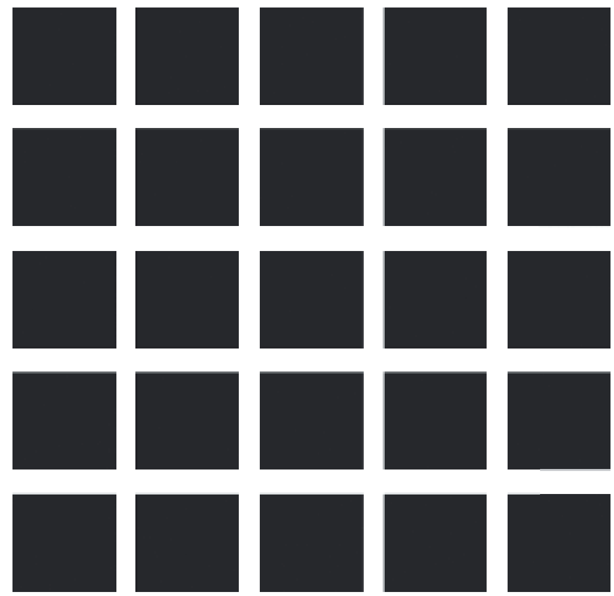
Sometimes, illusions are based on early sensory processes, subsequent processing, or higher-level assumptions made by the brain's visual system (Eagleman, 2001; Macknik et al., 2008).

We've already discussed one visual illusion, color afterimages, which is due to opponent-processes in the retina or lateral geniculate nucleus (LGN) of the thalamus after light information has been detected by the rods and cones. Another postdetection but still rather early process has been offered for yet another illusion.

THE HERMANN GRID Look at the matrix of squares in **Figure 3.25**. Notice anything interesting as you look at different parts of the figure, particularly at the intersections of the white lines? You probably see gray blobs or diamonds that fade away or disappear completely when you try to look directly at them. This is the Hermann grid.

One explanation for this illusion is attributed to the responses of neurons in the primary visual cortex that respond best to bars of light of a specific orientation (Schiller & Carvey, 2005). Such neurons are called "simple cells" and were first discovered by David Hubel and Torsten Wiesel (Hubel & Wiesel, 1959). They also discovered other cells, including "complex cells" that respond to orientation and movement and "end-stopped cells" that respond best to corners, curvature, or sudden edges. Collectively these cells have been referred to as *feature detectors* because they respond to specific features of a stimulus. Hubel and Wiesel were later awarded the Nobel Prize for extensive work in the visual system. Other research into the Hermann grid illusion has documented that straight edges are necessary for this illusion to occur, as the illusion disappears when the edges of the grid lines are slightly curved, and further suggests that the illusion may be due to a unique function of how our visual system processes information (Geier et al., 2008).

Figure 3.25 Hermann Grid



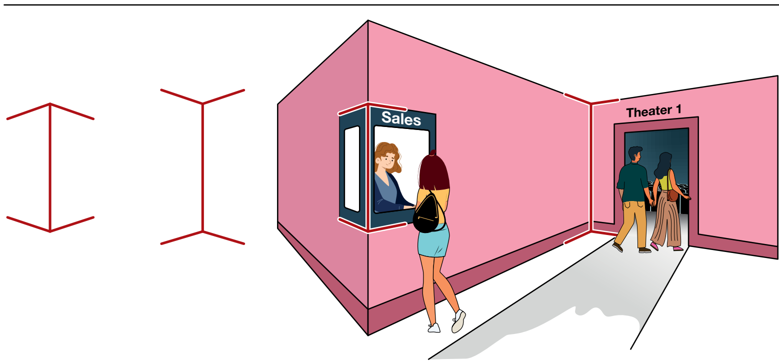
Look at this matrix of squares. Do you notice anything interesting at the white intersections? What happens if you focus your vision directly on one of the intersections?

MÜLLER-LYER ILLUSION One of the most famous visual illusions, the **Müller-Lyer illusion**, is shown in **Figure 3.26**. The distortion happens when the viewer tries to determine if the two lines are exactly the same length. They are identical, but one line looks longer than the other. (It's always the line with the angles on the end facing outward.)

Why is this illusion so powerful? The explanation is that most people live in a world with lots of buildings. Buildings have corners. When a person is outside a building, the corner of the building is close to that person, while the walls seem to be moving away (like the line with the angles facing inward). When the person is inside a building, the corner of the room seems to move away from the viewer while the walls are coming closer (like the line with the angles facing outward). In their minds, people "pull" the inward-facing angles toward them like the outside corners of a building, and they make

Müller-Lyer illusion
illusion of line length that is distorted by inward-turning or outward-turning corners on the ends of the lines, causing lines of equal length to appear to be different.

Figure 3.26 Müller-Lyer Illusion

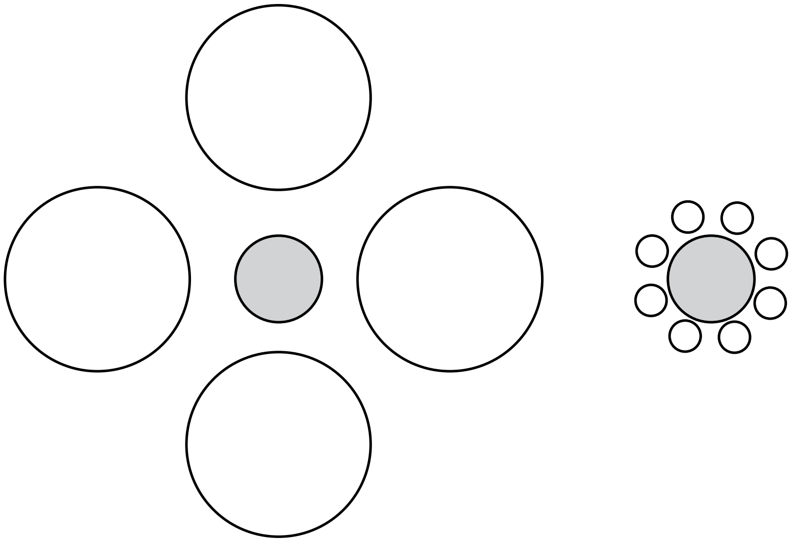


The Müller-Lyer optical illusion features two lines, with one appearing to be longer than the other. In reality, both lines are equal in length.

the outward-facing angles "stretch" away from them like the inside corners of the room (Enns & Coren, 1995; Gregory, 1990).

Marshall Segall and colleagues (Segall et al., 1966) found that people in European and American samples, having been more likely to have been exposed to square buildings and city blocks with lots of straight lines and corners (Segall and colleagues refer to this as a "carpentered world"), are far more susceptible to this illusion than people from some countries in Africa and the Philippines. Richard Gregory (1990) found that Zulus, for example, rarely see this illusion. They live in round huts arranged in circles, use curved tools and toys, and experience few straight lines and corners in their world.

Figure 3.27 The Ebbinghaus Illusion



Which of the two gray circles in the center of each cluster is larger? The visual context effects of the surrounding circles influence our perception.

EBBINGHAUS ILLUSION Another famous visual illusion is the *Ebbinghaus illusion*, shown in **Figure 3.27**. The challenge lies in determining if the central circles in each group are identical in size. They are the same size but the one surrounded by larger circles appears to be smaller.

This illusion is based on one facet of our visual system, namely the tendency to use context, or surrounding information, to determine the size of objects. In the Ebbinghaus illusion, the central circles are the *target* elements being compared and the surrounding large or small circles are *inducer* elements influencing our perception (Axelrod et al., 2017).

As with other perceptual illusions, culture and the environment in which we grow up and develop can influence how these figures are perceived. In a comparison of individuals living in a remote village, the Himba of Northern Namibia, and groups of urbanized Himba, urban British, and urban Japanese, the traditional Himba were less susceptible to this illusion, suggesting a strong local bias in processing visual information (Caparos et al., 2012). In contrast, exposure to an urban environment increased susceptibility to this illusion or a tendency to process visual information from a more global bias.

In this study, urbanized Himba, urban British, and urban Japanese groups were more likely to report the circles were not the same size (Caparos et al., 2012). In other words, the traditional Himba focused on the central circles more than the surrounding circles in making their judgments. Other research has demonstrated that such cross-cultural biases in processing visual information emerge in early childhood (Bremner et al., 2016) and brief exposures to nature can change the way we attend to and perceive the world around us (Berman et al., 2008). We hope you recognize how our perceptions of some illusions may vary as a function of culture as an illustration of Integrative Theme C: *Psychological, biological, social, and cultural factors influence behavior and mental processes*.

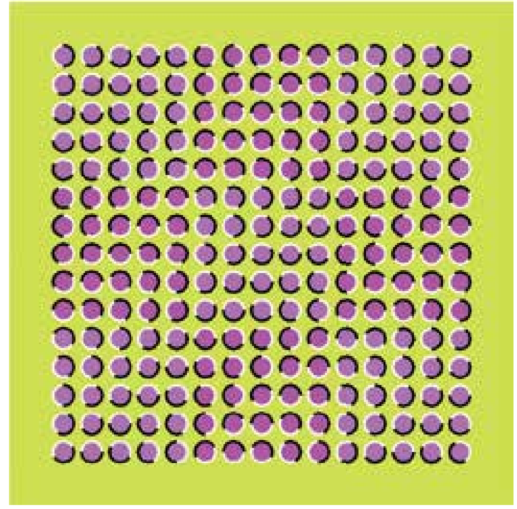
The moon illusion. The moon is perceived to be much larger when near the horizon than when it is high in the night sky. Although depth cues are one possible explanation, they cannot fully explain the illusion, as astronauts in space see the illusion without objects in the foreground.

THE MOON ILLUSION Another common illusion is the *moon illusion*, in which the moon on the horizon* appears to be much larger than the moon in the sky (Plug & Ross, 1994). One explanation for this is that the moon high in the sky is all alone, with no cues for depth surrounding it. But on the horizon, the moon appears behind trees and houses, cues for depth that make the horizon seem very far away. The moon is seen as being behind these objects and,

*horizon: the place where the earth apparently meets the sky.

therefore, farther away from the viewer. Because people know that objects that are farther away from them yet still appear large are very large indeed, they "magnify" the moon in their minds—a misapplication of the principle of size constancy. This explanation of the moon illusion is called the *apparent distance hypothesis*. This explanation goes back to the second century A.D., first written about by the Greek–Egyptian astronomer Ptolemy and later further developed by an eleventh-century Arab astronomer, Al-Hazan (Ross & Ross, 1976).

Figure 3.28 Perceived Motion



Notice anything as you move your eyes over this image? The image is not moving; seeing the "ripples" is likely due, at least in part, to the movements of your eyes.

Source: Skripnichenko Tatiana/Shutterstock

ILLUSIONS OF MOTION Sometimes, people perceive an object as moving when it is actually still. One example of this takes place as part of a famous experiment in conformity called the *autokinetic effect*. See Learning Objective 11.1. In this effect, a small, stationary light in a darkened room will appear to move or drift because there are no surrounding cues to indicate that the light is *not* moving. Another is the *stroboscopic motion* seen in motion pictures, in which a rapid series of still pictures will seem to be in motion. Many a student has discovered that drawing little figures on the edges of a notebook and then flipping the pages quickly will also produce this same illusion of movement.

Another movement illusion related to stroboscopic motion is the *phi phenomenon*, in which lights turned on in sequence appear to move. For example, if a light is turned on in a darkened room and then turned off, and then another light a short distance away is flashed on and off, it will appear to be one light moving across that distance. This principle is used to suggest motion in many theater marquee signs, flashing arrows indicating direction that have a series of lights going on and off in a sequence, and even in strings of decorative lighting, such as the "chasing" lights seen on houses at holiday times.

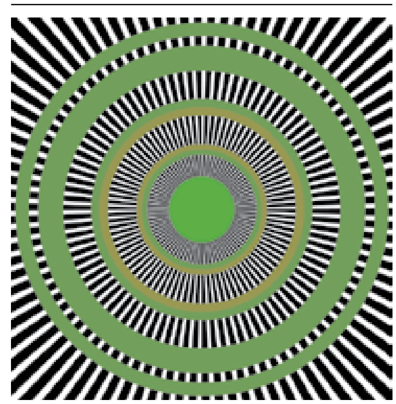
What about seeing motion in static images? There are several examples, both classic and modern, of illusory movement or apparent motion being perceived in a static image. The debate about the causes for such illusions, whether they begin in the eyes or the brain, has been going on for at least 200 years (Troncoso et al., 2008).

Look at **Figure 3.28**. What do you see?

There have been a variety of explanations for this type of motion illusion, ranging from factors that depend on the image's luminance and/or the color arrangement to possibly slight differences in the time it takes the brain to process this information. When fMRI and equipment used to track eye movements were used to investigate participants' perception of a similar illusion, researchers found that there was an increase in brain activity in a visual area sensitive to motion. However, this activity was greatest when accompanied by guided eye movements, suggesting eye movements play a significant role in the perception of the illusion (Kuriki et al., 2008).

Eye movements have also been found to be a primary cause for the illusory motion seen in images based on a 1981 painting by Isia Leviant, *Enigma*. Look at the center of **Figure 3.29**; notice anything within the green rings? Many people will see the rings start to "sparkle" or the rings rotating. Why does this occur? By using special eye-tracking equipment that allowed them to record even the smallest of eye movements, researchers found that tiny eye movements called *microsaccades*, discussed earlier in the chapter, are directly linked to the perception of motion in *Enigma* and are at least one possible cause of the illusion (Troncoso et al., 2008).

Figure 3.29 "Reinterpretation of Enigma"



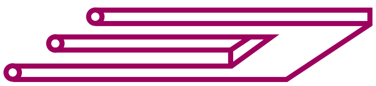
As in Figure 3.28, the motion you see in this static image is because of movements of your eyes, this time due more to tiny movements called *microsaccades*.

Source: Created by and courtesy of Jorge Otero-Millan, Martinez-Conde Laboratory, Barrow Neurological Institute.

OTHER FACTORS THAT INFLUENCE PERCEPTION Human perception of the world is obviously influenced by things such as culture and misinterpretations of cues. Following are other factors that cause people to alter their perceptions.

perceptual set (perceptual expectancy) the tendency to perceive things a certain way because previous experiences or expectations influence those perceptions; see AP® LO EK 2.1.A.2.

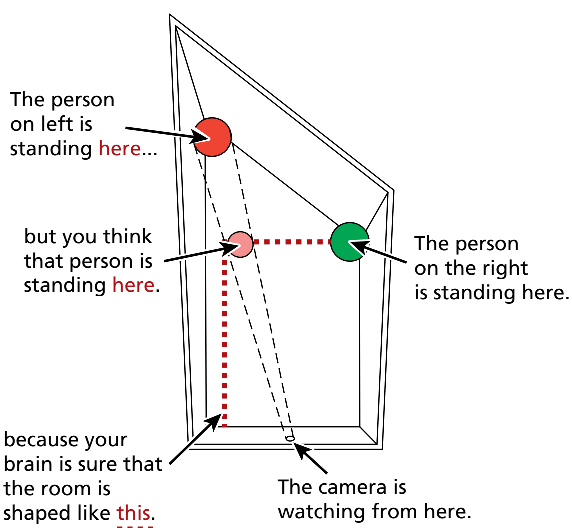
Figure 3.30 Devil's Trident



Take a closer look at this figure. Follow the lines of the top prong to see what goes wrong.

Epa european pressphoto agency b.v./ Alamy Stock Photo

The Ames Room illusion. This illusion is influenced by our past experiences and expectancies. The viewer perceives the room as a rectangle, but in reality, it is actually a trapezoid with angled walls and floor.



A diagram of the Ames Room as viewed from the top.

Source: https://bpb-us-e1.wpmucdn.com/sites.psu.edu/dist/a/109764/files/2019/10/Annotation-2.png

People often misunderstand what is said to them because they were expecting to hear something else. People's tendency to perceive things a certain way because their previous experiences or expectations influence them is called **perceptual set** or **perceptual expectancy**. Although expectancies can be useful in interpreting certain stimuli, they can also lead people down the wrong path. What you see depends upon what you expect to see.

The way in which people *interpret* what they perceive can also influence their perception. For example, people can try to understand what they perceive by using information they already have (as is the case of perceptual expectancy). But if there is no existing information that relates to the new information, they can look at each feature of what they perceive and try to put it all together into one whole.

Anyone who has ever worked on a jigsaw puzzle knows that it's a lot easier to put it together if there is a picture of the finished puzzle to refer to as a guide. It also helps to have worked the puzzle before—people who have done that already know what it's going to look like when it's finished. In the field of perception, this is known as **top-down processing**—the use of existing knowledge to organize individual features into a unified whole. This is also a form of perceptual expectancy.

If the puzzle is one the person has never worked before or if that person has lost the top of the box with the picture on it, they would have to start with a small section, put it together, and keep building up the sections until the recognizable picture appears. This analysis of smaller features and building up to a complete perception is called **bottom-up processing** (Cave & Kim, 1999). In this case, there is no expectancy to help organize the perception, making bottom-up processing more difficult in some respects. Fortunately, the two types of processing are often used together in perceiving the surrounding world.

Would people of different cultures perceive objects differently because of different expectancies? Some research suggests this is true. For example, refer back to the section on the Ebbinghaus illusion and the potential impact of an urban environment on perception. Also, take a look at **Figure 3.30**. This figure is often called the "devil's trident." Europeans and North Americans insist on making this figure three dimensional, so they have trouble looking at it—the figure is impossible if it is perceived in three dimensions. But people in less technologically oriented cultures have little difficulty with seeing or even reproducing this figure because they see it as a two-dimensional drawing, quite literally a collection of lines and circles rather than a solid object (Deregowski, 1969). By contrast, if you give Europeans and North Americans the task of reproducing a drawing of an upside-down face, their drawings tend to be more accurate as compared to drawing regular, upright faces, because the upside-down face has become a "collection of lines and circles." That is, they draw what they actually see in terms of light and shadow rather than what they "think" is there three-dimensionally.

Culture is related to more than expectancies. As discussed in Chapter Seven, Eleanor Rosch-Heider and others (Rosch-Heider, 1972; Rosch-Heider & Olivier, 1972) found that the members of the Dani tribe of Papua, New Guinea, only had two names for colors. They had one for all dark colors and another for all light colors. Nonetheless, when tested with a variety of different colors, they were able to perceive and discriminate them from one another. See Learning Objective 7.14. Similar findings have been observed for other groups. Perception is not restricted by one's language, and it is possible that having specific words for different colors might be influenced by the actual need to communicate those colors to others (Phillips, 2019). Perception can also be affected by local life experiences. Most humans have poor vision underwater. However, what if diving for shellfish and other items without a mask or goggles was part of daily life? This was the case among Moken children, who live in the archipelago of Burma and the West Coast of Thailand, when they were tested against a control group of European children. Underwater, they had twice the visual acuity of a control group of European children (Gislen et al., 2003). The reason why? While they had the same pupil size on land as the European children, when measured underwater, the Moken children had significantly smaller pupils and better accommodation, allowing much greater visual acuity (Gislen et al., 2003). They had learned to constrict their pupils and better accommodate when diving. Can this be taught? Turns out that it can. In a later study, the researchers taught a group of European children to do so, and they were able to perform at the same level as the Moken children (Gislen et al., 2006).

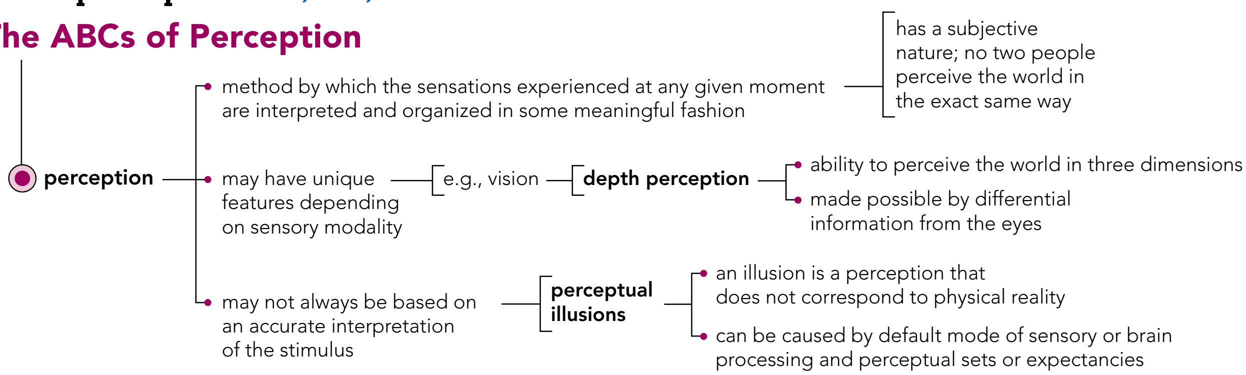
Ok, now an opportunity to check your understanding. To test your recall, recognition, and ability to identify these concepts' applications, complete the *Factors That Can Influence Perception* activities in **Revel**.

top-down processing
the use of preexisting knowledge to organize individual features into a unified whole; see AP® LO EK 2.1.A.1.

bottom-up processing
the analysis of the smaller features to build up to a complete perception; see AP® LO EK 2.1.A.1.

Concept Map L.O. 3.15, 3.16, 3.17

The ABCs of Perception



Practice Quiz How much do you remember?

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. When opening a door, the actual image on your retina changes drastically, but you still perceive the door as a rectangle. This is an example of ________ constancy.
- **a.** brightness
- **b.** size
- **c.** color
- **d.** shape

2. Hunters who wear camouflage so they can blend in with their surroundings are relying on which principle of perception A?
- **a.** closure
- **b.** proximity
- **c.** figure–ground relationships
- **d.** good continuation

3. What monocular depth cue can best explain why railroad tracks appear to come together in the distance?
- **a.** linear perspective
- **b.** convergence
- **c.** interposition
- **d.** texture gradient

4. The Müller-Lyer illusion occurs more frequently in ________.
- **a.** men than women
- **b.** children than adults
- **c.** people living in a Western culture
- **d.** individuals living in economic disadvantage

5. Elijah's uncle claimed to have seen a black panther in the trees beside the highway, although no one else saw it. Knowing that his uncle has been looking for a black panther for years, Elijah attributes his uncle's "sighting" to ________.
- **a.** sensory overload
- **b.** perceptual set
- **c.** bottom-up processing
- **d.** inattentional blindness

6. While listening to a new song, Mckenna has difficulty figuring out some words she hears. She searches for the lyrics online, and as she reads them while listening to the song, she can better "hear" the words being sung. Her improved ability to recognize the words is partially attributable to ________.

a. top-down processing
b. bottom-up processing
c. cognitive dissonance
d. the phi phenomenon

APA IPI Learning Outcome: Scientific Thinking

Perceptual Influences on Metacognition

Addresses APA Introductory Psychology Initiative (IPI) Learning Objectives:

- **1.3:** Apply psychological principles to personal growth and other aspects of everyday life.
- **2.3:** Draw logical and objective conclusions about behavior and mental processes from empirical evidence.

AP® SP 4.A: Propose a defensible claim.

AP® SP 4.B: Provide reasoning that is grounded in scientifically derived evidence to support, refute, or modify an established or provided claim, policy, or norm.

As you can see, what we perceive as being real does not always match the actual visual stimulus we are presented with. Perceptual information can also influence how we think about a given object. For example, many of us assume things that are larger weigh more than things that are smaller. The color of an object can also have an influence (De Camp, 1917). Darker objects are often appraised to be heavier than comparable objects that are lighter in color (Walker et al., 2010). Both of these are examples of stimulus influences on perceptual expectations. But what about stimulus influences on expectations for a cognitive task, like assessing how well we will be able to remember something?

Remember from the Psychology in Action chapter (see PIA.1) that metacognition is thinking about thinking. It includes being aware of our own thought processes, such as evaluating how well we actually understand something or how well we will remember something. For example, the font size of a given word appears to have an effect. In one study, words that were printed in a larger font were rated as being more memorable than words appearing in a smaller font (Rhodes & Castel, 2008). In other words, when evaluated as part of a sequential list, psychology might be rated as being more memorable than macroeconomics. At least it was for one of your authors during college. Despite the initial ratings on memorability, when tested later, word font size did not yield significant effects on recall (Rhodes & Castel, 2008).

Research also suggests that students often report using study strategies such as focusing primarily on **bold** or *italicized* terms in a textbook (Gurung, 2003, 2004), or overreliance on strategies such as highlighting. These are methods that have less of an overall positive impact on retention of material, especially when compared to more robust study and memory strategies. See PIA.1 and Learning Objectives 6.5 and 6.6.

Which of the following is a better way to study, assess, and improve learning? Look at the two example questions following the study techniques below and think about which would be more effective.

1. **Memorizing key terms:**

similarity a Gestalt principle of perception; the tendency to perceive things that look similar to each other as being part of the same group.

2. **Taking practice quizzes:**

Of the Gestalt principles, the tendency to perceive things that look similar as being part of the same group is known as

a. proximity. b. similarity. c. closure. d. continuity. Correct answer: b

As compared to relying on memorization of the key term or glossary word as in the first item, research suggests repeated quizzing or testing as in #2 is a better way to study, assess, and improve learning.

Applying Psychology to Everyday Life

Using Your Senses to Be More Mindful

3.18 Describe how mindfulness and paying attention to our senses, thoughts, and feelings can impact perceptions, personal experiences, and overall sense of well-being.

AP® SP 1.A: Apply psychological perspectives, theories, concepts, and research findings to a scenario.

Being mindful, or maintaining full or focused awareness of the sensations, feelings, and thoughts we experience at any given moment, can enhance our perceptions and a variety of personal experiences. For example, distracted eating can result in eating when you are not hungry, overeating for a given meal or snack, and eating more food in later meals. Mindfulness can also impact how we feel in a given situation. By focusing on our breath or specific bodily sensations, we can shift an experience of nervousness during an exam to one of calm and control. To see how some students practice mindfulness in different situations, watch the video, in **Revel**, *Using Your Senses to Be More Mindful*.

After watching the video, answer the following questions:

1. As discussed in the video, people who eat emotionally, eat too fast, or have a difficult time with portion control can use mindfulness to increase awareness of their eating behaviors. What are two of the strategies for mindful eating that were highlighted in the video?
2. The video highlighted various applications of mindfulness to experiences such as eating and walking in nature or noticing our immediate environment. What are some other situations in which paying attention to your senses, thoughts, and feelings can impact your perceptions?

Chapter Summary

The ABCs of Sensation

3.1 Describe how we get information from the outside world into our brains.

- Sensation is the activation of receptors located in the eyes, ears, skin, nasal cavities, and tongue.
- Sensory receptors are specialized forms of neurons activated by different stimuli such as light and sound.

3.2 Describe the difference and absolute thresholds.

- A just noticeable difference is the point at which a stimulus is detectable half the time it is present.
- Weber's law of just noticeable differences states that the just noticeable difference between two stimuli is always a constant.
- Absolute thresholds are the smallest amount of energy needed for conscious detection of a stimulus at least half the time it is present.
- Subliminal stimuli are stimuli presented just below the level of conscious awareness, and subliminal perception has been demonstrated in the laboratory. It has not been shown to be effective in advertising.

3.3 Explain why some sensory information is ignored.

- Habituation occurs when the brain ignores a constant stimulus.
- Sensory adaptation occurs when the sensory receptors stop responding to a constant stimulus.

The Science of Seeing

3.4 Describe how light travels through the various parts of the eye.

- Brightness corresponds to the amplitude of light waves, whereas color corresponds to the length of the light waves.
- Saturation is the psychological interpretation of wavelengths that are all the same (highly saturated) or varying (less saturated).
- Light enters the eye and is focused through the cornea, passes through the aqueous humor, and then through the hole in the iris muscle called the pupil.
- The lens also focuses the light on the retina, where it passes through ganglion and bipolar cells to stimulate the rods and cones.

3.5 Explain how light information reaches the visual cortex.

- Visual pathway = retina → optic nerve → optic chiasm → optic tract → LGN of thalamus → optic radiations → primary visual cortex.
- Light from the right visual field projects to the left side of each retina; light from the left visual field projects to the right side of each retina.
- Axons from the temporal halves of each retina project to the visual cortex on same side of the brain; axons from the nasal halves of each retina project to the visual cortex on the opposite side of the brain; the optic chiasm is the point of crossover.

3.6 Compare and contrast two major theories of color vision, and explain how color-deficient vision occurs.

- Cones are sensitive to colors and work best in bright light. They are responsible for the sharpness of visual information and are found in the fovea.
- Rods detect changes in brightness but do not see color and function best in low levels of light. They are found everywhere in the retina except the center, or fovea.
- Trichromatic theory of color perception assumes three types of cones: red, green, and blue. All colors would be perceived as various combinations of these three.
- Opponent-process theory of color perception assumes four primary colors of red, green, blue, and yellow. Colors are arranged in pairs, and when one member of a pair is activated, the other is not.
- Color vision deficiency refers to color perception limited primarily to yellows and blues or reds and greens only, while total achromatopsia, or color blindness, is a total lack of color perception.

The Hearing Sense: Can You Hear Me Now?

3.7 Explain the nature of sound, and describe how it travels through the various parts of the ear.

- Sound has three aspects: pitch (frequency), loudness, and timbre (purity).
- Sound enters the ear through the visible outer structure, or pinna, and travels to the eardrum and then to the small bones of the middle ear.
- The bone called the stirrup rests on the oval window, causing the cochlea and basilar membrane to vibrate with sound.
- The organ of Corti on the basilar membrane contains the auditory receptors, which send signals to the brain about sound qualities as they vibrate.

3.8 Summarize three theories of how the brain processes information about pitch.

- Place theory states that the locations of the hair cells on the organ of Corti correspond to different pitches of sound. This can explain pitch above 1,000 Hz.
- Frequency theory states that the speed with which the basilar membrane vibrates corresponds to different pitches of sound. This can explain pitch below 1,000 Hz.
- The volley principle states that neurons take turns firing for sounds above 400 Hz and below 4,000 Hz.

3.9 Describe how we determine the loudness and location of sounds.

- For low-frequency sounds, loudness is signaled by the number of active hair cells (rate coding), while for moderate to high-frequency sounds, loudness is influenced by the firing rate of hair cells (place coding).
- We determine the horizontal position (left/right) of sounds by utilizing timing differences (more effective for lower frequencies) and intensity differences (more effective for higher frequencies) between our ears.
- The shape and folds of the outer ear influence sound timbre and assist in locating sounds vertically and from front to back.

3.10 Identify types of hearing loss and treatment options for each.

- Conductive hearing loss is caused by damage to the outer or middle ear structures, whereas sensorineural hearing loss is caused by damage to the inner ear or auditory pathways in the brain.
- Hearing aids may be used for those with conductive hearing loss, while cochlear implants may restore some hearing to those with sensorineural hearing loss.

Chemical Senses: It Tastes Good and Smells Even Better

3.11 Explain how the sense of taste works.

- Gustation is the sense of taste. Taste buds in the tongue receive molecules of substances, which fit into receptor sites.
- Gustation is a chemical sense that involves detection of chemicals dissolved in saliva.
- The five basic types of taste are sweet, sour, salty, bitter, and umami (brothy).

3.12 Explain how the sense of smell works.

- Olfaction is the sense of smell. The olfactory receptors in the upper part of the nasal passages receive molecules of substances and create neural signals that then go to the olfactory bulbs under the frontal lobes.
- Olfaction is a chemical sense that involves detection of chemicals suspended in the air.

The Other Senses: What the Body Knows

3.13 Describe how we experience the sensations of touch, pressure, temperature, and pain.

- The skin senses are one part of our somesthetic senses.
- Pacinian corpuscles respond to pressure, certain nerve endings around hair follicles respond to pain and pressure, and free nerve endings respond to pain, pressure, and temperature.
- The gate-control theory of pain states that when receptors sensitive to pain are stimulated, a neurotransmitter and neuromodulator called substance P is released into the spinal cord, activating other pain receptors by opening "gates" in the spinal column and sending the message to the brain.

3.14 Describe the systems that tell us about balance and position and movement of our bodies.

- The kinesthetic sense (also called kinesthesia or kinesthesis) allows the brain to know about the movement of the body.
- Proprioception, or information about where the body and its parts are in relation to each other and the ground, comes from the activity of special receptors responsive to movement of the joints and limbs.
- The vestibular sense also contributes to the body's sense of spatial orientation and movement through the activity of the otolith organs (up-and-down movement) and the semicircular canals (movement through arcs).
- Motion sickness is explained by sensory conflict theory, in which information from the eyes conflicts with information from the vestibular sense, causing nausea.

The ABCs of Perception

3.15 Describe how perceptual constancies and the Gestalt principles account for common perceptual experiences.

- Perception is the interpretation and organization of sensations.
- Size constancy is the tendency to perceive objects as always being the same size, no matter how close or far away they are.
- Shape constancy is the tendency to perceive objects as remaining the same shape even when the shape of the object changes on the retina of the eye.
- Brightness constancy is the tendency to perceive objects as a certain level of brightness, even when the light changes.
- The Gestalt psychologists developed several principles of perception that involve interpreting patterns in visual stimuli. The principles are figure–ground relationships, closure, similarity, continuity, contiguity, common region, and elemental connectedness.

3.16 Explain how we perceive depth using both monocular and binocular cues.

- Depth perception is the ability to see in three dimensions.
- Monocular cues for depth perception include linear perspective, relative size, interposition (or overlap), aerial (atmospheric) perspective, texture gradient, motion parallax, and accommodation.
- Binocular cues for depth perception include convergence and binocular disparity.

3.17 Identify some common visual illusions and the factors that influence our perception of them.

- Illusions are perceptions that do not correspond to reality or are distortions of visual stimuli.
- Perceptual set or expectancy refers to the tendency to perceive objects and situations in a particular way because of prior experiences or our expectations in a given situation.
- Top-down processing involves the use of existing knowledge to organize individual features into a unified whole.
- Bottom-up processing involves the analysis of smaller features, building up to a complete perception.
- Culture and personal experiences affect our perceptions.

Applying Psychology to Everyday Life: Using Your Senses to Be More Mindful

3.18 Describe how mindfulness and paying attention to our senses, thoughts, and feelings can impact perceptions, personal experiences, and overall sense of well-being.

- Being mindful, or being fully aware of and paying attention to our breathing, sensory experiences, feelings, and thoughts, can help us establish a sense of peace and control, benefiting our overall sense of well-being.
- Paying closer attention to our senses can enhance both perceptions and personal experiences. For example, mindful eating consists of paying closer attention to the various tastes, colors, and smells of food; chewing more slowly; and enjoying smaller portions to fully appreciate the experience of eating.

Integrative Themes in Psychological Science: What have you learned?

Integrative Theme A Psychological science relies on empirical evidence and adapts as new data develop.

- Subliminal perception is an area that has fascinated many people, and there are still likely some misconceptions about its influence on our behavior. Researchers are still investigating the different ways in which we process information, even those that occur without our conscious awareness.

Integrative Theme B Psychology explains general principles that govern behavior while recognizing individual differences.

- While there are basic principles of sensory processing, and for each of the modalities, the experience of supertasters and individuals with synesthesia illustrates how individual differences can come into play.

Integrative Theme C Psychological, biological, social, and cultural factors influence behavior and mental processes.

- Our perceptions of some illusions may vary as a function of our primary culture. Two examples are the Müller-Lyer illusion and the Ebbinghaus illusion.

Integrative Theme D Our perceptions and biases filter our experiences of the world through an imperfect personal lens.

- We are prone to various perceptual illusions across multiple sensory modalities. These illusions influence how we perceive stimuli, affecting our personal experiences.

Test Yourself: Preparing for the AP® Exam

Please note, assessments in your **Revel** course are updated periodically and may no longer exactly match those in the printed textbook. See **Revel** for the most recent version.

Four possible answers or completions follow each question or incomplete statement. Select the one that is best in each case.

1. The process by which external stimuli in their physical form are converted into neural signals that can be sent to the brain is called ________.

a. perception
b. sensation
c. transduction
d. interpolation

2. Grandma Leoni has made a big pot of pasta sauce and asks you to taste it. You tell her, "It needs more garlic." She adds a small teaspoon of garlic, and when you taste it again, you don't notice a difference. A teaspoon of garlic added to a small bowl of sauce, however, would be very noticeable. This demonstrates ________ law.

a. Fechner's
b. Weber's
c. Young's
d. Helmholtz's

3. A study purportedly conducted by James Vicary teaches us what about the power of subliminal perception and its effect on advertising?

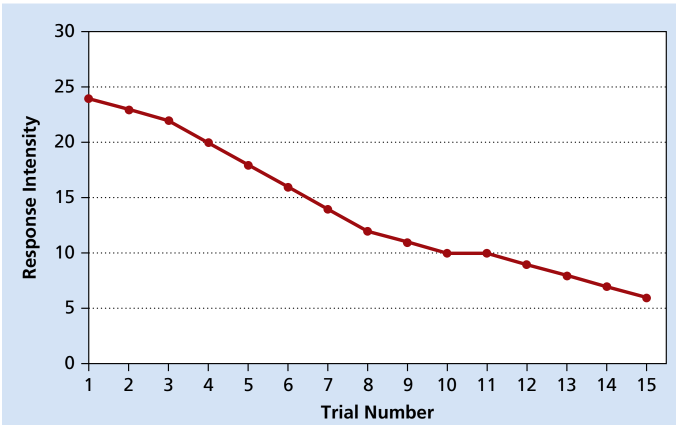
a. Subliminal advertising was never supported, since Vicary ultimately admitted that he never truly conducted such a study.
b. Subliminal advertising can profoundly affect a consumer's decision-making process.
c. Subliminal advertising affects a consumer's decision-making process but only when it involves comfort foods such as popcorn and soda.
d. Subliminal advertising is effective on those who believe in the power of the unconscious.

4. You detect the strong smell of cedar when you enter a furniture store. After a while, your sensory receptors become less sensitive to this smell. This is likely due to __________.

a. accommodation
b. habituation
c. perceptual constancy
d. sensory adaptation

Questions 5 through 8 refer to the following:

A researcher is interested in participants' subjective responses when a stimulus is repeatedly presented at a consistent level across fifteen trials. The graph illustrates a potential pattern of participant responses across trials:



5. What phenomena is illustrated by the pattern of responses?

a. sensory integration
b. contiguity
c. habituation
d. accommodation

6. What is the mean response intensity?

a. 24 **c.** 12
b. 14 **d.** 10

7. What is the median response intensity?

a. 24 **c.** 12
b. 14 **d.** 10

8. 8. What is the modal response intensity?

a. 24 **c.** 12
b. 14 **d.** 10

9. Which of the following terms refers to the amplitude of a light wave, such as how high or low the wave is?

a. color
b. brightness
c. pitch
d. hue

10. When an ophthalmologist surgically corrects a patient's vision through LASIK or PRK, the doctor is making adjustments to the patient's __________.

a. retina
b. lens
c. cornea
d. iris

11. When going from a brightly lit room to a darkened room, the rods play a role in the process of __________, or our ability to adjust to seeing in low levels of light.

a. light adaptation **c.** myopia
b. dark adaptation **d.** presbyopia

12. The national flag of Germany consists of three stacked horizontal bars of color. The top bar is black, the middle red, and the bottom yellow. From top to bottom, how would the flag look as a negative afterimage?

a. white, green, and blue
b. white, orange, and red
c. black, blue, and green
d. black, purple, and orange

13. The hammer, the anvil, and the stirrup are part of the __________.

a. inner ear
b. outer ear
c. middle ear
d. cochlea

14. Which concept of pitch suggests that sound waves of frequencies from about 400 to 4,000 Hz cause the receptors in the cochlea to take turns as they fire?

a. frequency theory **c.** place theory
b. volley principle **d.** ciliary theory

15. Ace hears a low-frequency sound coming from an unknown direction. What would be most effective in helping them determine whether the sound is coming from their left or right?

a. the intensity difference at each ear
b. the timing difference at each ear
c. the shape and folds of the outer ear
d. the firing rate of hair cells

16. Tynise has played her music loudly for years. Now, in her 40s, she finds she has a continuous ringing in both of her ears. What would Tynise probably be diagnosed with?

a. otitis media, which will be addressable with prescription medications

b. conduction-based hearing loss, which hearing aids may be able to help

c. damage to the pinna, which can be corrected with surgery

d. tinnitus, which is a nerve-based disorder that has no permanent cure

17. Studies show that taste preference can typically begin __________.

a. before a baby is born

b. in the first 3 to 6 months after birth

c. by age 1

d. during preschool

18. Which of the following is not readily attributable to sensory interaction?

a. the effect of taste and smell on what we recognize as flavor

b. the experience of the Müller-Lyer illusion

c. the effect of background music on emotional responses to visual scenes in movies or live performances

d. the experience of synesthesia

19. If a child lives with congenital analgesia, why must they be careful when outside playing?

a. The child cannot feel pain and can be injured without even knowing it.

b. The child often cannot hear sounds unless they are within 3 feet of the source.

c. The child lacks the ability to react to a dangerous situation.

d. The child's sense of smell does not work properly.

20. If Jahswill closes his eyes when he rides in his parents' car, he can still tell that the car is moving. This is due to the movement of tiny crystals in the __________.

a. cochlea

b. outer ear

c. otolith organs

d. middle ear

21. A child may sometimes play by quickly turning around in a circle. When the child stops, they often feel like their head is still spinning. What is responsible for this sensation?

a. proprioceptors

b. fluid still rotating in the semicircular canals

c. compression of the otolith organs

d. disruption of the otolith crystals

22. Little Sophie is with her mother at the docks waiting for her daddy to return from his naval deployment. While the boat is still a ways out, her mother says, "There is Daddy's boat." Sophie is confused. She cannot understand how her dad can be on a boat that is so small that she can hold up her thumb and cover the entire boat. It's safe to assume that Sophie does not yet understand __________ constancy.

a. color

b. shape

c. brightness

d. size

23. From experience, you know that some commercial jets typically fly around 500 miles per hour at a height of around 34,000 feet. However, as you watch one fly high overhead, it seems to slowly pass by. What monocular depth cue best explains this?

a. overlap

b. linear perspective

c. motion parallax

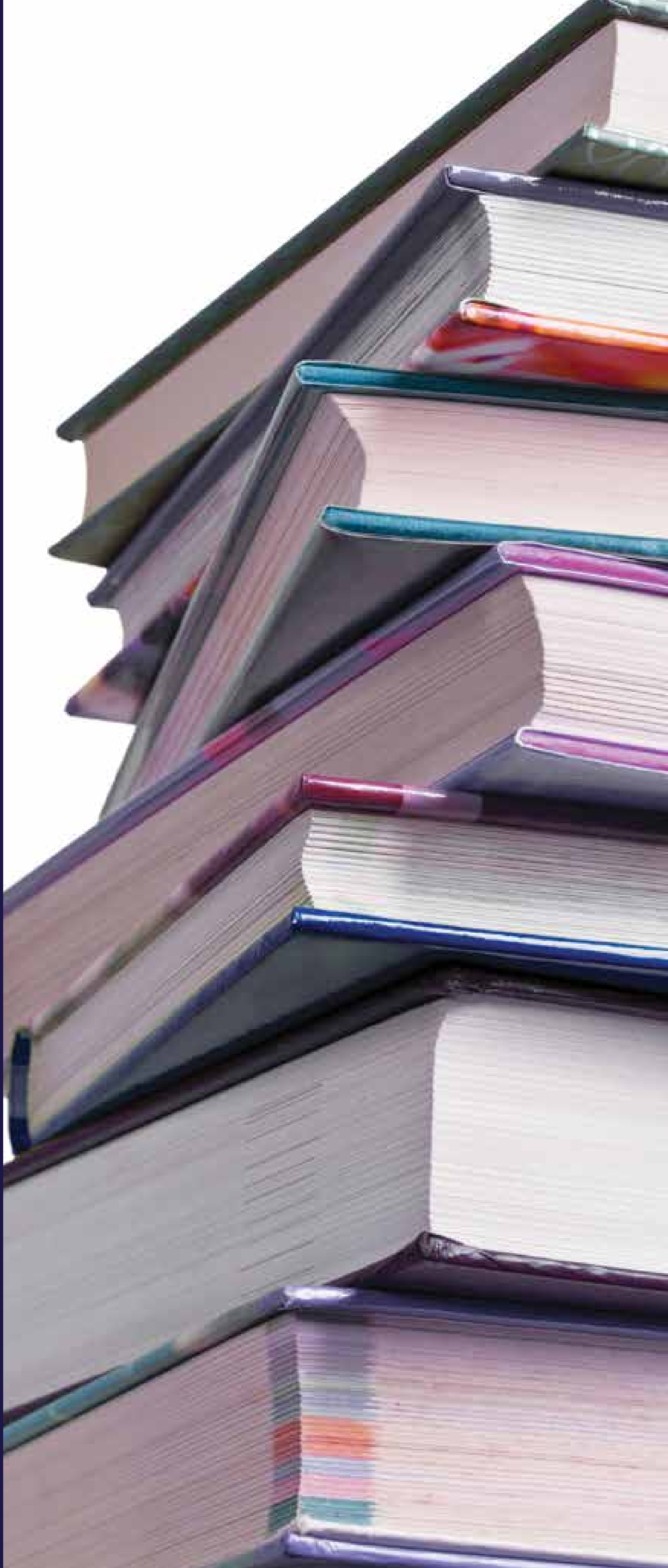
d. texture gradient

24. The Müller-Lyer illusion is significantly influenced by one's __________.

a. age
b. culture
c. gender
d. level of intellect

25. Felicia asks her friend Elspeth to come shopping with her to find a dress to the prom. Elspeth agrees even though she is angry that she does not have a date to the big dance. When Felicia finds a beautiful blue dress, Elspeth tells her, "I don't know… it's sort of dreary" even though everyone else at the store says it is gorgeous. Which of psychology's integrative themes is exemplified by this case?

a. Our perceptions and biases filter our experiences of the world through an imperfect personal lens.
b. Psychology explains general principles that govern behavior while recognizing individual differences.
c. Psychological, biological, social, and cultural factors influence behavior and mental processes.
d. Psychological science relies on empirical evidence and adapts as new data develop.



Pearson