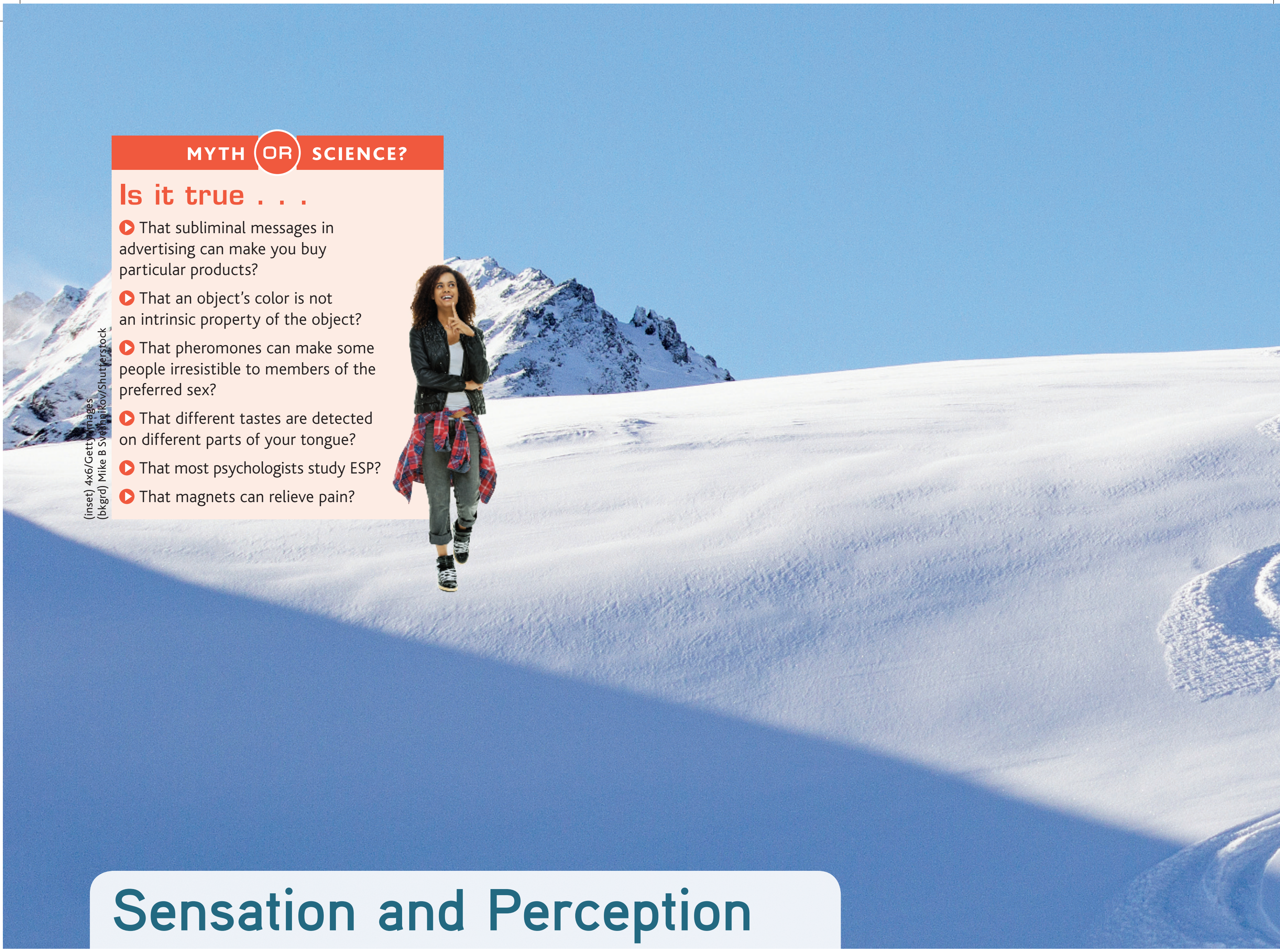


(inset) 4x6/Getty Images
(bkgrd) Mike B Sveshnikov/Shutterstock

**MYTH OR SCIENCE?**

**Is it true . . .**

- That subliminal messages in advertising can make you buy particular products?
- That an object's color is not an intrinsic property of the object?
- That pheromones can make some people irresistible to members of the preferred sex?
- That different tastes are detected on different parts of your tongue?
- That most psychologists study ESP?
- That magnets can relieve pain?

# Sensation and Perception

PROLOGUE

## Learning to See

Mike was just three years old when a jar of chemicals, left in an old storage shed, exploded in his face. The blast destroyed his left eye and severely damaged his right eye. For more than four decades, Mike May was completely blind (Kurson, 2007).

But despite his blindness, Mike experienced—and accomplished—much more than most people ever dream of achieving. Always athletic, Mike played flag football in elementary school and wrestled and played soccer in high school and college. As an adult, he earned a master's degree in international affairs from Johns Hopkins University, went to work for the CIA, and then became a successful businessman.

He also learned to skydive, windsurf, water-ski, and snow-ski. How does a blind person ski down mountains? If you answered, "Very carefully," you'd be wrong—at least in Mike's case. With a guide skiing in front of him shouting "left" or "right" to identify obstacles, Mike hurtled down the most difficult black diamond slopes at speeds up to 65 miles per hour. In fact, Mike has won several medals in national and international championships for blind downhill speed skiing.

It was through skiing that Mike met his wife, Jennifer. An accomplished skier herself, she volunteered to be his guide at a ski slope. Today, Mike and Jennifer and their two sons are all avid skiers (Abrams, 2002).

In the 1990s, Mike started a successful company that develops global positioning devices—along with other mobility devices—for the blind. The portable navigation system gives visually impaired people information about their location, landmarks, streets, and so forth wherever they travel. With his white cane and guide dog, Josh, Mike traveled the world,

# 3

both as a businessperson and as a tourist, ever optimistic and open to adventure (Kurson, 2007). His personal motto: "There is always a way."

But in 1999, Mike's keen sensory world of touch, sounds, and aroma was on the verge of expanding. A new surgical technique became available that offered the chance that Mike's vision might be restored in his right eye. On March 7, 2000, Jennifer held her breath as the bandages were removed. "It was so unexpected—there was just a whoosh! of light blasting into my eye," Mike later recalled (May, 2002). For the first time since he was three years old, Mike May could see.

And what was it like when Mike could see Jennifer for the first time? "It was incredible," he explained, "but the truth is, I knew exactly what she looked like, so it wasn't all that dramatic to see her. The same with my kids. Now, seeing other people that I can't touch, well, that's interesting because I couldn't see them before."

But what did Mike see? Anatomically, his right eye was now normal. But rather than being 20/20, his vision was closer to 20/1,000. What that means is his view of the world was very blurry. He could see colors, shapes, lines, shadows, and light and dark patches. So why wasn't the world crystal clear?

## IN THIS CHAPTER:

**Mike's Moment of Sight: A Little Bit of Vision . . .** Although Mike could "see" from the moment the bandages were removed from his eye (below), he still had trouble identifying objects, especially stationary ones. Mike tells this story of a walk down an unfamiliar street in Barcelona, Spain: "I picked my way through some street construction. I saw a fluorescent green object in my path and tapped it with my cane. It wasn't hard like a sign so I tapped it a bit harder as I still couldn't figure out visually what it was. I was startled as a burst of Spanish profanity came from the workman bent over digging out a hole in the sidewalk. He didn't take too kindly to me poking him in the behind with my cane. A little bit of vision can be dangerous sometimes" (May, 2004).

Florence Low

Florence Low

Although the structures of his eye were working, his brain did not know how to interpret the signals it was receiving. As neuropsychologist Ione Fine (2002) explained, "Most people learn the language of vision between the age of birth and two years old. Mike has had to learn it as an adult." Indeed, there is much more to *seeing* than meets the eye.

Faces posed a particular challenge for Mike. During conversations, he found it very distracting to look at people's faces. As Mike wrote in his journal, "I can see their lips moving, eyelashes flickering, head nodding, and hands gesturing. It was easiest to close my eyes or tune out the visual input. This was often necessary in order to pay attention to what they were saying" (May, 2004).

And what was it like the first time he went skiing, just weeks after his surgery? Mike was dazzled by the sight of the tall, dark green trees, the snow, and the distant peaks against the blue sky (May, 2004). But although you might think that vision, even blurry vision, would be a distinct advantage to an expert skier, this was not the case. Mike found it easier to ski with his eyes closed, with Jennifer skiing ahead and shouting out directions. With his eyes open, he was overwhelmed by all the visual stimuli and the frightening sense that objects were rushing toward him. "By the time I thought about and guessed at what the shadows on the snow meant, I would miss the turn or fall on my face. It was best to close my eyes," he explained.

Throughout this chapter, we will come back to Mike's story. We'll also tell you what neuropsychologists Ione Fine and Don MacLeod learned after conducting fMRI scans of Mike's brain. And, later in the chapter, we'll see how well you do, compared to Mike, at deciphering some visual illusions.

INTRODUCTION:

## What Are Sensation and Perception?

Glance around you. Notice the incredible variety of colors, shades, shadows, and images. Listen carefully to the diversity of sounds, loud and soft, near and far. Focus on everything that's touching you—your clothes, your shoes, the chair you're sitting on. Now, inhale deeply through your nose and identify the aromas in the air.

With these simple observations, you have exercised four of your senses: vision, hearing, touch, and smell. As we saw in Chapter 2, the primary function of the nervous system is communication—the transmission of information from one part of the body to the other. Where does that information come from? Put simply, your senses are the gateway through which your brain receives all its information about the environment. It's a process that is so natural and automatic that we typically take it for granted until it is disrupted by illness or injury. Nevertheless, as Mike's story demonstrates, people with one nonfunctional sense are amazingly adaptive. Often, they learn to compensate for the missing environmental information by relying on their other senses.

In this chapter, we will explore the overlapping processes of *sensation* and *perception*. **Sensation** refers to the detection and basic sensory experience of environmental stimuli, such as sounds, images, and odors. **Perception** occurs when we integrate, organize, and interpret sensory information in a way that is meaningful. Here's a simple

**sensation** The process of detecting a physical stimulus, such as light, sound, heat, or pressure.

**perception** The process of integrating, organizing, and interpreting sensations.

example to contrast the two terms. Your eyes' physical response to light, splotches of color, and lines exemplifies *sensation*. Integrating and organizing those sensations so that you interpret the light, splotches of color, and lines as a painting, a flag, or some other object represents *perception*. Mike's visual world reflects this distinction. Although his eye was accurately transmitting visual information from his environment (*sensation*), his brain was unable to make sense out of the information (*perception*).

Where does the process of sensation leave off and the process of perception begin? There is no clear boundary line between the two processes as we actually experience them. However, we'll discuss sensation and perception separately. We'll begin with the basics of *sensation*—how our sensory receptors respond to stimulation and transmit that information in usable form to the brain. We'll then explore *perception*—how the brain actively organizes and interprets the signals sent from our *sensory receptors*.

Erik Isakson/Blend Images/Getty Images

**Experiencing the World Through Our Senses** Imagine biting into a sweet, sticky ball of cotton candy. All your senses are involved in your experience—vision, smell, taste, hearing, and touch. Although we're accustomed to thinking of our different senses as being quite distinct, all forms of sensation involve the stimulation of specialized cells called sensory receptors.

## Basic Principles of Sensation

**KEY THEME**

Sensation is the result of neural impulses transmitted to the brain from sensory receptors that have been stimulated by physical energy from the external environment.

**KEY QUESTIONS**

- What is the process of transduction?
- What is a sensory threshold, and what are two main types of sensory thresholds?
- How do sensory adaptation and Weber's law demonstrate that sensation is relative rather than absolute?

We're accustomed to thinking of the senses as being quite different from one another. However, all our senses involve some common processes. All sensation is a result of the stimulation of specialized cells, called **sensory receptors,** by some form of *energy*.

Imagine biting into a ball of cotton candy. Your experience of hearing the cotton candy crackle is a response to the physical energy of vibrations in the air, or *sound waves*. The sweet taste of the cotton candy is a response to the physical energy of *dissolvable chemicals* in your mouth, just as the distinctive aroma of the cotton candy is a response to *airborne chemical molecules* that you inhale through your nose. The sticky feel of cotton candy is a response to the *pressure* of the cotton candy against your chin. And the pink color of the candy is a response to the physical energy of *light waves* reflecting from the irregularly shaped sphere.

Sensory receptors convert these different forms of physical energy into electrical impulses that are transmitted via neurons to the brain. The process by which physical energy is converted into a coded neural signal that can be processed by the nervous system is called **transduction.** These neural signals are sent to the brain, where perceptual processes organize and interpret the coded messages. Figure 3.1 on the next page illustrates the steps involved in sensation and perception.

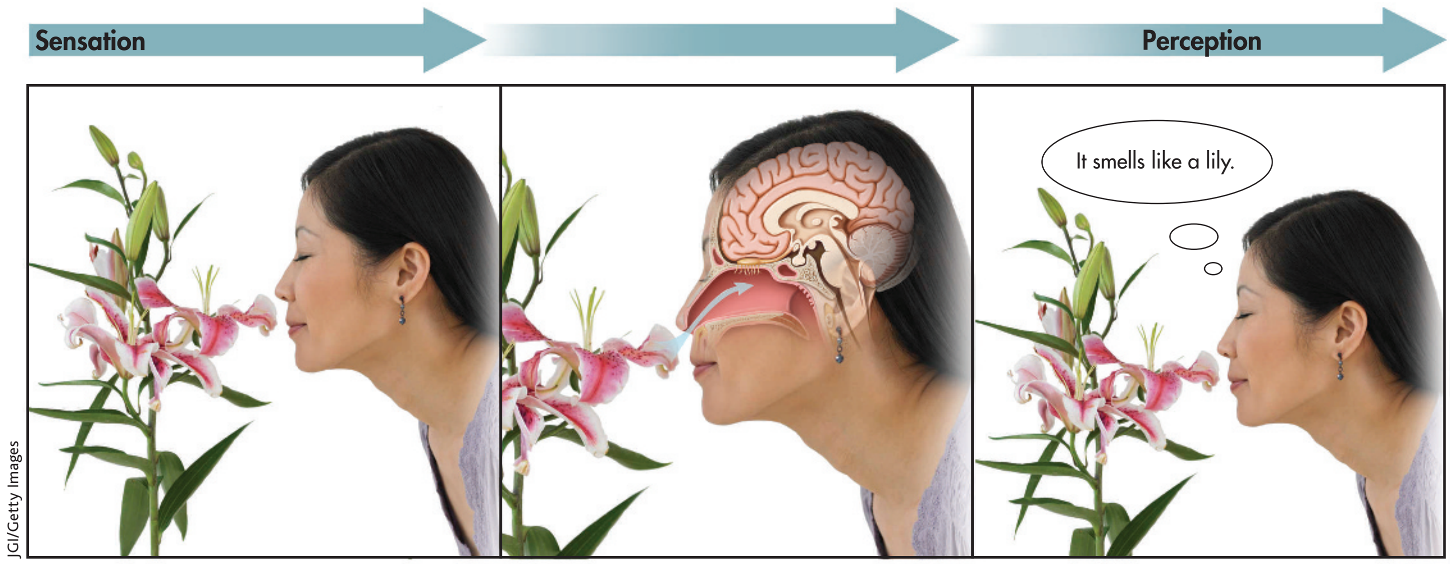
We are constantly being bombarded by many different forms of energy. For instance, at this very moment radio and television waves are bouncing around the atmosphere and passing through your body. However, sensory receptors are so highly specialized that they are sensitive only to very specific types of energy (which is lucky, or you might be seeing *Friends* reruns in your brain right now). So, for any type of stimulation to be sensed, the stimulus energy must first be in a form that can be detected by our sensory receptor cells. Otherwise, transduction cannot occur.

### Sensory Thresholds

Along with being specialized as to the types of energy that can be detected, our senses are specialized in other ways as well. We do not have an infinite capacity to detect all levels of energy. To be sensed, a stimulus must first be strong enough to be detected—loud enough to be heard, concentrated enough to be smelled, bright enough to be seen. The point at which a stimulus is strong enough to be detected because it activates a sensory receptor cell is called a *threshold*. There are two

**sensory receptors** Specialized cells unique to each sense organ that respond to a particular form of sensory stimulation.

**transduction** The process by which a form of physical energy is converted into a coded neural signal that can be processed by the nervous system.




Energy from an environmental stimulus activates specialized receptor cells in the sense organ.

Coded neural messages are sent along a specific sensory pathway to the brain.

These neural messages are decoded and interpreted in the brain as a meaningful perception.

**FIGURE 3.1** The Basic Steps of Sensation and Perception

general kinds of sensory thresholds for each sense—the absolute threshold and the difference threshold.

The **absolute threshold** refers to the smallest possible strength of a stimulus that can be detected half the time. Why just half the time? The level for detection varies from person to person and from trial to trial. Because of this variability, researchers have arbitrarily set the limit as the minimum level of stimulation that can be detected half the time. Under ideal conditions (which rarely occur in normal daily life), our sensory abilities are far more sensitive than you might think (see Table 3.1). Can stimuli that are below the absolute threshold affect us? We discuss this question in the Science Versus Pseudoscience box, "Subliminal Perception."

The other important threshold involves detecting the *difference* between two stimuli. The **difference threshold** is the smallest possible difference between two stimuli that can be detected half the time. Another term for the difference threshold is *just noticeable difference*, which is abbreviated *jnd*.

The just noticeable difference will *vary* depending on its relation to the original stimulus. This principle of sensation is called *Weber's law*, after the German physiologist Ernst Weber (1795–1878). Imagine holding a pebble (the original stimulus). If a second pebble is placed in your hand, you will notice an increase in weight. But if you start off holding a very heavy rock (the original stimulus), you probably won't detect an increase in weight when the same pebble is balanced on it. **Weber's law** holds that for each sense, the size of a just noticeable difference is a constant proportion of the size of the initial stimulus. So, whether we can detect a change in the strength of a stimulus depends on the intensity of the *original* stimulus. Weber's law underscores that our psychological experience of sensation is *relative*.

**absolute threshold** The smallest possible strength of a stimulus that can be detected half the time.

**difference threshold** The smallest possible difference between two stimuli that can be detected half the time; also called *just noticeable difference*.

**Weber's law** (VAY-berz) A principle of sensation that holds that the size of the just noticeable difference will vary depending on its relation to the strength of the original stimulus.

**sensory adaptation** The decline in sensitivity to a constant stimulus.

TABLE 3.1

### Absolute Thresholds

| Sense | Absolute Threshold |
|---|---|
| Vision | A candle flame seen from 30 miles away on a clear, dark night |
| Hearing | The tick of a watch at 20 feet |
| Taste | One teaspoon of sugar in two gallons of water |
| Smell | One drop of perfume throughout a three-room apartment |
| Touch | A bee's wing falling on your cheek from a height of about half an inch |

Psychologist Eugene Galanter provided these classic examples of the absolute thresholds for our senses. In each case, people are able to sense these faint stimuli at least half the time.

Source: Information from Galanter (1962).

## Sensory Adaptation

Suppose your best friend has invited you over for tacos. As you walk in the front door, you're almost overwhelmed by the odor of onions, chilies, and garlic cooking on the stove. However, after just a few moments, you no longer notice the smell. Why? Because your sensory receptor cells become less responsive to a constant stimulus. This gradual decline in sensitivity to a constant stimulus is called **sensory adaptation.** Once again, we see that our experience of sensation is relative—in this case, relative to the *duration of exposure*.

SCIENCE VERSUS PSEUDOSCIENCE

## Subliminal Perception

Walter Daran/The LIFE Images Collection/Getty Images

What are subliminal messages? Can they influence people to quit smoking, lose weight, or change their personalities? **Subliminal perception** refers to the detection of stimuli that are below the threshold of conscious awareness. Such stimuli might be rapidly flashed visual images, sounds, or odors that are too faint to be consciously detected. Although not consciously perceived, subliminal stimuli can evoke a brain response (Bahrami & others, 2007; Tamietto & de Gelder, 2010).

The notion that people's behavior could be manipulated by subliminal messages first attracted public attention in 1957. James Vicary, a marketing executive, claimed to have increased concession sales at a New Jersey movie theater by subliminally flashing the words "Eat popcorn" and "Drink Coke" during the movie.

Controlled tests, however, failed to replicate Vicary's claims, and Vicary later admitted that his boast was a hoax to drum up customers for his failing marketing business (Dijksterhuis & others, 2005; Fullerton, 2010). Nevertheless, to this day, many people still believe—and some advertisements claim—that subliminal messages can exert an irresistible, lasting influence.

*Can* your behavior be profoundly influenced by subliminal self-help programs or by words embedded in advertisements? No. Numerous studies have shown that subliminal self-help products do *not* produce the changes they claim to produce (Strahan & others, 2005). Likewise, numerous studies on subliminal messages in advertising have shown that they do not influence actual consumer decisions (Simons & others, 2007).

MYTH ◀ ~~SCIENCE~~

Is it true that subliminal messages in advertising can make you buy particular products?

But do subliminal stimuli have *any* effect? Surprisingly, the answer is a qualified *yes*. For example, consider the **mere exposure effect**, which refers to the well-documented finding that repeated exposure to a particular stimulus leads to increased liking for that stimulus (Zajonc, 2001; Moreland & Topolinski, 2010). The mere exposure effect also holds for subliminally presented stimuli. For example, when people are exposed to subliminal images of a particular geometric shape and, minutes later, are asked to pick the shape they prefer from a group of shapes, they are much more likely to choose the subliminally presented shape.

Beyond preferences, attitudes and emotions can also be influenced by subliminal stimuli (Smith & others, 2008; Westen & others, 2007). For example, participants were subliminally exposed to faces expressing fear, disgust, or a neutral emotion before being asked to rate the pleasantness of other faces presented on a computer screen. Faces that were preceded by subliminal "fear" stimuli were rated as most unpleasant (Lee & others, 2011).

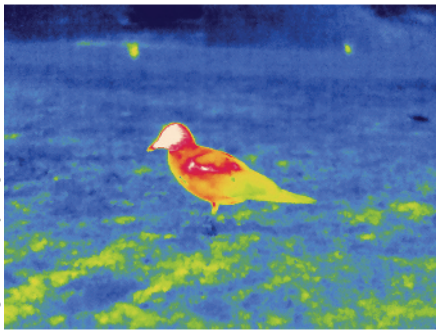
Other subliminal sensory cues have also been shown to affect attitudes. For example, faces that were paired with a pleasant odor that was too faint to consciously detect received higher ratings than faces paired with neutral or unpleasant odors (W. Li & others, 2007).

Although subliminal stimuli are unlikely to cause dramatic changes in motivation or behavior, researchers have found some intriguing experimental effects (see Ruch & others, 2016). Many of these studies involve flashing visual images or words on a computer screen at a rate that is too fast to be consciously perceived. In one fascinating study, older adults, ages 61 to 99, were exposed to words like "spry" and "wise" that reflected a positive view of aging, but at speeds that were too fast to be consciously perceived. A control group of older adults was also exposed to positive views of aging, but through words and images that could be consciously perceived. In contrast to the older adults in the control group, those in the subliminal group showed improved physical function up to three weeks after the study (Levy & others, 2014). One possible explanation is that the participants adopted healthier behaviors because they internalized the more positive views of aging. The study has yet to be replicated, however, so such results must be viewed with caution. For the most part, there is no evidence that subliminal stimuli can produce sweeping changes in behavior, personality, or motivation—or that it can force you to buy a particular product against your will.

Because of sensory adaptation, we become accustomed to constant stimuli, which allows us to quickly notice new or changing stimuli. This makes sense. If we were continually aware of all incoming stimuli, we'd be so overwhelmed with sensory information that we wouldn't be able to focus our attention. So, for example, once you manage to land your posterior on the sofa, you don't need to be constantly reminded that the sofa is beneath you.

**subliminal perception** The detection of stimuli that are below the threshold of conscious awareness; nonconscious perception.

**mere exposure effect** The finding that repeated exposure to a stimulus increases a person's preference for that stimulus.



Tyrone Turner/National Geographic Magazines/Getty Images

**How a Pit Viper Sees a Bird at Night**
Does the world look different to other species? In many cases, yes. Each species has evolved a unique set of sensory capabilities. Pit vipers see infrared light, which we sense only as warmth. The bird here has been photographed through an infrared viewer. The image shows how a pit viper uses its infrared "vision" to detect warm-blooded prey at night (Van Dyke & Grace, 2010). Similarly, many insect and bird species can detect ultraviolet light, which is invisible to humans.

# Vision

## FROM LIGHT TO SIGHT

**KEY THEME**

The receptor cells for vision respond to the physical energy of light waves and are located in the retina of the eye.

**KEY QUESTIONS**

- What is the visible spectrum?
- What are the key structures of the eye and their functions?
- What are rods and cones, and how do their functions differ?

A lone caterpillar on the screen door, the pile of dirty laundry in the corner, the intricate play of color and texture in a painting by Monet. The sense organ for vision is the eye, which contains receptor cells that are sensitive to the physical energy of *light*. But before we can talk about how the eye functions, we need to briefly discuss some characteristics of light as the visual stimulus.

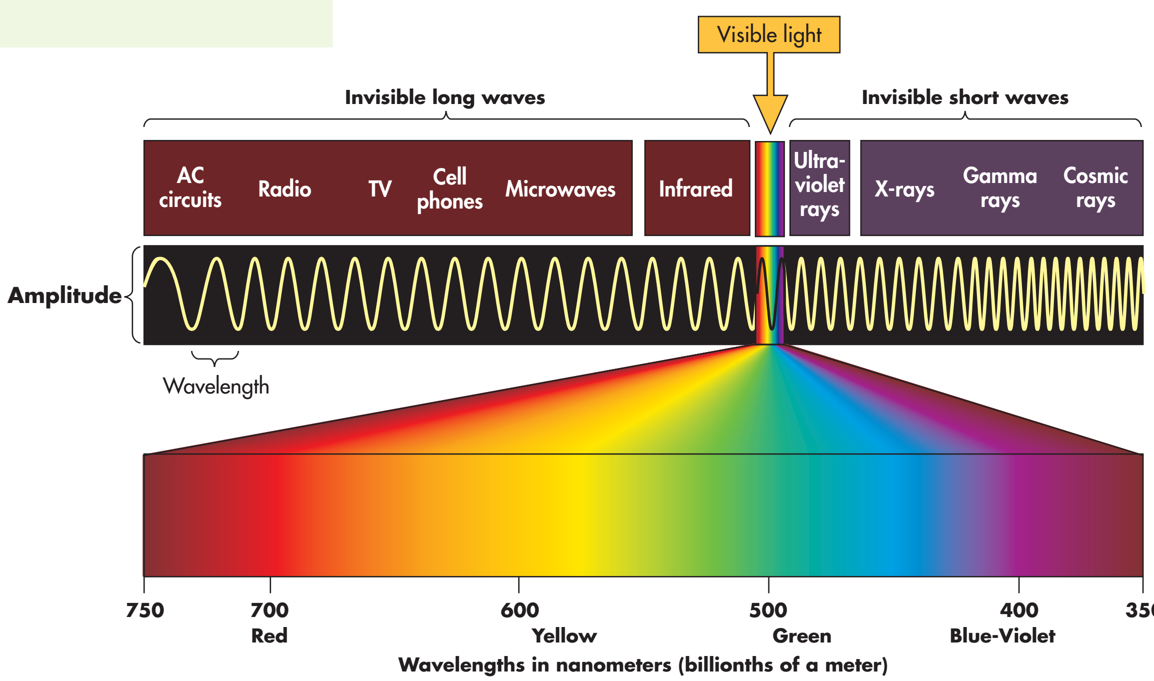
## What We See

### THE NATURE OF LIGHT

Light is just one of many different kinds of electromagnetic energy that travel in the form of waves. Other forms of electromagnetic energy include X-rays, microwaves, and the infrared signals or radio waves transmitted by your TV's remote control. The various types of electromagnetic energy differ in **wavelength,** which is the distance from one wave peak to another.

Humans are capable of seeing only a minuscule portion of the electromagnetic energy range. In Figure 3.2, notice that the visible portion of the electromagnetic energy spectrum can be further divided into different wavelengths. As we'll discuss in more detail later, the different wavelengths of visible light correspond to our psychological perception of different colors.

**FIGURE 3.2** The Electromagnetic Spectrum
We are surrounded by different kinds of electromagnetic energy waves, yet we are able to see only a tiny portion—less than 1 percent—of the entire spectrum of electromagnetic energy. Some electronic instruments, like radio and television, are specialized receivers that detect a specific wavelength range. Similarly, the human eye is sensitive to a specific and very narrow range of wavelengths.



## How We See

### THE HUMAN VISUAL SYSTEM

Imagine you're watching your author Susan's cat Milla, shown in Figure 3.3, sun herself in a nearby window. How do light waves bouncing off Milla's fur culminate in the visual image of a brown cat with green eyes?

First, light waves reflected from the cat enter your eye, passing through the *cornea, pupil,* and *lens*. The *cornea*, a clear membrane that covers the front of the eye, helps gather and direct incoming light. The **pupil** is the black opening in the eye's center. The pupil is surrounded by the *iris,* the colored structure that we refer to when we say that someone has brown eyes. The iris is actually a ring of muscular tissue that contracts or expands to precisely control the size of the pupil and thus the amount of light entering the eye. In dim light, the iris widens the pupil to let light in; in bright light, the iris narrows the pupil.

Behind the pupil is the **lens,** another transparent structure. In a process called **accommodation,** the lens thins or thickens to bend or focus the incoming light so that the light falls on the retina. If the eyeball is abnormally shaped, the lens may not properly focus the incoming light on the retina, resulting in a visual disorder. In nearsightedness, or *myopia,* distant objects appear blurry because the light reflected off the objects focuses in front of the retina. In farsightedness, or *hyperopia,* objects near the eyes appear blurry because light reflected off the objects is focused behind the retina. During middle age, another form of farsightedness often occurs, called *presbyopia*. Presbyopia is caused when the lens becomes brittle and inflexible. In

**wavelength** The distance from one wave peak to another.

**pupil** The opening in the middle of the iris that changes size to let in different amounts of light.

**lens** A transparent structure, located behind the pupil, that actively focuses, or bends, light as it enters the eye.

**accommodation** The process by which the lens changes shape to focus incoming light so that it falls on the retina.

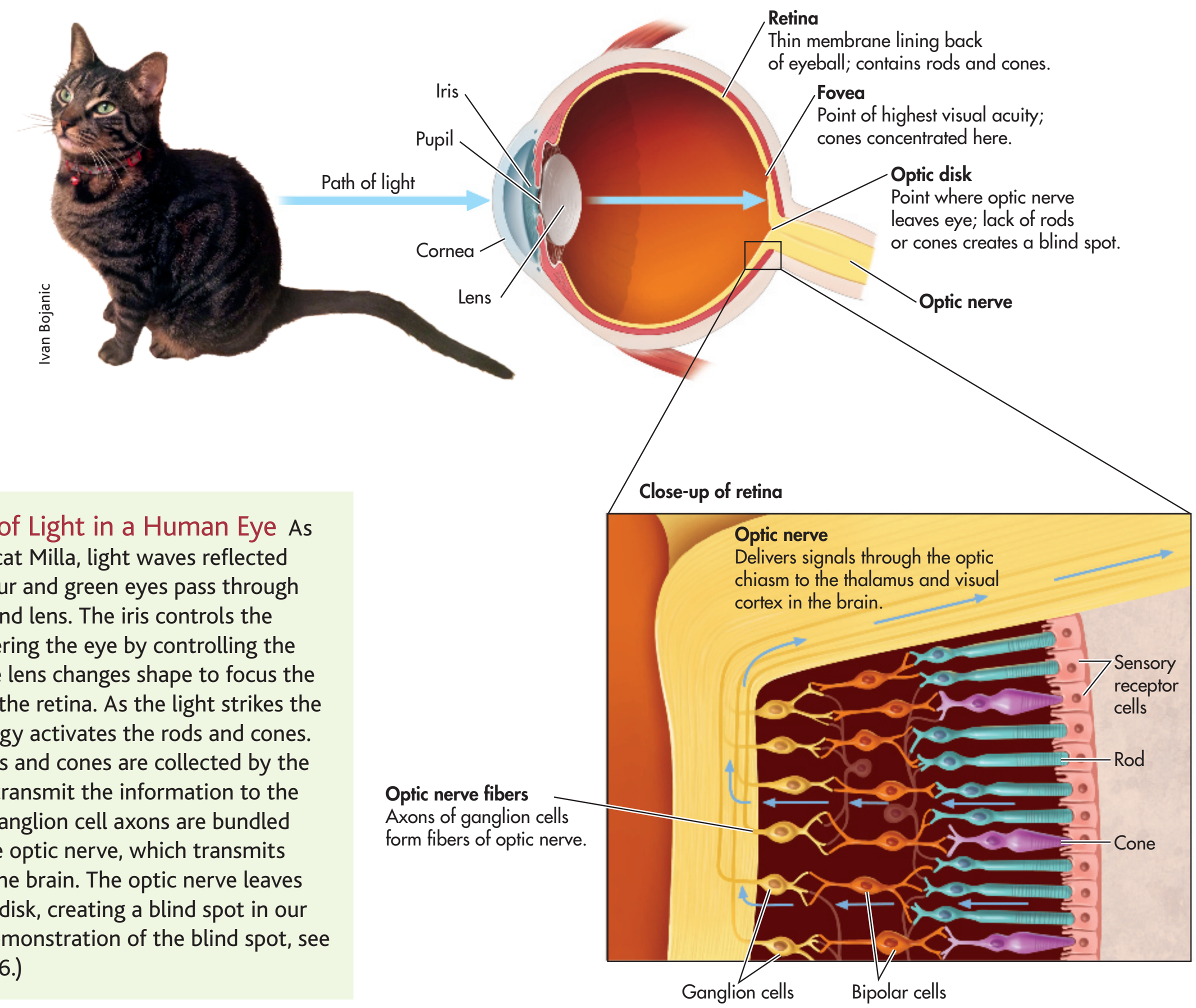
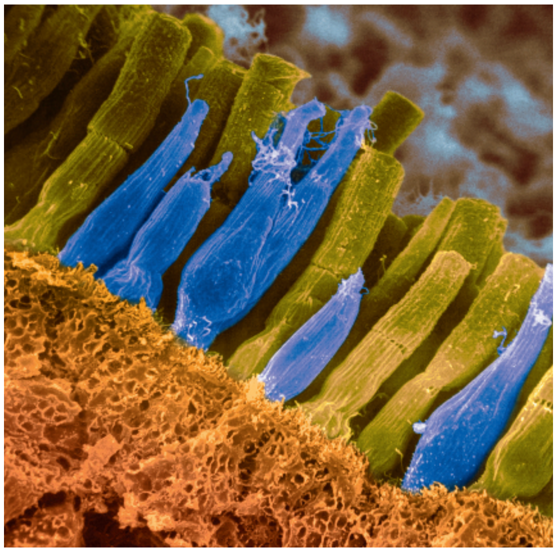



**FIGURE 3.3** Path of Light in a Human Eye As you look at Susan's cat Milla, light waves reflected from Milla's brown fur and green eyes pass through your cornea, pupil, and lens. The iris controls the amount of light entering the eye by controlling the size of the pupil. The lens changes shape to focus the incoming light onto the retina. As the light strikes the retina, the light energy activates the rods and cones. Signals from the rods and cones are collected by the bipolar cells, which transmit the information to the ganglion cells. The ganglion cell axons are bundled together to form the optic nerve, which transmits the information to the brain. The optic nerve leaves the eye at the optic disk, creating a blind spot in our visual field. (For a demonstration of the blind spot, see Figure 3.4 on page 86.)



Omikron/Science Source

**Slim Rods and Fat Cones** The rods and cones in the retina convert light into electrical impulses that are ultimately transmitted to the brain. Color has been added to this scanning electron micrograph to clearly distinguish the rods and cones. The rods, colored yellow-green, are long, thin, and more numerous than the cones, colored blue, which are tapered at one end and shorter and fatter than the rods. As the photo shows, the rods and cones are densely packed in the retina, with many rods surrounding a few cones.

*astigmatism,* an abnormally curved eyeball results in blurry vision for lines in a particular direction. Corrective glasses remedy these conditions by intercepting and bending the light so that the image falls properly on the retina. Surgical techniques like LASIK correct visual disorders by reshaping the cornea so that light rays focus more directly on the retina.

## The Retina

### RODS AND CONES

The **retina** is a thin, light-sensitive membrane that lies at the back of the eye, covering most of its inner surface (see Figure 3.3). Contained in the retina are the **rods** and **cones.** Because these sensory receptor cells respond to light, they are often called *photoreceptors.* When exposed to light, the rods and cones undergo a chemical reaction that results in a neural signal.

Each eye contains about 7 million cones, but 125 million rods. Rods and cones differ in many ways. First, rods are long and thin, with blunt ends. Cones are shorter and fatter, with one end that tapers to a point.

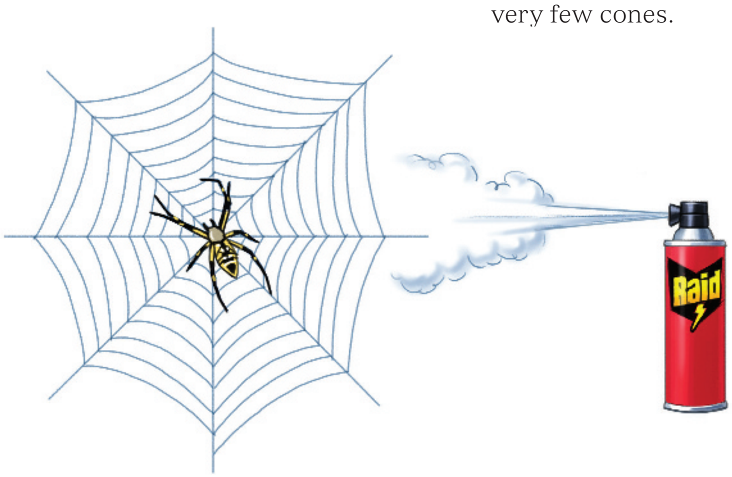
Rods and cones are also specialized for different visual functions. Rods are much more sensitive to light than are cones. Once the rods are fully adapted to the dark, they are about a thousand times better than cones at detecting weak visual stimuli (Masland, 2001). We rely primarily on rods for our vision in dim light and at night.

Rods and cones also react differently to *changes* in the amount of light. Rods adapt relatively slowly, reaching maximum sensitivity to light in about 30 minutes. In contrast, cones adapt quickly to bright light, reaching maximum sensitivity in about 5 minutes. That's why it takes several minutes for your eyes to adapt to the dim light of a darkened room but only a few moments to adapt to the brightness when you switch on the lights.

You may have noticed that it is difficult or impossible to distinguish colors in very dim light. This difficulty occurs because only the cones are sensitive to the different wavelengths that produce the sensation of color, and cones require much more light than rods do to function effectively. Cones are also specialized for seeing fine details and for vision in bright light.

Most of the cones are concentrated in the **fovea,** which is a region in the very center of the retina. Cones are scattered throughout the rest of the retina, but they become progressively less common toward the periphery. There are no rods in the fovea. Images that do not fall on the fovea tend to be perceived as blurry or indistinct. For example, focus your eyes on the word "For" at the beginning of this sentence. In contrast to the sharpness of the letters in "For," the words to the left and right are somewhat blurry. The image of the outlying words is striking the peripheral areas of the retina, where rods are more prevalent and there are very few cones.

**FIGURE 3.4 Demonstration of the Blind Spot** Hold this book a few feet in front of you. Close your right eye and stare at the insect spray can with your left eye. Slowly bring the book toward your face. At some point the spider will disappear because you have focused it onto the part of your retina where the blind spot is located. Notice, however, that you still perceive the spider web. That's because your brain has filled in information from the surrounding area (Komatsu, 2006).




One part of the retina lacks rods and cones altogether. This area, called the *optic disk,* is the point at which the fibers that make up the optic nerve leave the back of the eye and project to the brain. Because there are no photoreceptors in the optic disk, we have a tiny hole, or **blind spot,** in our field of vision. To experience the blind spot, try the demonstration in Figure 3.4.

Why don't we notice this hole in our visual field? The most compelling explanation is that the brain actually fills in the missing background information (Ramachandran, 1992a, 1992b; Weil & Rees, 2010). In effect, signals from neighboring neurons fill in the blind spot with the color and texture of the surrounding visual information (Supèr & Romeo, 2011).

# Processing Visual Information

**KEY THEME**

Signals from the rods and cones undergo preliminary processing in the retina before they are transmitted to the brain.

**KEY QUESTIONS**

- What are the bipolar and ganglion cells, and how do their functions differ?
- How is visual information transmitted from the retina to the brain?
- What properties of light correspond to color perceptions, and how is color vision explained?

Visual information is processed primarily in the brain. However, before visual information is sent to the brain, it undergoes some preliminary processing in the retina by specialized neurons called *ganglion cells*. This preliminary processing of visual data in the cells of the retina is possible because the retina develops from a bit of brain tissue that "migrates" to the eye during fetal development (Hubel, 1995).

When the numbers of rods and cones are combined, there are over 130 million receptor cells in each retina. However, there are only about 1 million ganglion cells. How do just 1 million ganglion cells transmit messages from 130 million visual receptor cells?

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Can you identify the major structures and basic functions of the eye? Try **Concept Practice: Structures of the Eye**.

## Visual Processing in the Retina

Information from the sensory receptors, the rods and cones, is first collected by specialized neurons, called *bipolar cells*. Look back at the lower portion of Figure 3.3. The bipolar cells then funnel the collection of raw data to the ganglion cells. Each ganglion cell receives information from the photoreceptors that are located in its *receptive field* in a particular area of the retina. In this early stage of visual processing, each ganglion cell combines, analyzes, and encodes the information from the photoreceptors in its receptive field before transmitting the information to the brain (Ringach, 2009).

Signals from rods and signals from cones are processed differently in the retina. For the most part, a single ganglion cell receives information from only one or two cones but might well receive information from a hundred or more rods. The messages from these many different rods are combined in the retina before they are sent to the brain. Thus, the brain receives less specific visual information from the rods and messages of much greater visual detail from the cones.

As an analogy to how rod information is processed, imagine listening to a hundred people trying to talk at once over the same telephone line. You would hear the sound of many people talking, but individual voices would be blurred. Now imagine listening to the voice of a single individual being transmitted across the same telephone line. Every syllable and sound would be clear and distinct. In much the same way, cones use the ganglion cells to provide the brain with more specific visual information than is received from rods.

Because of this difference in how information is processed, cones are especially important in *visual acuity*—the ability to see fine details. Visual acuity is strongest when images are focused on the fovea because of the high concentration of cones there.

## From Eye to Brain

How is information transmitted from the ganglion cells of the retina to the brain? The 1 million axons of the ganglion cells are bundled together to form the **optic nerve,** a thick nerve that exits from the back of the eye at the optic disk and extends to the brain. The optic nerve has about the same diameter as a pencil. After exiting the eyes, the left and right optic nerves meet at the **optic chiasm.** Then the fibers of the left and right optic nerves split in two. One set of axons crosses

**retina** (RET-in-uh) A thin, light-sensitive membrane, located at the back of the eye, which contains the sensory receptors for vision.

**rods** The long, thin, blunt sensory receptors of the eye that are highly sensitive to light, but not to color, and that are primarily responsible for peripheral vision and night vision.

**cones** The short, thick, pointed sensory receptors of the eye that detect color and are responsible for color vision and visual acuity.

**fovea** (FOE-vee-uh) A small area in the center of the retina, composed entirely of cones, where visual information is most sharply focused.

**blind spot** The point at which the optic nerve leaves the eye, producing a small gap in the field of vision.

**optic nerve** The thick nerve that exits from the back of the eye and carries visual information to the visual cortex in the brain.

**optic chiasm** (KY-az-uhm) The point in the brain where the optic nerve fibers from each eye meet and partly cross over to the opposite side of the brain.

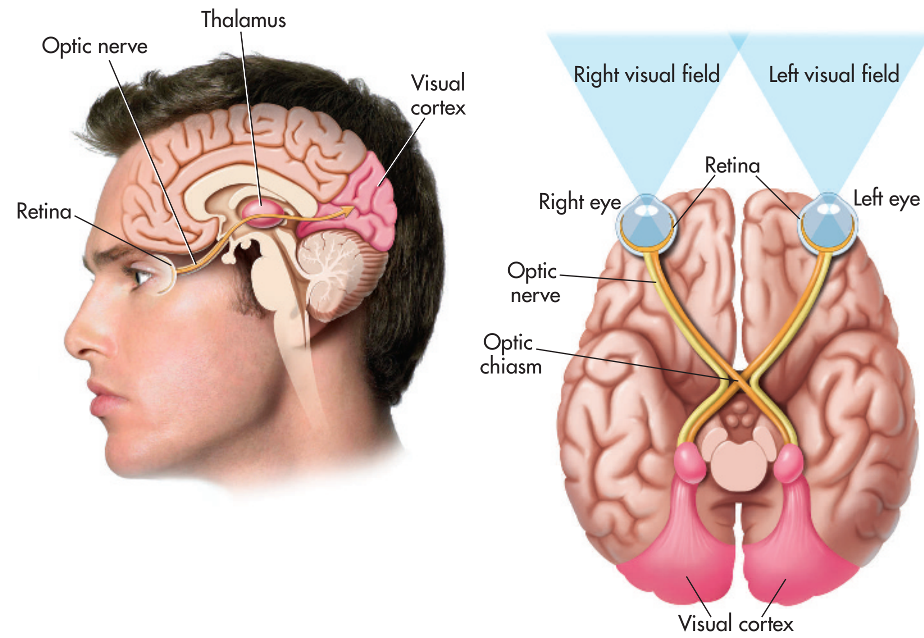



**FIGURE 3.5** Neural Pathways from Eye to Brain The bundled axons of the ganglion cells form the optic nerve, which exits the retina at the optic disk. The optic nerves from the left and right eyes meet at the optic chiasm, then split apart. One set of nerve fibers crosses over and projects to the opposite side of the brain, and another set of nerve fibers continues along the same side of the brain. Most of the nerve fibers travel to the thalamus and then on to the visual cortex of the occipital lobe.

Image Source Plus/Alamy

over and projects to the opposite side of the brain. The other set of axons forms a pathway that continues along the same side of the brain (see **Figure 3.5**).

From the optic chiasm, most of the optic nerve axons project to the brain structure called the thalamus. (For more on the brain structures involved in vision, see Chapter 2). This primary pathway seems to be responsible for processing information about form, color, brightness, and depth. A smaller number of axons follow a detour to areas in the midbrain before they make their way to the thalamus. This secondary pathway seems to be involved in processing information about the location of an object.

Neuroscientists now know that there are several distinct neural pathways in the visual system, each responsible for handling a different aspect of vision (Paik & Ringach, 2011; Purves, 2009). Although specialized, the separate pathways are highly interconnected. From the thalamus, the signals are sent to the visual cortex, where they are decoded and interpreted.

Most of the receiving neurons in the visual cortex of the brain are highly specialized. Each responds to a particular type of visual stimulation—such as angles, edges, lines, and other forms—and even to the movement and distance of objects (Hubel & Wiesel, 2005; Livingstone & Hubel, 1988). These neurons are sometimes called *feature detectors* because they detect, or respond to, particular features or aspects of more complex visual stimuli. Reassembling the features into a recognizable image involves additional levels of processing in the visual cortex and other regions of the brain, including the frontal lobes.

Understanding exactly how neural responses of individual feature detection cells become integrated into the visual perceptions of faces and objects is a major goal of contemporary neuroscience (Celesia, 2010; Mahon & Caramazza, 2011). Experience also plays an important role in the development of perception, especially visual perception (Huber & others, 2015). In the Focus on Neuroscience box, we explore how Mike May's perceptual abilities were affected by his lack of visual experience.

## Color Vision

We see images of an apple, a banana, and an orange because these objects reflect light waves. But why do we perceive that the apple is red and the banana yellow? What makes an orange orange?

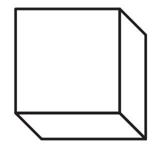
FOCUS ON NEUROSCIENCE

## Vision, Experience, and the Brain

After Mike's surgery, his retina and optic nerve were completely normal. Formal testing showed that Mike had excellent color perception and that he could easily identify simple shapes and lines that were oriented in different directions. These abilities correspond to visual pathways that develop very early. Mike's motion perception was also very good. When thrown a ball, he could catch it more than 80 percent of the time.

Perceiving and identifying common objects, however, was difficult. Although Mike could "see" an object, he had to consciously use visual cues to work out its identity. For example, when shown the simple drawing above right, called a "Necker cube," Mike described it as "a square with lines." But when shown the same image as a rotating image on a computer screen, Mike immediately identified it as a cube. Functional MRI scans showed that Mike's brain activity was nearly normal when shown a *moving* object.

What about more complex objects, like faces? Three years after regaining sight, Mike recognized his wife and sons by their hair color, gait, and other clues, *not* by their faces. But even ten years after his surgery, Mike is unable to identify a face as male or female, or its expression as happy or sad (Huber & others, 2015). Despite a decade of visual experience, functional MRI scans revealed that when Mike is shown faces or objects, the part of the brain that is normally activated is still silent (see scans below).

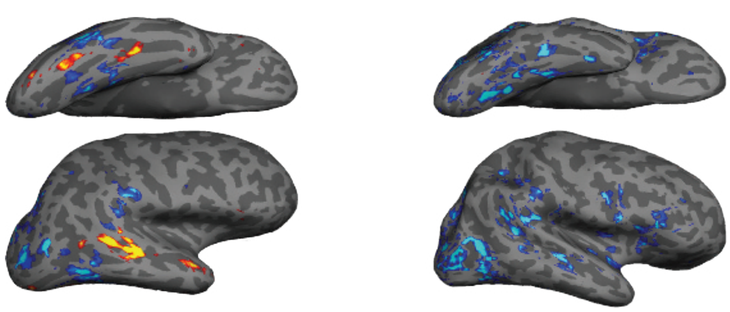


Necker Cube

Shown a stationary image of a Necker cube, Mike described it as "a square with lines." Only when the image began to rotate did Mike perceive it as a drawing of a cube.

For people with normal vision, recognizing complex three-dimensional objects—like tables, shoes, trees, or pencils—is automatic. But as Mike's story shows, these perceptual conclusions are actually based on experience and built up over time.

Neuroscientist Ione Fine and her colleagues (2003, 2008), who have studied Mike's visual abilities, believe that Mike's case indicates that some visual pathways develop earlier than others. Color and motion perception, they point out, develop early in infancy. But because people will continue to encounter new objects and faces throughout life, areas of the brain that are specialized to process faces and objects show plasticity (Huber & others, 2015). In Mike's case, these brain centers never developed (Levin & others, 2010).



Sighted Control — Mike May

**Scanning Mike's Brain** The red, orange, and yellow colors in the left fMRI scans show the areas of the occipital lobe that were activated in response to faces in normally sighted control participants. Blue and purple indicate brain activity in response to objects. In contrast to the controls, Mike's fMRI scans on the right show no response to faces, and his visual response to objects did not reflect the pattern typical in sighted participants (Huber & others, 2015).



## The Experience of Color

### WHAT MAKES AN ORANGE ORANGE?

To explain how we perceive **color**, we must return to the original visual stimulus—light. Our experience of color involves three properties of the light wave—hue, saturation, and brightness. *Hue* varies with the wavelength of light; different wavelengths are perceived as different colors. *Saturation* corresponds to the purity of the wavelength; a color produced by a single wavelength will appear vivid, while a color produced by a mix of wavelengths will appear faded. *Brightness* corresponds to the amplitude of the wavelength; the higher the amplitude, the brighter the color appears to be.

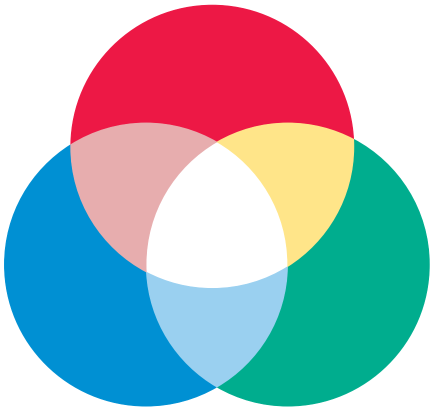
So we're back to the question: What makes an orange orange? Intuitively, it seems obvious that the color of any object is an inseparable property of the object—unless we spill paint or spaghetti sauce on it. In reality, *color is a sensation perceived in the brain* (Werner & others, 2007).

Our perception of color is primarily determined by the wavelength of light that an object reflects. If your T-shirt is red, it's red because the cloth is *reflecting* only the

~~MYTH~~ ▶ SCIENCE

Is it true that an object's color is not an intrinsic property of the object?

**color** The perceptual experience of different wavelengths of light, involving hue, saturation (purity), and brightness (intensity).



**When Red + Blue + Green = White**
When light waves of different wavelengths are combined, the wavelengths are added together, producing the perception of a different color. Thus, when green light is combined with red light, yellow light is produced. When the wavelengths of red, green, and blue light are added together, we perceive the blended light as white. If you're wondering why mixing paints together produces a muddy mess rather than pure white, it's because the wavelengths are *subtracted* rather than added. Each color of pigment absorbs a different part of the color spectrum, and each time a color is added, less light is reflected. Thus, the mixed color appears darker. If you mix all three primary colors together, they absorb the entire spectrum—so we perceive the splotch as black.

wavelength of light that corresponds to the red portion of the spectrum. The T-shirt is *absorbing* the wavelengths that correspond to all other colors. An object appears white because it *reflects* all the wavelengths of visible light and absorbs none. An object appears black when it *absorbs* all the wavelengths of visible light and reflects none. Of course, in everyday life, our perceptions of color are also strongly affected by the amount or type of light falling on an object or the textures and colors that surround it (Purves, 2009; Shevell & Kingdom, 2008).

## How We See Color

Color vision has interested scientists for hundreds of years. The first scientific theory of color vision, proposed by Hermann von Helmholtz (1821–1894) in the mid-1800s, was called the *trichromatic theory*. A rival theory, the *opponent-process theory,* was proposed in the late 1800s. Each theory was capable of explaining some aspects of color vision, but neither could explain all aspects of color vision. Technological advances in the past few decades have allowed researchers to gather direct physiological evidence to test both theories. The resulting evidence indicates that *both* theories of color vision are accurate. Each theory describes color vision at a different stage of visual processing (Hubel, 1995).

**The Trichromatic Theory** As you'll recall, only the cones are involved in color vision. According to the **trichromatic theory of color vision,** there are three varieties of cones. Each type of cone is especially sensitive to certain wavelengths—red light (long wavelengths), green light (medium wavelengths), or blue light (short wavelengths). For the sake of simplicity, we will refer to red-sensitive, green-sensitive, and blue-sensitive cones, but keep in mind that there is some overlap in the wavelengths to which a cone is sensitive (Purves, 2009). A given cone will be very sensitive to one of the three colors and only slightly responsive to the other two.

When a color other than red, green, or blue strikes the retina, it stimulates a *combination* of cones. For example, if yellow light strikes the retina, both the red-sensitive and green-sensitive cones are stimulated; purple light evokes strong reactions from red-sensitive and blue-sensitive cones. The trichromatic theory of color vision received compelling research support in 1964, when George Wald showed that different cones were indeed activated by red, blue, and green light.

The trichromatic theory provides a good explanation for the most common form of **color blindness:** red–green color blindness. People with red–green color blindness cannot discriminate between red and green. That's because they have normal blue-sensitive cones, but their other cones are *either* red-sensitive or green-sensitive (Carroll & others, 2009). Thus, red and green look the same to them. Because red–green color blindness is so common, stoplights are designed so that the location of the light as well as its color provides information to drivers. In vertical stoplights the red light is always on top, and in horizontal stoplights the red light is always on the far left.

**The Opponent-Process Theory** The trichromatic theory cannot account for all aspects of color vision. One important phenomenon that the theory does not explain is the afterimage. An **afterimage** is a visual experience that occurs after the original source of stimulation is no longer present. To experience an afterimage firsthand, follow the instructions in **Figure 3.6**. What do you see?

Afterimages can be explained by the opponent-process theory of color vision, which proposes a different mechanism of color detection from the one set forth in the trichromatic theory. According to the **opponent-process theory of color vision,** there are four basic colors, which are divided into two pairs of color-sensitive neurons: red–green and blue–yellow. The members of each pair *oppose* each other. If red is stimulated, green is inhibited; if green is stimulated, red is inhibited. Green and red cannot be stimulated simultaneously. The same is true for the blue–yellow pair. In addition, black and white act as an opposing pair.

**trichromatic theory of color vision** The theory that the sensation of color results because cones in the retina are especially sensitive to red light (long wavelengths), green light (medium wavelengths), or blue light (short wavelengths).

**color blindness** One of several inherited forms of color deficiency or weakness in which an individual cannot distinguish between certain colors.

**afterimage** A visual experience that occurs after the original source of stimulation is no longer present.

**opponent-process theory of color vision** The theory that color vision is the product of opposing pairs of color receptors: red–green, blue–yellow, and black–white; when one member of a color pair is stimulated, the other member is inhibited.

PicturesWild/Shutterstock

**The Most Common Form of Color Blindness** To someone with the most common form of red–green color blindness, these two photographs look almost exactly the same. People with this type of color blindness have normal blue-sensitive cones, but their other cones are sensitive to either red *or* green. Because of the way red–green color blindness is genetically transmitted, it is much more common in men than in women. About 8 percent of the male population is born with red–green color deficiency, and about a quarter of these males experience only the colors coded by the blue–yellow cones. People who are completely color blind and see the world only in shades of black, white, and gray are extremely rare (Shevell & Kingdom, 2008).

Color, then, is sensed and encoded in terms of its proportion of red *or* green and blue *or* yellow.

For example, red light evokes a response of RED-YES–GREEN-NO in the red–green opponent pair. Yellow light evokes a response of BLUE-NO–YELLOW-YES. Colors other than red, green, blue, and yellow activate one member of each of these pairs to differing degrees. Purple stimulates the *red* of the red–green pair plus the *blue* of the blue–yellow pair. Orange activates *red* in the red–green pair and *yellow* in the blue–yellow pair.

Afterimages can be explained when the opponent-process theory is combined with the general principle of sensory adaptation (Jameson & Hurvich, 1989). If you stare continuously at one color, sensory adaptation eventually occurs and your visual receptors become less sensitive to that color. What happens when you subsequently stare at a white surface?

If you remember that white light is made up of the wavelengths for *all* colors, you may be able to predict the result. The receptors for the original color have adapted to the constant stimulation and are temporarily "off duty." Thus, they do not respond to that color. Instead, only the receptors for the opposing color will be activated, and you perceive the wavelength of only the *opposing* color. For example, if you stare at a patch of green, your green receptors eventually become "tired." The wavelengths for both green and red light are reflected by the white surface, but since the green receptors are "off," only the red receptors are activated. Staring at the green, black, and yellow flag in Figure 3.6 should have produced an afterimage of opposing colors: a red, white, and blue American flag.

**An Integrated Explanation of Color Vision** At the beginning of this section, we said that current research has shown that *both* the trichromatic theory and the opponent-process theory of color vision are accurate. How can both theories be right? It turns out that each theory correctly describes color vision at a *different level* of visual processing.

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Watch **Video: Vision: How We See** to review visual processing and how we perceive color.

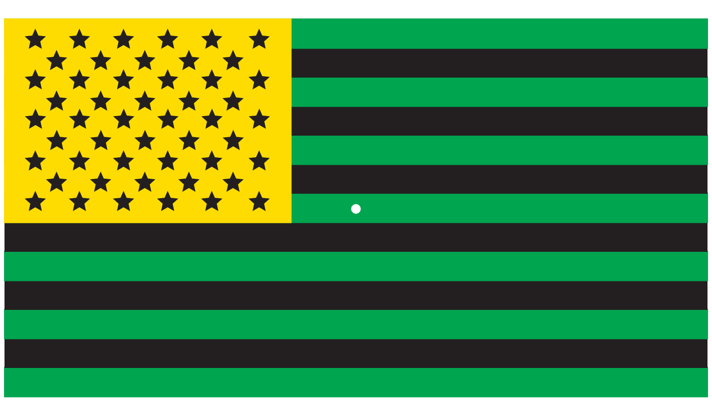

**FIGURE 3.6** Experiencing an Afterimage Stare at the white dot in the center of this oddly colored flag for about 30 seconds, and then look at a white wall or white sheet of paper. What do you see?

As described by the *trichromatic theory,* the cones of the retina do indeed respond to and encode color in terms of red, green, and blue. But recall that signals from the cones and rods are partially processed in the ganglion cells before being transmitted along the optic nerve to the brain. Researchers now believe that an additional level of color processing takes place in the ganglion cells (Demb & Brainard, 2010).

As described by the *opponent-process theory,* the ganglion cells respond to and encode color in terms of opposing pairs (DeValois & DeValois, 1975; Solomon & Lennie, 2007). In the brain, the thalamus and visual cortex also encode color in terms of opponent pairs. Consequently, both theories contribute to our understanding of the process of color vision. Each theory simply describes color vision at a different stage of visual processing (Hubel, 1995; Werner & others, 2007).

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# Hearing

## FROM VIBRATION TO SOUND

**KEY THEME**

Auditory sensation, or hearing, results when sound waves are collected in the outer ear, amplified in the middle ear, and converted to neural messages in the inner ear.

**KEY QUESTIONS**

- How do sound waves produce different auditory sensations?
- What are the key structures of the ear and their functions?
- How do place theory and frequency theory explain pitch perception?

Your author Sandy has hiked in a desert area that was so quiet she could hear the whir of a single grasshopper's wings in the distance. And she has waited on a subway platform where the screech of metal wheels against metal rails forced her to cover her ears.

The sense of hearing, or **audition,** is capable of responding to a wide range of sounds, from faint to blaring, simple to complex, harmonious to discordant. The ability to sense and perceive very subtle differences in sound is important to physical survival, social interactions, and language development. Most of the time, all of us are bathed in sound—so much so that moments of near-silence, like Sandy's experience in the desert, can seem almost eerie.

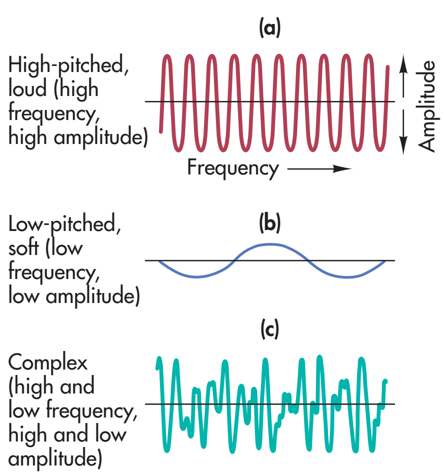



**FIGURE 3.7 Characteristics of Sound Waves** The length of a wave, its height, and its complexity determine the loudness, pitch, and timbre that we hear. The sound produced by **(a)** would be high-pitched and loud. The sound produced by **(b)** would be soft and low. The sound in **(c)** is complex, like the sounds we usually experience in the natural world.

**audition** The technical term for the sense of hearing.

**pitch** The relative highness or lowness of a sound, determined by the frequency of a sound wave.

**frequency** The rate of vibration, or the number of sound waves per second.

# What We Hear

## THE NATURE OF SOUND

Whether it's the ear-splitting screech of metal on metal or the subtle whir of a grasshopper's wings, *sound waves* are the physical stimuli that produce our sensory experience of sound. Usually, sound waves are produced by the rhythmic vibration of air molecules, but sound waves can be transmitted through other media, such as water, too. Our perception of sound is directly related to the physical properties of sound waves (see Figure 3.7).

One of the first things that we notice about a sound is how loud it is. *Loudness* is determined by the intensity, or *amplitude,* of a sound wave and is measured in units called *decibels.* Zero decibels represents the loudness of the softest sound that humans can hear, or the absolute threshold for hearing. As decibels increase, perceived loudness increases.

**Pitch** refers to the relative "highness" or "lowness" of a sound. Pitch is determined by the frequency of a sound wave. **Frequency** refers to the rate of vibration, or number of waves per second, and is measured in units called *hertz.* Hertz simply refers to the number of wave peaks per second. The faster the vibration, the higher the frequency, the closer together the waves are—and the higher the tone produced. If you pluck the high E and the low E strings on a guitar, you'll notice that the low E vibrates far fewer times per second than does the high E.

Most of the sounds we experience do not consist of a single frequency but are *complex,* consisting of several sound-wave frequencies. The *complexity* of a sound wave, or its unique combination of frequencies, produces the distinctive quality, or *timbre*, of a sound, which enables us to distinguish easily between the same note played on a saxophone and on a piano. Every human voice has its own distinctive timbre, which is why you can immediately identify a friend's voice on the telephone from just a few words.

**outer ear** The part of the ear that collects sound waves; consists of the pinna, the ear canal, and the eardrum.

**eardrum** A tightly stretched membrane at the end of the ear canal that vibrates when hit by sound waves.

## How We Hear

### THE PATH OF SOUND

The ear is made up of the outer ear, the middle ear, and the inner ear. Sound waves are *collected* in the outer ear, *amplified* in the middle ear, and *transduced,* or *transformed into neural messages,* in the inner ear (see Figure 3.8).

The **outer ear** includes the *pinna,* the *ear canal,* and the *eardrum*. The pinna is that oddly shaped flap of skin and cartilage that's attached to each side of your head. The pinna helps us pinpoint the location of a sound. But the pinna's primary role is to catch sound waves and funnel them into the ear canal. The sound wave travels down the ear canal and then bounces into the **eardrum,** a tightly stretched membrane. When the sound wave hits the eardrum, the eardrum vibrates, matching the vibrations of the sound wave in intensity and frequency.

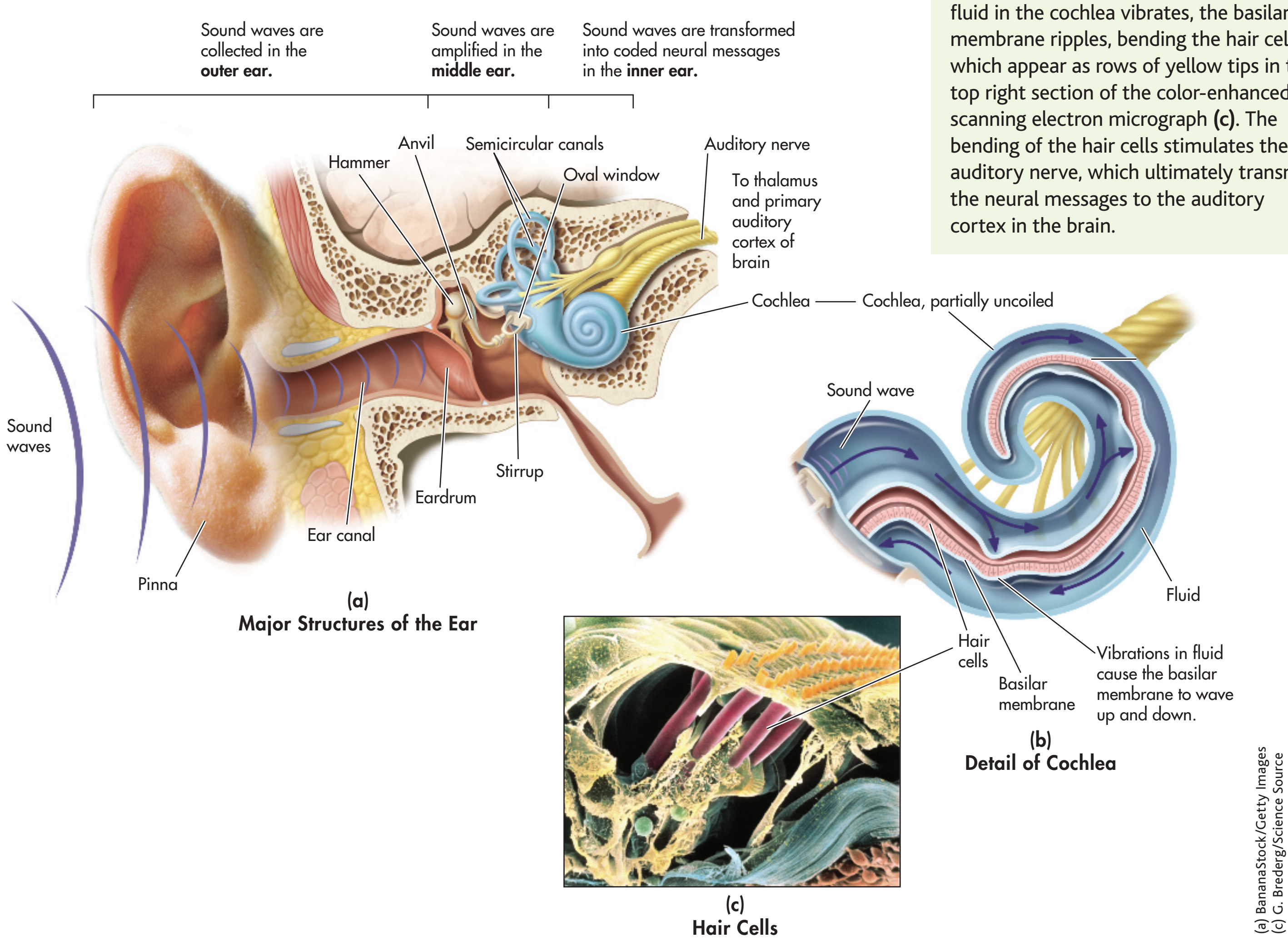



**FIGURE 3.8 The Path of Sound Through the Human Ear** The path that sound waves take through the major structures of the human ear is shown in **(a)**. After being caught by the outer ear, sound waves are funneled down the ear canal to the eardrum, which transfers the vibrations to the structures of the middle ear. In the middle ear, the vibrations are amplified and transferred in turn to the oval window and on to the fluid-filled cochlea in the inner ear **(b)**. As the fluid in the cochlea vibrates, the basilar membrane ripples, bending the hair cells, which appear as rows of yellow tips in the top right section of the color-enhanced scanning electron micrograph **(c)**. The bending of the hair cells stimulates the auditory nerve, which ultimately transmits the neural messages to the auditory cortex in the brain.

(a) BananaStock/Getty Images
(c) G. Bredeberg/Science Source

Suki Dhanda

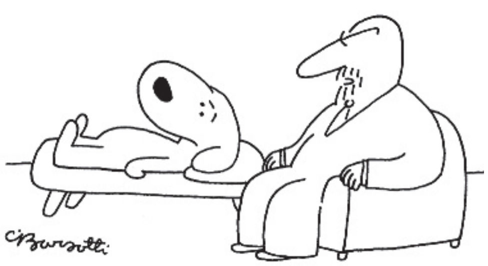
**Restoring Hearing** Cochlear implants convert sound into electrical impulses that directly stimulate the auditory nerve via electrodes implanted in the cochlea. Cochlear implants do *not* restore normal hearing (Farris-Trimble & others, 2014). However, their use can allow hearing-impaired individuals to perceive speech and other everyday sounds (Clark & others, 2013; O'Donoghue, 2013).

The eardrum separates the outer ear from the **middle ear.** The eardrum's vibration is transferred to three tiny bones in the middle ear—the *hammer,* the *anvil,* and the *stirrup*. Each bone sets the next bone in motion. The joint action of these three bones almost doubles the amplification of the sound. The innermost bone, the stirrup, transmits the amplified vibration to the *oval window*. If the tiny bones of the middle ear are damaged or become brittle, as they sometimes do in old age, *conduction deafness* may result. Conduction deafness can be helped by a hearing aid, which amplifies sounds.

Like the eardrum, the oval window is a membrane, but it is many times smaller than the eardrum. The oval window separates the middle ear from the **inner ear.** As the oval window vibrates, the vibration is next relayed to an inner structure called the **cochlea,** a fluid-filled tube that's coiled in a spiral. The word *cochlea* comes from the Greek word for "snail," and the spiral shape of the cochlea does resemble a snail's shell. Although the cochlea is a very complex structure, it is quite tiny—no larger than a pea.

As the fluid in the cochlea ripples, the vibration in turn is transmitted to the **basilar membrane,** which runs the length of the coiled cochlea. Embedded in the basilar membrane are the sensory receptors for sound, called **hair cells,** which have tiny, projecting fibers that look like hairs. Damage to the hair cells or auditory nerve can result in *nerve deafness*. Exposure to loud noise can cause nerve deafness (see Table 3.2). Hearing aids are of no use in this form of deafness because the neural messages cannot reach the brain. However, nerve deafness *can,* in some cases, be treated with a *cochlear implant,* which is an electronic device surgically implanted behind the ear (see photo).

The hair cells bend as the basilar membrane ripples. It is here that transduction finally takes place: The physical vibration of the sound waves is converted into neural impulses. As the hair cells bend, they stimulate the cells of the auditory nerve, which carries the neural information to the thalamus and the auditory cortex in the brain (Hackett & Kaas, 2009; Recanzone & Sutter, 2008).



Charles Barsotti The New Yorker Collection/The Cartoon Bank

*"And only you can hear this whistle?"*

## Distinguishing Pitch

How do we distinguish between the low-pitched throb of a bass guitar and the high-pitched tones of a piccolo? Remember, pitch is determined by the *frequency* of a sound wave. The basilar membrane is a key structure involved in our discrimination of pitch. Two complementary theories describe the role of the basilar membrane in the transmission of differently pitched sounds.

According to **frequency theory,** the basilar membrane vibrates at the *same* frequency as the sound wave. Thus, a sound wave of about 100 hertz would excite each hair cell along the basilar membrane to vibrate 100 times per second, and neural impulses would be sent to the brain at the same rate. However, there's

Damage to the hair cells is cumulative, and noise exposure, not age, is the leading cause of hearing loss. One survey found that 12–15% of school-age children have some hearing deficits due to noise exposure (Harrison, 2012). Along with exposure to environmental noise, phones and other personal music players can also expose the listener to dangerously high levels of noise (Breinbauer & others, 2012). As a general rule, if other people can hear what you are listening to, the sound is turned up too high.

JGI/Jamie Grill/Blend Images/Getty Images

TABLE 3.2

### Decibel Levels of Some Common Sounds

| Decibels | Examples | Exposure Danger |
|---|---|---|
| 140 | Shotgun blast, jet plane | Any exposure is dangerous |
| 120 | Speakers at rock concert, sandblasting, thunderclap | Immediate danger |
| 100 | Chain saw, pneumatic drill | 2 hours |
| 90 | Truck traffic, noisy home appliances, lawn mower | Less than 8 hours |
| 80 | Subway, heavy city traffic, alarm clock at 2 feet | More than 8 hours |
| 70 | Busy traffic, noisy restaurant | Critical level begins with constant exposure |
| 50 | Light traffic at a distance, refrigerator | |
| 30 | Quiet library, soft whisper | |
| 0 | Lowest sound audible to human ear | |

a limit to how fast neurons can fire. Individual neurons cannot fire faster than about 1,000 times per second. But we can sense sounds with frequencies that are many times higher than 1,000 hertz. A child, for example, can typically hear pitches ranging from about 20 to 20,000 hertz.

So how can higher-frequency sounds be transmitted? A partial explanation involves the *volley principle,* which draws upon a military strategy created before the development of modern firearms. To deal with the problem of slow reload times, different groups of soldiers would fire in sequence to minimize the amount of time between "volleys" of bullets launched at the enemy.

The volley principle holds that hair cells also fire in "volleys." Imagine three groups of neurons, each of which can fire at a rate of 1,000 times per second. But rather than firing in unison, the neuron groups take turns, each group firing in rapid succession while the other groups are in the resting state. In this way, impulses can be sent to the brain at rates that exceed 1,000 impulses per second.

So how do we hear higher-pitched sounds above 3,000 hertz? According to **place theory,** different frequencies cause larger vibrations at different *locations* along the basilar membrane. High-frequency sounds, for example, cause maximum vibration near the stirrup end of the basilar membrane. Lower-frequency sounds cause maximum vibration at the opposite end. Thus, different pitches excite different hair cells along the basilar membrane. Higher-pitched sounds are interpreted according to the place where the hair cells are most active.

*Both* frequency theory and place theory are involved in explaining our discrimination of pitch (Kaas & others, 2013). Frequency theory helps explain our discrimination of low frequencies. Place theory helps explain our discrimination of higher-pitched sounds. For intermediate frequencies or midrange pitches, both place and frequency are involved.

Andy Hunger/AGE Fotostock

**Can Snakes Hear?** Snakes have functional inner ears, but they don't have outer ears. So how do snakes hear? With their jaws. When a desert viper rests its head on the ground, a bone in its jaw picks up minute vibrations in the sand. From the jaw, these vibrations are transmitted along a chain of tiny bones to the cochlea in the inner ear, allowing the snake to "hear" the faint footsteps of a mouse or other prey (Freidel & others, 2008).

## The Chemical and Body Senses

### SMELL, TASTE, TOUCH, AND POSITION

**KEY THEME**

Chemical stimuli produce the sensations of smell and taste, while pressure and other stimuli are involved in touch, pain, position, and balance sensations.

**KEY QUESTIONS**

- How do airborne molecules result in the sensation of an odor?
- What are the primary tastes, and how does the sensation of taste arise?
- How do fast and slow pain systems differ, and what is the gate-control theory of pain?
- How are body sensations of movement, position, and balance produced?

The senses of smell and taste are closely linked. If you've ever temporarily lost your sense of smell because of a bad cold, you've probably noticed that your sense of taste was also disrupted. Even a hot fudge sundae tastes bland.

Smell and taste are linked in other ways, too. Unlike vision and hearing, which involve sensitivity to different forms of energy, the sensory receptors for taste and smell are specialized to respond to different types of *chemical* substances. That's why smell, or **olfaction,** and taste, or **gustation,** are sometimes called the "chemical senses" (Travers & Travers, 2009).

People can get along quite well without a sense of smell. A surprisingly large number of people are unable to smell specific odors or lack a sense of smell completely, a condition called *anosmia*. Fortunately, humans gather most of their information about the world through vision and hearing. However, many animal species depend on chemical signals as their primary source of information.

Even for humans, smell and taste can provide important information about the environment. Tastes help us determine whether a particular substance is to be savored or spat out. Smells, such as the odor of a smoldering fire, leaking gas, or spoiled food, alert us to potential dangers.

**middle ear** The part of the ear that amplifies sound waves; consists of three small bones: the hammer, the anvil, and the stirrup.

**inner ear** The part of the ear where sound is transduced into neural impulses; consists of the cochlea and semicircular canals.

**cochlea** (COKE-lee-uh) The coiled, fluid-filled inner-ear structure that contains the basilar membrane and hair cells.

**basilar membrane** (BAZ-uh-ler or BAYZ-uh-ler) The membrane within the cochlea of the ear that contains the hair cells.

**hair cells** The hair-like sensory receptors for sound, which are embedded in the basilar membrane of the cochlea.

**frequency theory** The view that the basilar membrane vibrates at the same frequency as the sound wave.

**place theory** The view that different frequencies cause larger vibrations at different locations along the basilar membrane.

**olfaction** Technical name for the sense of smell.

**gustation** Technical name for the sense of taste.

Nutnarin Khetwong/Shutterstock

**What Does Popcorn Smell Like?** English and other European languages have many abstract words that can be used to describe sights, tastes, and textures, but very few words that specifically apply to odors. Typically, odors are described as "smelling like" other objects, such as "smells moldy" or "smells lemony."

The same is not true of all languages, however. Two hunter-gatherer groups, the Jahai in Malaysia and the Mani in Thailand, have rich odor vocabularies (Majid & Burenhult, 2014; Wnuk & Majid, 2014). For example, the Jahai word *p?us* (pronounced pa-OOS) is used to describe the smell of old huts, day-old food, and cabbage (Majid, 2014). Given an odor identification test, the Jahai easily outscored English-speaking participants. Their olfactory expertise may reflect the importance of smells in their culture and environment.

## How We Smell (Don't Answer That!)

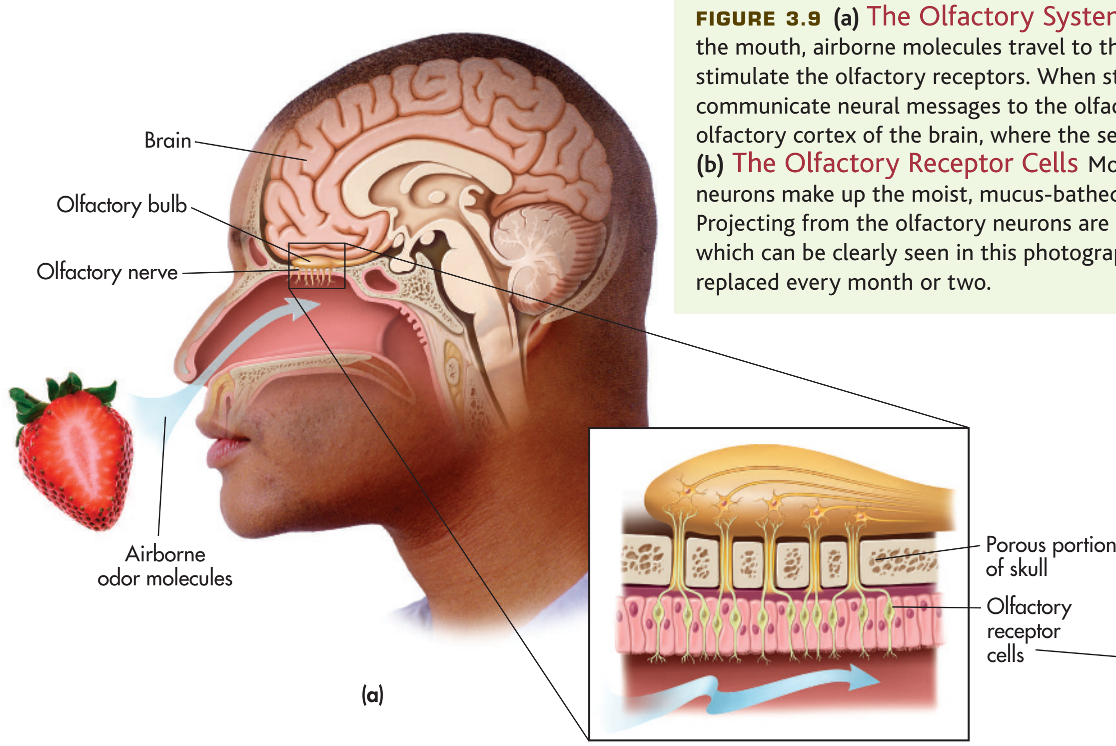
The sensory stimuli that produce our sensation of an odor are *molecules in the air*. These airborne molecules are emitted by the substance we are smelling. We inhale them through the nose and through the opening in the palate at the back of the throat. In the nose, the molecules encounter millions of *olfactory receptor cells* located high in the nasal cavity. Many species use airborne chemical signals, called *pheromones*, to communicate information about territory, mating strategies, and so forth. What about humans? The In Focus box "Do Pheromones Influence Human Behavior?" explores this question.

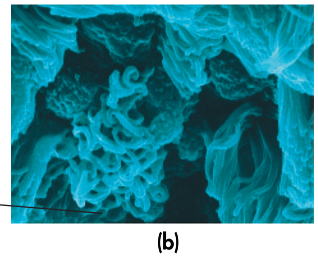
Unlike the sensory receptors for hearing and vision, the olfactory receptors are constantly being replaced. Each cell lasts for only about 30 to 60 days. Like synaptic receptors, each odor receptor seems to be specialized to respond to molecules of a different chemical structure. When these olfactory receptor cells are stimulated by the airborne molecules, the stimulation is converted into neural messages that pass along their axons, bundles of which make up the *olfactory nerve*.

So far, hundreds of different odor receptors have been identified (Gottfried, 2010). Humans have about 350 different olfactory receptors, far less than the 1,000 different receptors in mice and rats. And scientists have identified only about 10 to 20 percent of the odor molecules that activate these receptors (Ravindran, 2016). We don't have a separate receptor for each of the estimated 10,000 different odors that we can detect, however. Rather, each receptor is like a letter in an olfactory alphabet. Just as different combinations of letters in the alphabet are used to produce recognizable words, different combinations of olfactory receptors produce the sensation of distinct odors. Thus, the airborne molecules activate specific combinations of receptors. In turn, the brain identifies an odor by interpreting the *pattern* of olfactory receptors that are stimulated (Shepherd, 2006).

As shown in Figure 3.9, the olfactory nerves directly connect to the **olfactory bulb** in the brain, which is actually the enlarged ending of the *olfactory cortex* at the front of the brain. Axons from the olfactory bulb form the *olfactory tract*. These neural pathways project to different brain areas, including the temporal lobe and

**FIGURE 3.9 (a) The Olfactory System** Inhaled through the nose or the mouth, airborne molecules travel to the top of the nasal cavity and stimulate the olfactory receptors. When stimulated, these receptor cells communicate neural messages to the olfactory bulb, which is part of the olfactory cortex of the brain, where the sense of smell is registered.
**(b) The Olfactory Receptor Cells** More than 5 million olfactory neurons make up the moist, mucus-bathed tissue at the back of the nose. Projecting from the olfactory neurons are the fiber-like olfactory hairs, which can be clearly seen in this photograph. Olfactory neurons are replaced every month or two.

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IN FOCUS

## Do Pheromones Influence Human Behavior?

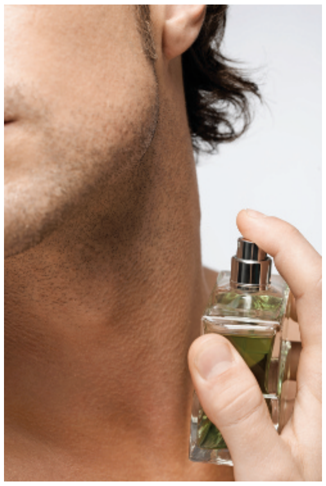
Many animals, including primates, communicate by releasing **pheromones**, chemical signals that have evolved for communication with other members of the same species (Drea, 2015; Wyatt, 2015). Pheromones may mark territories, advertise sexual status, or serve as warning signals. From insects to mammals, pheromones are used to communicate aggression, alarm, and fearful states (Radulescu & Mujica-Parodi, 2013). Pheromones are also extremely important in regulating sexual attraction, mating, and reproductive behavior in many animals (Wyatt, 2009). A lusty male cabbage moth, for example, can detect pheromones released from a sexually receptive female cabbage moth that is several miles away.

Do humans produce pheromones as other animals do? Early evidence for the existence of human pheromones comes from studies of the female menstrual cycle by University of Chicago biopsychologist Martha McClintock (1992). While still a college student, McClintock (1971) set out to scientifically investigate the folk notion that women who live in the same dorm eventually develop synchronized menstrual periods. McClintock found that the more time women spent together, the more likely their cycles were to be in sync, but some studies have cast doubt on that conclusion (see Doty, 2014; Ziomkiewicz, 2006).

Later research showed that smelling an unknown chemical substance in underarm sweat from female donors synchronized the recipients' menstrual cycles with the donors' cycles (Preti & others, 1986; Stern & McClintock, 1998).

Since these findings, McClintock and other researchers have made a number of discoveries in their quest to identify human pheromones, which they prefer to call *human chemosignals*. The most likely candidates are chemicals found in steroid compounds that are naturally produced by the human body and found in sweat, armpit hair, blood, and semen. One study in McClintock's lab showed that exposure to a chemical compound in the perspiration of breast-feeding mothers significantly increased sexual motivation in other non–breast-feeding women (Spencer & others, 2004). The study's authors speculate that the presence of breast-feeding women acts as a social signal—an indicator that the social and physical environment is one in which pregnancy and breast-feeding will be supported.

**The Scent of Attraction** Some perfume manufacturers claim that their products contain human pheromones that will make you "irresistible" to members of the opposite sex. But is there any evidence that pheromones affect human sexual attraction?



Mario Castello/AGE Fotostock

Later studies found that the same chemical affected women's, but not men's, mood and attitudes. For example, it was shown to increase women's attraction to men at a speed-dating event (Saxton & others, 2008), improve positive mood (Bensafi & others, 2004), and increase generosity and positive mood in women playing an economic game (Perrotta & others, 2016). There is also evidence that human chemosignals are involved in communicating emotional states, including stress, anxiety, and fear (see Radulescu & Mujica-Parodi, 2013). For example, women watched either a frightening video or a neutral video while being exposed to either "neutral sweat" or "fear sweat." Regardless of which video the women watched, women who were exposed to the "fear sweat" were more likely to react with fearful expressions than the women who were exposed to the neutral sweat (de Groot & others, 2014).

**MYTH ◀ ~~SCIENCE~~**

Is it true that pheromones can make some people irresistible to members of the preferred sex?

Pheromones may not make people irresistible to the preferred sex, as they do in other animal species. Instead, it may be that these consciously undetectable chemosignals play an important role in communicating and synchronizing emotional states among people in groups (de Groot & others, 2014).

structures in the limbic system (Gottfried, 2010; Shepherd, 2006). The projections to the *temporal lobe* are thought to be part of the neural pathway involved in our conscious recognition of smells. The projections to the *limbic system* are thought to regulate our emotional response to odors.

The direct connection of olfactory receptor cells to areas of the cortex and limbic system is unique to our sense of smell. As discussed in Chapter 2, all other bodily sensations are first processed in the thalamus before being relayed to the higher brain centers in the cortex. Olfactory neurons are unique in another way, too. They are the only neurons that *directly* link the brain and the outside world. The axons of the sensory neurons that are located in your nose extend directly into your brain!

Olfactory function tends to decline with age. About half of those aged 65 to 80 have a significant loss of olfactory function, a number that increases to two-thirds

**olfactory bulb** (ole-FACK-tuh-ree) The enlarged ending of the olfactory cortex at the front of the brain where the sensation of smell is registered.

**pheromones** Chemical signals released by an animal that communicate information and affect the behavior of other animals of the same species.

Courtesy Noam Sobel

**Can Humans Track a Scent?** Dogs are famous for their ability to track a scent. Humans? Not so much. However, it turns out that people are better trackers than you might think. Scientists embedded a long line of chocolate-scented twine into the ground and then tested whether college students could track the scent using olfaction alone (Porter & others, 2007). To block all other sensory cues, participants wore eye masks, earmuffs, thick pads, and work gloves. Although the human trackers were able to locate and follow the trail, their average speed was only about one inch per second. However, after only a few days of practice, the trackers' speed doubled.

of people aged 80 and older (Lafreniere & Mann, 2009; Rawson, 2006). At any age, air pollution, smoking, and exposure to some industrial chemicals can decrease the ability to smell. Loss of olfactory function is also associated with several diseases—including Parkinson's disease, schizophrenia, and multiple sclerosis—and may be an early marker of Alzheimer's disease (J. Wang & others, 2010; R. Wilson & others, 2009).

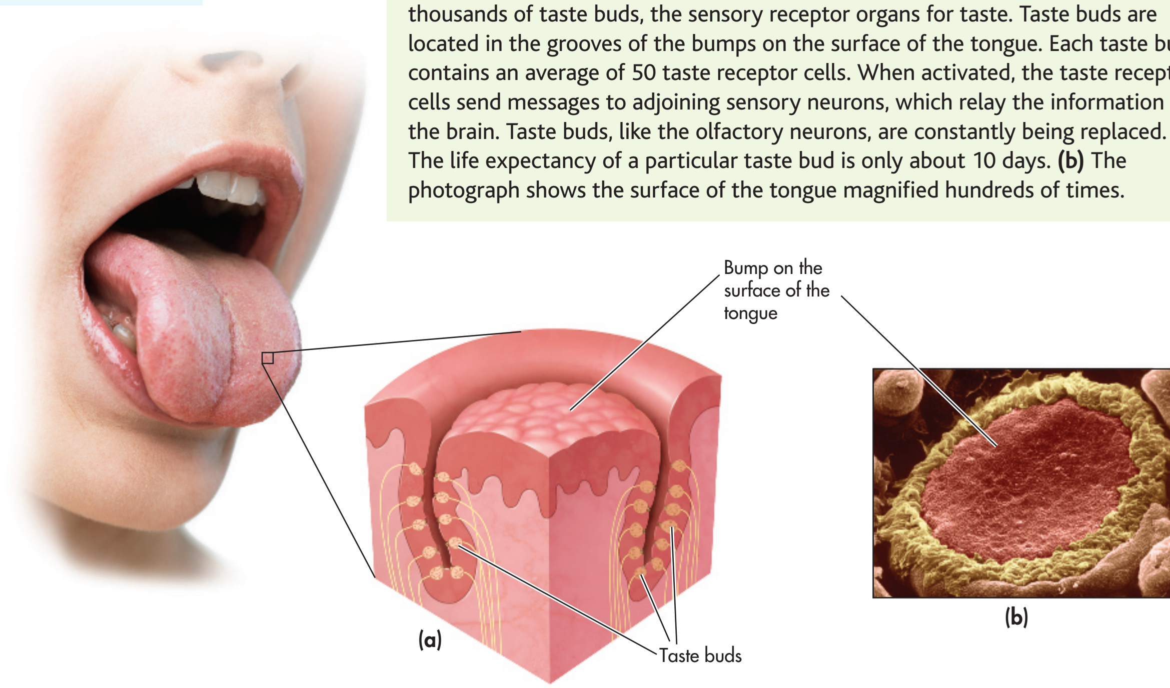
Although humans are highly sensitive to odors, many animals display even greater sensitivity. Dogs, for example, have about 200 million olfactory receptor cells, compared with the approximately 12 million receptors that humans have (Sela & Sobel, 2010). However, humans are more sensitive to smell than most people realize (McGann, 2017; Shepherd, 2004). In fact, people can train their sense of smell (see photo).

## Taste

Our sense of taste, or *gustation*, results from the stimulation of special taste receptors by chemical substances in food and drink. When dissolved by saliva, these chemicals activate the 50-odd taste receptor cells found in the **taste buds**. Interestingly, taste receptor cells are also found in the gut and even the upper airway, where they seem to play a role in triggering immune responses (Ravindran, 2016).

The surface of the tongue is covered with thousands of little bumps with grooves in between (see Figure 3.10). These grooves are lined with the taste buds. Taste buds are also located on the insides of your cheeks, on the roof of your mouth, and in your throat. Contrary to popular belief, there is no "tongue map" in which different regions of the tongue are specialized to respond to sweet, sour, salty, and bitter tastes. Instead, responsiveness to the five basic tastes is present in all tongue areas. Each taste bud shows maximum sensitivity to one particular taste and lesser sensitivity to other tastes (Chandrashekar & others, 2006). When activated, special receptor cells in the taste buds send neural messages along pathways to the thalamus in the brain. In turn, the thalamus directs the information to several regions in the cortex (Shepherd, 2006).

**FIGURE 3.10** Taste Buds **(a)** Embedded in the surface of the tongue are thousands of taste buds, the sensory receptor organs for taste. Taste buds are located in the grooves of the bumps on the surface of the tongue. Each taste bud contains an average of 50 taste receptor cells. When activated, the taste receptor cells send messages to adjoining sensory neurons, which relay the information to the brain. Taste buds, like the olfactory neurons, are constantly being replaced. The life expectancy of a particular taste bud is only about 10 days. **(b)** The photograph shows the surface of the tongue magnified hundreds of times.




Whitemann/Corbis/VCG/Getty Images
Omikron/Science Source

There were long thought to be four basic taste categories: sweet, salty, sour, and bitter. However, scientists identified the receptor cells for a fifth basic taste, *umami* (Chaudhari & others, 2000). Loosely translated, *umami* means "yummy" or "delicious" in Japanese. *Umami* is the distinctive taste of monosodium glutamate and is associated with meat and other protein-rich foods. It's also responsible for the savory flavor of Parmesan and other aged cheeses, mushrooms, and seaweed.

From an evolutionary view, these five basic tastes supply the information we need to seek out nutrient-rich foods and avoid potentially hazardous substances (Chandrashekar & others, 2006; Eisenstein, 2010). Sweet tastes attract us to energy-rich foods, *umami* to protein-rich nutrients. Bitter or sour tastes warn us to avoid many toxic or poisonous substances (Peyrot des Gachons & others, 2011). Sensitivity to salty-tasting substances helps us regulate the balance of electrolytes in our diets.

Evolutionary influences are also apparent in the taste receptors of different animal species (Breslin, 2013). Animals vary in their ability to sense different tastes. For example, cats, who almost exclusively eat meat, do not have functioning sweet receptors. But dogs, rats, and raccoons, who eat a variety of different foods, are attracted to sweet-tasting foods (Jiang & others, 2012).

Most tastes are complex and result from the activation of different combinations of basic taste receptors. Taste is just one aspect of *flavor,* which involves several sensations, including the aroma, temperature, texture, and appearance of food (Shepherd, 2006).

## The Skin and Body Senses

While vision, hearing, smell, and taste provide you with important information about your environment, another group of senses provides you with information that comes from a source much closer to home: your own body. In this section, we'll first consider the *skin senses,* which provide essential information about your physical status and your physical interaction with objects in your environment. We'll next consider the *body senses,* which keep you informed as to your position and orientation in space.

### Touch

We usually don't think of our skin as a sense organ. But the skin is in fact the largest and heaviest sense organ. The skin of an average adult covers about 20 square feet of surface area and weighs about six pounds.

There are many different kinds of sensory receptors in the skin. Some of these sensory receptors are specialized to respond to just one kind of stimulus, such as pressure, warmth, or cold (McGlone & Reilly, 2010). Other skin receptors respond to more than one type of stimulus (Delmas & Rodat-Despoix, 2011).

One important receptor involved with the sense of touch, called the *Pacinian corpuscle,* is located beneath the skin. When stimulated by pressure, the Pacinian corpuscle converts the stimulation into a neural message that is relayed to the brain. If a pressure is constant, sensory adaptation takes place (which is fortunate, or you'd be unable to forget the fact that you're wearing underwear).

Sensory receptors are distributed unevenly among different areas of the body, which is why sensitivity to touch and temperature varies from one area of the body to another. Your hands, face, and lips, for example, are much more sensitive to touch than are your back, arms, and legs. That's because your hands, face, and lips are much more densely packed with sensory receptors.

### Pain

From the sharp sting of a paper cut to the dull ache of a badly sprained ankle, a wide variety of stimuli can trigger pain. Traditionally, **pain** is defined as an unpleasant sensory and emotional experience associated with actual or potential tissue damage (Peirs & Seal, 2016).

**MYTH ◀ ~~SCIENCE~~**

Is it true that different tastes are detected on different parts of your tongue?

Maren Caruso/Getty Images

**Expensive Taste** Although wine experts may be able to discern subtle differences among wines, amateurs may not be as objective. To determine the effect of *price* on perceived quality, researchers asked participants to decide which tasted better: a $90 bottle of wine or one that cost $10 (Plassmann & others, 2008). Although the wine in the two bottles was identical, participants overwhelmingly thought the $90 bottle tasted better. Their subjective, verbal rating was confirmed by brain scans: Activity in a brain region associated with pleasant sensations was much higher when they sipped the wine that they thought was more expensive. Thus, many different factors affect taste, not the least of which is your expectation of just how good something is likely to taste.

**taste buds** The specialized sensory receptors for taste that are located on the tongue and inside the mouth and throat.

**pain** The unpleasant sensory and emotional experience associated with actual or potential tissue damage.

TABLE 3.3

### Sensitivity of Different Body Areas to Pain

| Most Sensitive | Least Sensitive |
|---|---|
| Back of the knee | Tip of the nose |
| Neck region | Sole of the foot |
| Bend of the elbow | Ball of the thumb |

Source: Information from Geldard (1972).

Although unpleasant, pain is important to our survival, warning us to avoid a hot stove or nurse an injured wrist. People who have a rare genetic condition that makes them unable to feel pain tend to have short lifespans because of injuries and infections (Bennett & Woods, 2014).

Your body's pain receptors are called **nociceptors.** Nociceptors are actually small sensory fibers, called *free nerve endings*. You have millions of nociceptors throughout your body, mostly in your skin (see Table 3.3). Your fingertips may have as many as 1,200 nociceptors per square inch. Your muscles and joints have fewer nociceptors, and your internal organs have the smallest number of nociceptors.

**Fast and Slow Pain Systems** Have you ever stubbed your toe on a piece of furniture? If so, your injury triggered two types of nociceptors. One type activates the myelinated fibers of the *fast pain system,* which transmits the sharp, intense, but short-lived pain of the immediate injury. These pain signals travel up the spinal cord to the brain to the thalamus, then to the somatosensory cortex, where the sensory aspects of the pain message are interpreted, such as the location and intensity of the pain.

In most cases, acute pain gradually diminishes to a burning, dull throbbing sensation, caused by the activation of the unmyelinated fibers of the *slow pain system* (Guindon & Hohmann, 2009). While less intense than the pain signals carried by the fast pain system, the slow pain system is longer lasting. In contrast to the fast pain system, slow pain messages travel first to the hypothalamus and thalamus and then to limbic system structures, such as the amygdala. Its connections to the limbic system suggest that the slow pain system is more involved in the emotional aspects of pain.

**Factors That Influence the Experience of Pain** There is considerable individual variation in the experience of pain (Denk & others, 2014; Jensen & Turk, 2014). Pain signals are integrated in the brain with psychological and cognitive factors that determine how the information is interpreted and the pain ultimately perceived (Wiech, 2016). According to the classic **gate-control theory of pain,** depending on how the brain interprets the experience, it regulates pain by sending signals down the spinal cord that either open or close pain "gates," or pathways (Melzack & Wall, 1965, 1996; Katz & Rosenblum, 2015). If, because of psychological, social, or situational factors, the brain signals the gates to open, pain is experienced or intensified. If the brain signals the gates to close, pain is reduced.

Psychological factors that can intensify the experience of pain include anxiety, fear, and a sense of helplessness (Edwards & others, 2009). Feelings of depression and sadness can also intensify the experience of pain (Berna & others, 2010).

On the other hand, positive mood and a sense of control can reduce the perception of pain (Ong & others, 2015). As one example, consider the athlete who has trained herself to minimize the experience of pain during competition. The experience of pain is also influenced by social and situational factors, along with cultural beliefs about the meaning of pain and the appropriate response to pain (Bosch & Cano, 2013; Gatchel & others, 2011).

Today, some pain researchers conceptualize the perception of pain as one that is *actively constructed,* determined by expectations and personal experience (Wiech, 2016). We discuss some helpful strategies that you can use to minimize pain in the Psych for Your Life section at the end of the chapter.

**Sensitization: Unwarranted Pain** One of the most frustrating aspects of pain management is that it can continue even after an injury has healed, such as after recovering from a spinal cord injury or severe burns. An extreme example of this phenomenon is *phantom limb pain,* in which a person continues to experience intense painful sensations in a limb that has been amputated (Wolff & others, 2011).

How can phantom limb pain be explained? Basically, the neurons involved in processing the pain signals undergo *sensitization*. Earlier in the chapter, we

**nociceptors** Specialized sensory receptors for pain that are found in the skin, muscles, and internal organs.

**gate-control theory of pain** The theory that pain is a product of both physiological and psychological factors that cause spinal gates to open and relay patterns of intense stimulation to the brain, which perceives them as pain.

discussed *sensory adaptation,* in which sensory receptors become gradually less responsive to steady stimulation over time. Sensitization is the opposite of adaptation. In sensitization, pain pathways in the brain become increasingly *more* responsive over time. It's like a broken volume-control knob on your stereo that you can turn up but not down or off.

As the pain circuits undergo sensitization, pain begins to occur in the absence of any sensory input. The result can be the development of persistent, *chronic pain* that continues even after the injury has healed (Denk & others, 2014; Wolff & others, 2011). In the case of phantom limb pain, sensitization has occurred in the pain transmission pathways from the site of the amputation. The sensitized pathways produce painful sensations that feel as though they are coming from a limb that is no longer there.

**Using Opioids to Treat Pain** Morphine, OxyContin, and other opioid prescription painkillers mimic the brain's natural painkillers, the endorphins (see Chapter 2). They have virtually no effect on the fast pain system, but very effectively block painful sensations in the slow pain system—at least in the short term. Unfortunately, these drugs have a high potential for misuse and addiction, as will be discussed in Chapter 4.

Ironically, increasing evidence shows that the long-term use of these opioid painkillers can actually *increase* pain and pain sensitivity in chronic pain sufferers (Hooten & others, 2015; see Servick, 2016). Further, a new study found that brief treatment with an opioid painkiller also increases the *duration* of chronic pain (Grace & others, 2016). Rats with chronic nerve pain who were treated with morphine for five days experienced pain sensitivity for two to three months, while rats in the control group who did not receive morphine were pain-free in just six weeks. Even after their injuries had physically healed, the morphine-treated rats experienced heightened pain sensitivity. Psychologist Linda Watkins (2016) comments, "The implications for people taking opioids like morphine, oxycodone and methadone are great, since we show the short-term decision to take such opioids can have devastating consequences of making pain worse and longer lasting."

Although such results should not be used to withhold opioids from people in severe pain, they do suggest that the drugs may be more problematic than once believed. The prolongation and intensification of pain may also help explain why some patients develop chronic pain or remain dependent on painkillers long after their conditions have healed.

## Proprioception: Movement, Position, and Balance

Stand in a dark room. Can you touch your right ear? If so, you have just demonstrated **proprioception**—the sense of body movement and position. Specialized neurons in the muscles and joints, called *proprioceptors,* continually communicate changes in body position and muscle tension to the brain (Proske & Gandevia, 2016). Your *vestibular system* maintains your sense of balance, posture, and position in space (Eatock & Songer, 2011). How? Changes in gravity, motion, and body position are detected by hair-like receptor cells embedded in fluid in the *semicircular canals* and *vestibular sacs* in the inner ear (see Figure 3.8 on page 96).

Maintaining your equilibrium requires the integration of knowledge from the proprioceptors, the vestibular system, and other senses, especially vision. When visual information conflicts with vestibular information, dizziness and disorientation may result. Thus, one strategy to combat motion sickness is to minimize sensory conflicts by focusing on a fixed point in the distance.

In the first part of this chapter, we described how the body's senses respond to stimuli in the environment. **Table 3.4** on the next page summarizes these different sensory systems. Next, we'll look at the process of perception—how we make sense out of the information that we receive from our environment. One long-standing question in psychology is whether information can be perceived *without* the involvement of normal sensory systems, a process called *extrasensory perception,* or *ESP.* We take a close look at this issue in the Critical Thinking box on page 103, "ESP: Can Perception Occur Without Sensation?"

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**Individual differences in pain perception and tolerance** People respond to pain very differently (Denk & others, 2014). Women tend to have a lower pain threshold than men, rating pain as more unpleasant and displaying more intense physiological responses to painful stimuli (Jarrett, 2011). Racial differences also influence pain response. Several studies have found that African Americans, Hispanic Americans, and Asians tend to have a lower pain threshold than white Americans. On the other hand, Native Americans have a much higher pain threshold than white Americans, possibly reflecting cultural beliefs that pain should be endured without complaint (Palit & others, 2013). Such differences appear to reflect cultural beliefs about the meaning of pain, social expectations about how people express their experience of pain, and actual physiological differences among ethnic groups (Rahim-Williams & others, 2012).

**proprioception** The sense of body movement and position

TABLE 3.4

**Summary Table of the Senses**

| Sense | Stimulus | Sense Organ | Sensory Receptor Cells |
|---|---|---|---|
| Hearing (audition) | Sound waves | Ear | Hair cells in cochlea |
| Vision | Light waves | Eye | Rods (light/dark) and cones (color) in retina |
| Smell (olfaction) | Airborne odor molecules | Nose | Hair-like receptor cells at top of nasal cavity |
| Taste (gustation) | Chemicals dissolved in saliva | Mouth, tongue | Taste buds |
| Touch | Pressure | Skin | Pacinian corpuscle |
| Pain | Tissue injury or damage; varied | Skin, muscles, and organs | Nociceptors |
| Body position and movement (proprioception) | Movement of the body | None; muscle and joint tissue | Proprioceptors in muscle and joint tissue |
| Balance and spatial orientation (vestibular sense) | Changes in position, gravity | Semicircular canals and vestibular sacs | Hair-like receptor cells in semicircular canals and vestibular sacs |

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**bottom-up processing** Information processing that emphasizes the importance of the sensory receptors in detecting the basic features of a stimulus in the process of recognizing a whole pattern; analysis that moves from the parts to the whole.

**top-down processing** Information processing that emphasizes the importance of the observer's knowledge, expectations, and other cognitive processes in arriving at meaningful perceptions; analysis that moves from the whole to the parts.

**ESP (extrasensory perception)** Perception of information by some means other than through the normal processes of sensation.

**parapsychology** The scientific investigation of claims of paranormal phenomena and abilities.

# Perception

**KEY THEME**

Perception refers to the process of integrating, organizing, and interpreting sensory information into meaningful representations.

**KEY QUESTIONS**

- What are bottom-up and top-down processing, and how do they differ?
- What is Gestalt psychology?
- What Gestalt principles explain how we perceive objects and their relationship to their surroundings?

As we've seen, our senses are constantly registering a diverse range of stimuli from the environment and transmitting that information to the brain. But to make use of this raw sensory data, we must organize, interpret, and relate the data to existing knowledge.

Psychologists sometimes refer to this flow of sensory data from the sensory receptors to the brain as **bottom-up processing.** Bottom-up processing is often at work when we're confronted with an ambiguous stimulus. We aren't immediately sure what it is as a whole, so we assemble individual features.

But as we interact with our environment, many of our perceptions are shaped by **top-down processing**. Top-down processing occurs when we draw on our knowledge, experience, and expectations to arrive at meaningful perceptions. Cultural experiences also affect perceptual processes, as discussed in the Culture and Human Behavior box on page 104, "Ways of Seeing: Culture and Top-Down Processes."

CRITICAL THINKING

## ESP: Can Perception Occur Without Sensation?

**ESP,** or **extrasensory perception,** means the detection of information by some means other than through the normal processes of sensation.

Do you believe in ESP? If you do, you're not alone (Ridolfo & others, 2010). Surveys conducted by the Associated Press and the Gallup Poll have found that close to 50 percent of American adults "believe in ESP" (Fram, 2007; D. Moore, 2005).

Forms of ESP include *telepathy,* which is the *direct* communication between the minds of two individuals; *clairvoyance,* the perception of a remote object or event, such as "sensing" that a friend has been injured in a car accident; *psychokinesis,* the ability to influence a physical object without touching it; and *precognition,* the ability to predict future events (Bem, 2016).

The general term for such unusual abilities is *paranormal phenomena*. *Paranormal* means "outside the range of normal experience." Thus, these phenomena cannot be explained by known laws of science and nature. **Parapsychology** refers to the scientific investigation of claims of various paranormal phenomena (Cardeña & others, 2015; Zingrone & others, 2015). Contrary to what many people think, very few psychologists conduct any kind of parapsychological research.

MYTH ~~SCIENCE~~

Is it true that most psychologists study ESP?

Have you ever felt as if you had just experienced ESP? Consider this example: Some years ago, Sandy had a vivid dream that her cat Nubbin got lost. The next morning, Nubbin sneaked out the back door, went for an unauthorized stroll in the woods, and was gone for three days. Did Sandy have a precognitive dream?

Such common instances are sometimes used to "prove" that ESP exists. However, two less extraordinary concepts can explain both occurrences: coincidence and the fallacy of positive instances. *Coincidence* describes an event that occurs simply by chance. For example, you have over a thousand dreams per year, most of which are about familiar people and situations. By mere chance, *some* aspect of *some* dream will occasionally correspond with reality.

The *fallacy of positive instances* is the tendency to remember coincidental events that seem to confirm our belief about unusual phenomena and to forget all the instances that do not. For example, think of the number of times you've had a dream that did *not* come true. Such situations are far more common than their opposites, but we quickly forget about the hunches that are not confirmed.

Why do people attribute chance events to ESP? Research has shown that believers in ESP are less likely to accurately estimate the probability of an event occurring by chance alone. Nonbelievers tend to be more realistic about the probability of events being the result of simple coincidence or chance (Dagnall & others, 2007; Rogers & others, 2009).

Parapsychologists attempt to study ESP in the laboratory under controlled conditions. Many initially convincing demonstrations of ESP are later shown to be the result of research design problems or of the researcher's unintentional cuing of the participant. Another problem involves *replication*. To be considered valid, experimental results must be able to be replicated, or repeated, by other scientists under identical laboratory conditions. Most psychologists

**The Ganzfeld Technique** Clairvoyance and telepathy experiments often involve use of the *ganzfeld* technique (Baptista & others, 2015). The research subject lies in a quiet room, with his eyes and ears covered to block external sensory stimuli, while a "sender" in another room attempts to communicate information.

Fortean/TopFoto/The Image Works

agree that, to date, no parapsychology experiment claiming to show evidence of the existence of ESP has been successfully replicated (Hyman, 2010).

This failure to replicate results has not ended the debate, however. Most recently, psychologist Daryl Bem (2011) tested precognition in a series of nine experiments involving more than 1,000 participants. Bem's strategy was to "time-reverse" standard psychological tasks, changing the normal order of cause and effect.

For example, participants taking a memory test better remembered words that they practiced *after* taking the test. In another experiment, participants predicted the location of a target image on a computer screen *before* they saw it.

In all, eight of Bem's nine experiments showed small but statistically significant effects in favor of precognition. These, and similar findings from Bem's series of experiments, cannot be easily explained (Judd & Gawronski, 2011).

Bem's research sparked a flurry of media attention, including an appearance on *The Colbert Report*. It also triggered a firestorm of reaction from psychologists and other scientists. Much of the criticism focused on the statistical methods used to analyze the data (see Palmer, 2015). So far, replication attempts have been mostly unsuccessful (Baruš & Rabier, 2014; Galak & others, 2012). Undaunted, Bem and his colleagues (2014) published their own meta-analysis of 90 replication attempts, concluding that the results showed solid support for the existence of precognition.

Of course, the history of science is filled with examples of phenomena that were initially scoffed at and later found to be real, such as the notion that moods affect health and immune system functioning. So keep an open mind about ESP, but also maintain a healthy sense of scientific skepticism. In the final analysis, all psychologists, including those who accept the possibility of ESP, recognize the need for evidence that meets the requirements of the scientific method.

### CRITICAL THINKING QUESTIONS

- Why do you think that people who believe in ESP are less likely to attribute events to chance than people who don't think ESP is a real phenomenon?
- Can you think of any reasons why replication might be particularly elusive in research on extrasensory perception?
- Why is replication important in all psychological research, but particularly so in studies attempting to prove extraordinary claims, like the existence of ESP?

CULTURE AND HUMAN BEHAVIOR

## Ways of Seeing: Culture and Top-Down Processes

Do people in different cultures perceive the world differently? In Chapter 1, we described two types of cultures. Unlike people in *individualistic* cultures, who tend to emphasize independence, people in *collectivistic* cultures see humans as being enmeshed in complex relationships. This social perspective is especially pronounced in the East Asian cultures of Korea, Japan, and China, where a person's sense of self is highly dependent upon his or her social context (Beins, 2011). Consequently, East Asians pay much closer attention to the social context in which their own actions, and the actions of others, occur (Nisbett, 2007; Varnum & others, 2010).

### The Cultural Eye of the Beholders

Do these cultural differences in social perspective influence visual perception and memory? Take a few seconds to look at the photo on the right. Was your attention drawn by the tiger? Or its surroundings?

In one study, Hannah Faye Chua and her colleagues (2005) used sophisticated eye-tracking equipment to monitor the eye movements of U.S. and Chinese students while they looked at similar photographs that showed a single focal object against a realistic, complex background. The results showed that their eye movements differed: The U.S. students looked sooner and longer at the focal object in the foreground than the Chinese students did. In contrast, the Chinese students spent more time looking at the background than the U.S. students did. And, the Chinese students were also less likely to recognize the foreground objects when they were placed in front of a new background.

Rather than separating the object from its background, the Chinese students tended to see—and remember—object and background as a single perceptual image. Many psychologists believe that this pattern of results reflects the more "holistic" perceptual style that characterizes collectivistic cultures (Boduroglu & others, 2009; Boland & others, 2008).

In another, similar experiment, researchers found that U.S. participants tended to focus their attention on the object alone, while the East Asian participants alternated looking at the object and the background, paying more attention to the *relationship* between the object and background (Goh & others, 2009). "Culture," the researchers observed, "may operate as a top-down mechanism that guides and interacts with basic neuro-perceptual processes."

### Cultural Comfort Zones and Brain Functioning

Many psychologists now believe that these cultural differences in social and perceptual style also influence brain function (Park & Huang, 2010). For example, psychologist Trey Hedden and his colleagues (2008) compared brain functioning in East Asian and U.S. participants while they made rapid perceptual judgments comparing two images of a square with an embedded line as shown in this image on the right.

The *relative* task involved determining whether the lines in the two images were in the same proportion to the surrounding squares. The *absolute* task involved determining whether the two lines were the same absolute length, regardless of the size of the squares (see figure). Each participant made these judgments while his or her brain activity was tracked by an fMRI scanner.

Both groups were equally proficient at the task and used the same brain regions in making the simple perceptual judgments. However, the *pattern* of brain activation differed.

James Warwick/Getty Images

Which do you notice first—the tiger or its rocky surroundings?

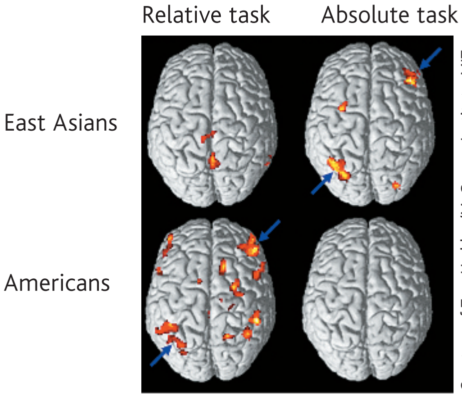
The individualistic U.S. participants showed greater brain activation while making relative judgments, meaning they had to exert more mental effort. The collectivistic East Asians showed the opposite pattern, devoting greater brain effort to making absolute judgments that required them to ignore the context. Essentially, all participants had to work harder at making perceptual judgments that were outside their cultural comfort zones.

The bottom line? People from different cultures use the same neural processes to make perceptual judgments. But, their culture trains them to use them in different ways. As John Gabrieli (2008) points out, "The way in which the brain responds to these simple drawings reflects, in a predictable way, how the individual thinks about independent or interdependent social relationships." People from different cultures may not literally see the world differently—but they notice different things and think differently about what they *do* see.

**Relative task:** Is the proportion of the vertical line to the box the same in both images?

**Absolute task:** Is the absolute length of the two vertical lines the same?






Courtesy of Trey Hedden/McGovern Institute, MIT

Both top-down and bottom-up processing are involved in our everyday perceptions. Look at the photograph—your author Sandy's daughter Laura when she was three. Top-down processing helps you quickly identify a child holding a cat, but the background is ambiguous. Deciphering these images involves both bottom-up and top-down processing. Bottom-up processing help you recognize individual features—a large, dark green object with brightly colored splotches. Top-down processing help you identify the object as a Christmas tree by using contextual information from your knowledge base, a conclusion you would not reach if you had no experience with a traditional U.S. Christmas. Learning experiences create a contextual knowledge base that we use to identify objects in our environment—including kids, cats, and Christmas trees.

One useful way to think about perception is to consider the basic perceptual questions we must answer in order to survive in an ever-changing environment. Whether it's a bulldozer or a bowling ball, we need to be able to identify objects, locate objects in space, and, if they are moving, track their motion. Thus, our perceptual processes must help us organize our sensations to answer three basic, important questions: (1) What is it? (2) How far away is it? and (3) Where is it going?

In the next few sections, we will look at what psychologists have learned about the principles we use to answer these perceptual questions. Much of our discussion reflects the work of an early school of psychology called **Gestalt psychology,** which was founded by German psychologist **Max Wertheimer** in the early 1900s (Wertheimer, 1923). The Gestalt psychologists emphasized that we perceive whole objects or figures (*gestalts*) rather than isolated bits and pieces of sensory information. Roughly translated, the German word *gestalt* means a unified whole, form, or shape. Although the Gestalt school of psychology no longer formally exists, the pioneering work of the Gestalt psychologists established many basic perceptual principles (S. Palmer, 2002).

Courtesy of the authors

**Organizing Sensations into Meaningful Perceptions** With virtually no conscious effort, the psychological process of perception allows you to integrate, organize, and interpret the lines, colors, and contours in this image as meaningful objects—a laughing child holding a panicky black cat in front of a Christmas tree. How did you reach those perceptual conclusions?

## The Perception of Shape

### WHAT IS IT?

When you look around your world, you don't see random edges, curves, colors, or splotches of light and dark. Rather, you see countless distinct objects against a variety of backgrounds. Although to some degree we rely on size, color, and texture to determine what an object might be, we rely primarily on an object's *shape* to identify it.

**Gestalt psychology** (geh-SHTALT) School of psychology that maintained sensations are actively processed according to consistent perceptual rules, producing meaningful whole perceptions, or *gestalts*.

**figure–ground relationship** Gestalt principle stating that a perception is automatically separated into the *figure*, which clearly stands out, from its less distinct background, the *ground*.

### Figure–Ground Relationship

How do we organize our perceptions so that we see an object as separate from other objects? The early Gestalt psychologists identified an important perceptual principle called the **figure–ground relationship,** which describes how this works. When we view a scene, we automatically separate the elements of that

Chris Mattison/FLPA/Science Source

Michael Patrick O'Neill/Science Source

**Survival and Figure–Ground Relationships** The importance of figure–ground relationships in nature is illustrated by animals that rely on camouflage for survival, like this Asian horned frog (left) and the pygmy seahorse, barely a half-inch long, which lives only in a specific type of coral in Indonesia (right). When an animal's coloring and markings blend with its background, a predator cannot distinguish the animal (the *figure*) from its surroundings (the *ground*).

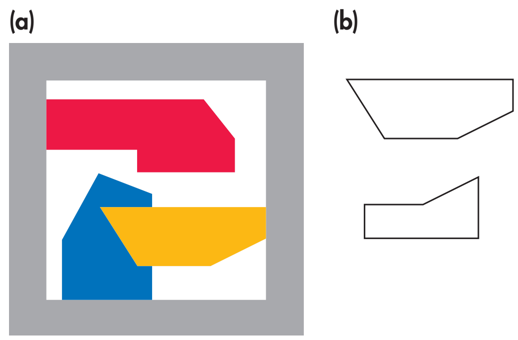



**FIGURE 3.11** Figures Have Shape, but Ground Doesn't Which shape in **(b)** can also be found in **(a)**? The answer is that both shapes are in **(a)**. It's easy to spot the top shape because it corresponds to one of the shapes perceived as a *figure* in **(a)** The bottom shape is harder to find because it is part of the *ground* or background of the total scene. Because we place more importance on figures, we're more likely to notice their shape while ignoring the shape of background regions (N. Rubin, 2001).

scene into the *figure,* which is the main element of the scene, and the *ground,* which is its background.

You can experience the figure–ground relationship by looking at a coffee cup on a table. The coffee cup is the figure, and the table is the ground. Notice that usually the figure has a definite shape, tends to stand out clearly, and is perceptually meaningful in some way. In contrast, the ground tends to be less clearly defined, even fuzzy, and usually appears to be behind and farther away from the figure.

The early Gestalt psychologists noted that figure and ground have vastly different perceptual qualities (N. Rubin, 2001). As Gestalt psychologist Edgar Rubin (1921) observed, "In a certain sense, the ground has no shape." We notice the shape of the figure but *not* the shape of the background, even when that ground is used as a well-defined frame (see Figure 3.11). It turns out that brain neurons *also* respond differently to a stimulus that is perceived as a figure versus a stimulus that is part of the ground (Baylis & Driver, 2001). Particular neurons in the cortex that responded to a specific shape when it was the shape of the figure did *not* respond when the same shape was presented as part of the background.

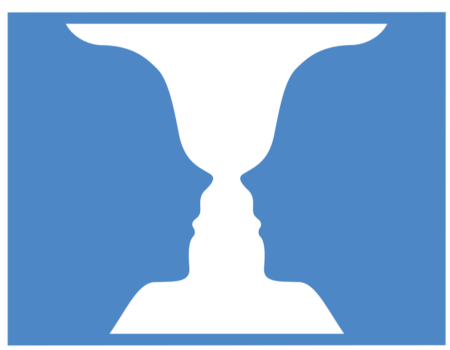


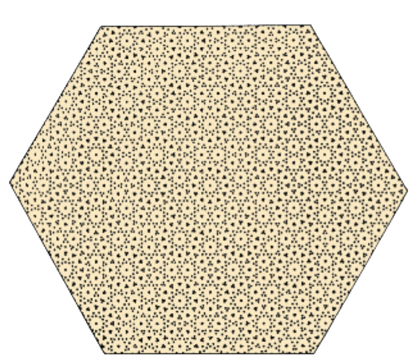
**FIGURE 3.12** A Classic Example of Figure–Ground Reversal Figure–ground reversals illustrate the psychological nature of our ability to perceptually sort a scene into the main element and the background. If you perceive the white area as the figure and the dark area as the ground, you'll perceive a vase. If you perceive the dark area as the figure, you'll perceive two faces.

The separation of a scene into figure and ground is not a property of the actual elements of the scene at which you're looking. Rather, your ability to separate a scene into figure and ground is a psychological accomplishment. To illustrate, look at the classic example shown in Figure 3.12. This perception of a single image in two different ways is called a *figure–ground reversal.*

## Perceptual Grouping

Many of the forms we perceive are composed of a number of different elements that seem to go together (Glicksohn & Cohen, 2011). It would be more accurate to say that we actively organize the elements to try to produce the stable perception of well-defined, whole objects. This is what perceptual psychologists refer to as "the urge to organize" (see image below). What principles do we follow when we attempt to organize visual elements?

The Gestalt psychologists studied how the perception of visual elements becomes organized into patterns, shapes, and forms. They identified several laws, or principles, that we tend to follow in grouping elements together to arrive at the perception of forms, shapes, and figures (see Figure 3.13). The Gestalt principles, which include *similarity, closure, good continuation,* and *proximity,* help us more efficiently remember groups of objects and perceive the relationships among them (Corbett, 2016).



**The Perceptual Urge to Organize** As you scan this image, you'll experience firsthand the strong psychological tendency to organize visual elements to arrive at the perception of whole figures, forms, and shapes. Notice that as you shift your gaze across the pattern, you momentarily perceive circles, squares, and other geometric forms.



The Gestalt psychologists also formulated a general principle called the *law of Prägnanz,* or the *law of simplicity.* This law states that when several perceptual organizations of an assortment of visual elements are possible, the perceptual interpretation that occurs will be the one


Air Images/Shutterstock

**(a)** The Law of Similarity


David Stoecklein/AGE Fotostock

**(b)** The Law of Closure


Laura A. Hockenbury

**(c)** The Law of Good Continuation


Rolf Hicker/AGE Fotostock

**(d)** The Law of Proximity

**FIGURE 3.13** The Gestalt Principles of Organization
**(a)** *The law of similarity* is the tendency to perceive objects of a similar size, shape, or color as a unit or figure. Thus, you perceive rows of tomatoes, avocados, lemons, and so forth rather than a mixed array of fruits and vegetables.
**(b)** The *law of closure* is the tendency to fill in the gaps in an incomplete image. Thus, you perceive the fence rails as continuous straight lines even though the image is interrupted by the boots and pants legs.
**(c)** The *law of good continuation* is the tendency to group elements that appear to follow in the same direction as a single unit or figure. Thus, you tend to see the straight and curved sections of the Chicago L-tracks as separate but continuous units.
**(d)** The *law of proximity* is the tendency to perceive objects that are close to one another as a single unit. Thus, you perceive these three puffins as two distinct units—one puffin standing apart from a puffin pair—rather than as a single group of three puffins.

that produces the "best, simplest, and most stable shape" (Koffka, 1935). For an illustration, look at Figure 3.14. Do you perceive the image as two six-sided objects and one four-sided object? If you are following the law of Prägnanz, you don't. Instead, you perceptually organize the elements in the most cognitively efficient and simple way, perceiving them as three overlapping squares.

According to the Gestalt psychologists, the law of Prägnanz encompasses all the other Gestalt principles, including the figure–ground relationship. The implication of the law of Prägnanz is that our perceptual system works in an economical way to promote the interpretation of stable and consistent forms (Pinna & Reeves, 2009). The ability to efficiently organize elements into stable objects helps us perceive the world accurately. In effect, we actively and automatically construct a perception that reveals "the essence of something," which is roughly what the German word *Prägnanz* means.

**FIGURE 3.14** The Law of Prägnanz: What Do You See? The most fundamental Gestalt principle is the *law of Prägnanz*, or simplicity. It refers to our tendency to efficiently organize the visual elements of a scene in a way that produces the simplest and most stable forms or objects. You probably perceived this image as three overlapping squares rather than as two six-sided objects and one four-sided object.

## Depth Perception

### HOW FAR AWAY IS IT?

**KEY THEME**

Perception of distance and motion helps us gauge the position of stationary objects and predict the path of moving objects.

**KEY QUESTIONS**

- What are the monocular and binocular cues for distance or depth perception, and how does binocular disparity explain our ability to see three-dimensional forms in two-dimensional images?
- What visual cues help us perceive distance and motion?
- Why do we perceive the size and shape of objects as unchanging despite changes in sensory input?

Being able to perceive the distance of an object has obvious survival value, especially regarding potential threats, such as snarling dogs or oncoming trains. But


BIZARRO © 2004 Dan Piraro, Dist. by King Features

**depth perception** The use of visual cues to perceive the distance or three-dimensional characteristics of objects.

**monocular cues** (moe-NOCK-you-ler) Distance or depth cues that can be processed by either eye alone.

simply walking through your house or apartment also requires that you accurately judge the distance of furniture, walls, other people, and so forth. Otherwise, you'd be constantly bumping into doors, walls, and tables. The ability to perceive the distance of an object as well as the three-dimensional characteristics of an object is called **depth perception.**

## Monocular Cues

We use a variety of cues to judge the distance of objects. **Monocular cues** require the use of only one eye (*mono* means "one"). Artists use monocular cues, sometimes called *pictorial cues*, to create the perception of distance or depth in paintings. These cues include:

1. *Relative size*. If two or more objects are assumed to be similar in size, the object that appears larger is perceived as being closer.
2. *Overlap*. When one object partially blocks or obscures the view of another object, the partially blocked object is perceived as being farther away.
3. *Aerial perspective*. Faraway objects appear hazy or blurred by the atmosphere.
4. *Texture gradient*. As a surface with a distinct texture extends into the distance, the details of the surface texture gradually become less clearly defined.
5. *Linear perspective*. Parallel lines seem to meet in the distance. The closer together the lines appear to be, the greater the perception of distance.

M. A. Otsoa de Alda/AGE Fotostock

**Texture Gradient, Overlap, and Aerial Perspective** Monocular cues are used to judge the distance of objects. Crisp orange-red poppies appear against a background of lavender flowers that become increasingly fuzzy, an example of texture gradient. Similarly, the hills at the top of the image are just blurs of color, creating an impression of even greater distance through aerial perspective. And, the poppies are perceived as being closer than the lavender flowers that they overlap.

margo_black/Shutterstock

**Relative Size and Linear Perspective** Monocular cues provide depth cues that create the illusion of a palm tree-lined road receding into the distance. Linear perspective is evident in the near-convergence of the palm trees as the road narrows. And, the palm trees appear to decrease in size, an example of relative size contributing to the perception of distance.

Steve McCurry/Magnum Photos

**Motion Parallax** This photograph of waiters in India passing a tray from one train car to the next captures the visual flavor of motion parallax. Objects that whiz by faster are perceptually judged as being closer, as in the case here of the blurred ground and grass. Objects that pass by more slowly are judged as being farther away, as conveyed by the clearer details of the distant buildings and trees.

6. *Motion parallax*. When you are moving, you use the speed of passing objects to estimate the distance of the objects. Nearby objects seem to zip by faster than do distant objects. When you are riding on a commuter train, for example, houses and parked cars along the tracks seem to whiz by, while the distant downtown skyline seems to move very slowly.

### Binocular Cues

**Binocular cues** for distance or depth perception require information from both eyes. One binocular cue is *convergence*—the degree to which muscles rotate your eyes to focus on an object. The more the eyes converge, or rotate inward, to focus on an object, the greater the strength of the muscle signals and the closer the object is perceived to be. For example, if you hold a dime about six inches in front of your nose, you'll notice the slight strain on your eye muscles as your eyes converge to focus on the coin. If you hold the dime at arm's length, less convergence is needed. Perceptually, the information provided by these signals from your eye muscles is used to judge the distance of an object.

Another binocular distance cue is *binocular disparity*. Because our eyes are set a couple of inches apart, a slightly different image of an object is cast on the retina of each eye. When the two retinal images are very different, we interpret the object as being close by. When the two retinal images are more nearly identical, the object is perceived as being farther away (Parker, 2007).

To experience how binocular disparity affects distance perception, hold a pen just in front of your nose. Close your left eye, then your right. Because the images from the two eyes are very different, the binocular disparity leads you to perceive the pen as being very close. Now focus on an object across the room and close each eye again. Because the images are much more similar, you perceive the object as farther away. With both eyes open, the two images are fused. Binocular disparity can be used to create the perception of three dimensions in a two-dimensional image, as shown in the illustration at the bottom of the page.

## The Perception of Motion

### WHERE IS IT GOING?

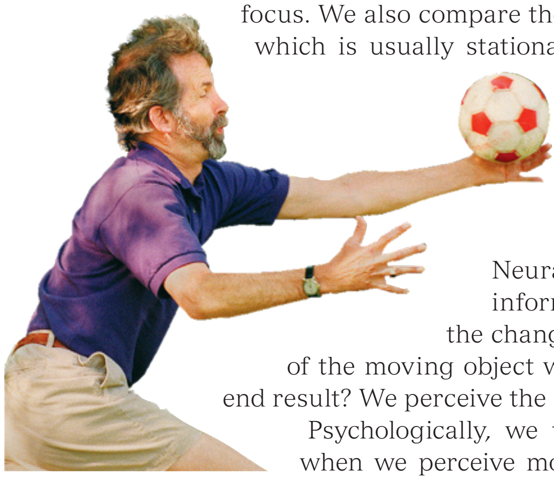
In addition to the ability to perceive the distance of stationary objects, we need the ability to gauge the path of moving objects, whether it's a baseball whizzing through the air, an approaching car, or an egg about to roll off the counter. How do we perceive movement?

As we follow a moving object with our gaze, the image of the object moves across the retina. Our eye muscles make microfine movements to keep the object in

**binocular cues** (by-NOCK-you-ler) Distance or depth cues that require the use of both eyes.

Hiroshi Kunoh

**Binocular Disparity and the Perception of Depth in Stereograms** This stereogram, *Rustling Hares*, was created by artist Hiroshi Kunoh (Kunoh & Takaoki, 1994). To see the three-dimensional images, first hold the picture close to your face. Focus your eyes as though you are looking at an object that is beyond the book and farther away. Without changing your focus, slowly extend your arms and move the picture away from you. The image of the leaves will initially be blurry, then details will come into focus and you should see three rabbits. The three-dimensional images that can be perceived in stereograms occur because of binocular disparity—each eye is presented with slightly different visual information.



Florence Low

**Mike and Motion Perception** Catching a ball involves calculating an array of rapidly changing bits of visual information, including the ball's location, speed, and trajectory. Mike was especially appreciative of his newly regained motion perception. As Mike wrote in his journal, "Top on my list is being able to catch a ball in the air. This is pretty hard to do if you are totally blind, and now I can play ball with my boys and catch the ball 80 percent of the time it is thrown to me. I have spent half my life chasing a ball around in one way or another, so this is a big deal."

focus. We also compare the moving object to the background, which is usually stationary. When the retinal image of an object enlarges, we perceive the object as moving toward us. Our perception of the speed of the object's approach is based on our estimate of the object's rate of enlargement (Harris & others, 2008). Neural pathways in the brain combine information about eye-muscle activity, the changing retinal image, and the contrast of the moving object with its stationary background. The end result? We perceive the object as moving.

Psychologically, we tend to make certain assumptions when we perceive movement. For example, we typically assume that the *object,* or figure, moves while the background, or frame, remains stationary (Rock, 1995). Thus, as you visually follow a bowling ball down the alley, you perceive the bowling ball as moving and not the alley, which serves as the background.

Because we have a strong tendency to assume that the background is stationary, we sometimes experience an illusion of motion called *induced motion*. This occurs when we look at a stationary object against a moving background, and we perceive that the *object* is moving. If you've ever looked up at a full moon on a windy night when the clouds were moving quickly across its face, you've probably experienced the induced motion effect: the moon appears to be racing across the sky.

Jean-Marc FavreE/vandystadt/Science Source

**Stroboscopic Motion and Movies** The perception of smooth movements in a movie is due to stroboscopic motion. Much like this image composed of superimposed still photographs of French gymnast Yann Cucherat performing a complex move on the horizontal bar, a motion picture is actually a series of static photographs that are projected onto the screen at the rate of 24 frames per second, producing the illusion of smooth motion.

The perception of smooth motion in a film is due to another illusion of apparent motion, called *stroboscopic motion*. To create the illusion of movement, photographs are projected onto a screen at a rate of 24 frames per second. Each image is slightly different from the one before. When the images are presented in a rapid sequence, we fill in the movement between them, creating the perception of continuous motion.

## Perceptual Constancies

Consider this scenario. As you're driving on a flat stretch of highway, a red SUV zips past you and speeds far ahead. As the distance between you and the SUV grows, its image becomes progressively smaller until it is no more than a dot on the horizon. Yet, even though the image of the SUV on your retinas has become progressively smaller, you don't perceive the vehicle as shrinking. Instead, you perceive its shape, size, and brightness as unchanged.

This tendency to perceive objects, especially familiar objects, as constant and unchanging despite changes in sensory input is called **perceptual constancy.** Without this perceptual ability, our perception of reality would be in a continual state of flux. If we simply responded to retinal images, our perceptions of objects

**perceptual constancy** The tendency to perceive objects, especially familiar objects, as constant and unchanging despite changes in sensory input.

would change as lighting, viewing angle, and distance from the object changed from one moment to the next. Instead, color, size, and shape constancy promote a stable view of the world. *Color constancy* may help explain the otherwise puzzling phenomenon described in the In Focus box, "The Dress That Broke the Internet."

Bruno Ehrs/Getty Images

**The Doors of Perception** Each door in the photograph is positioned at a different angle and thus produces a differently shaped image on your retinas. Nevertheless, because of the perceptual principles of size and shape constancy, you easily identify all five shapes as identically-sized rectangular doors.

## Size and Shape Constancy

**Size constancy** is the perception that an object remains the same size despite its changing image on the retina. When our distance from an object changes, the image of the object that is cast on the retinas of our eyes also changes, yet we still perceive it to be the same size. The example of the red SUV illustrates the perception of size constancy. As the distance between you and the red SUV increased, you could eventually block out the retinal image of the vehicle with your hand, but you don't believe that your hand has suddenly become larger than the SUV. Instead, your brain automatically adjusts your perception of the vehicle's size by combining information about retinal image size and distance.

An important aspect of size constancy is that if the retinal image of an object does *not* change but the perception of its distance *increases,* the object is perceived as larger. To illustrate, try this: Stare at a 75-watt light bulb for about 10 seconds. Then focus on a bright, distant wall. You should see an afterimage of the light bulb on

**size constancy** The perception of an object as maintaining the same size despite changing images on the retina.

**color constancy** The perception of a familiar object as being the same color under different light conditions.

**IN FOCUS**

### The Dress That Broke the Internet

It all started with a Facebook post showing a dress worn at a wedding on a tiny Scottish island. Picked up by a blogger and then by Buzzfeed, the photo blazed across the Internet, racking up an incredible 28 million views within 48 hours. The burning question: *What color is the dress?*

The dress in a photo from Caitlin McNeill's Tumblr site.

Even celebrities got into the "#TheDress" game. Kim Kardashian tweeted, "What color is that dress? I see white & gold. Kanye sees black & blue, who is color blind?"

Some suggested that subtle differences in the cones of the retina were involved. Others blamed the different types of screen displays, but that didn't explain why people looking at the photo on the same screen saw radically different colors.

The most likely explanation seems to involve the phenomenon of **color constancy** (Novella, 2015; Pinker, 2015). As you've learned, color perception is the result of a complex interaction between the light waves reflected off of an object and your brain's interpretation of those signals. But in determining the color of an object, your brain takes additional factors into account, such as the amount and brightness of background illumination. The brain automatically compensates for shadows and other changing light conditions to perceive the color of familiar objects as unchanging.

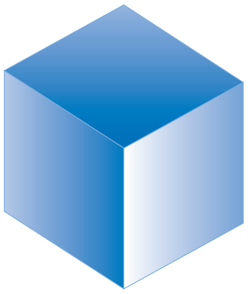
For the record, the *actual* dress is blue and black. But in the photo, the light conditions are ambiguous. Is the dress in shadow or bright light? Those who made the unconscious assumption that the dress was in shadow or dim light saw it as white and gold, because white tends to look blue in dim light. But those who assumed that the dress was in bright light saw it as blue and black—the actual colors (Pinker, 2015).

*#TheDress* is entertaining, but it also makes an important point about top-down processes in perception. As neuroscientist Steven Novella (2015) wrote, "this is not just an isolated weird case. This is how our brains work all the time. What we perceive is a constructed illusion, based upon algorithms that make reasonable assumptions about distance, shading, size, movement, and color—but they are assumptions, none the less, and sometimes they can be wrong or misleading."

**shape constancy** The perception of a familiar object as maintaining the same shape regardless of the image produced on the retina.

**perceptual illusion** The misperception of the true characteristics of an object or an image.

**FIGURE 3.15** How Many Right Angles Do You See? Most people find 12 right angles in this drawing of a slightly tilted cube. But look again. There are no right angles in the drawing. Shape constancy leads you to perceive an image of a cube with right angles, despite the lack of sensory data to support that perception.



the wall that will look several times larger than the original light bulb. Why? When you looked at the wall, the lingering afterimage of the light bulb on your retina remained constant, but your perception of distance increased. When your brain combined and interpreted this information, your perception of the light bulb's size increased. Remember this demonstration. We'll mention it again when we explain how some perceptual illusions occur.

**Shape constancy** is the tendency to perceive familiar objects as having a fixed shape regardless of the image they cast on our retinas. Try looking at a familiar object, such as a door, from different angles, as in the photograph on previous page. Your perception of the door's rectangular shape remains constant despite changes in its retinal image. Shape constancy has a greater influence on your perceptions than you probably realize (see Figure 3.15).

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## Perceptual Illusions

**KEY THEME**

Perceptual illusions underscore the idea that we actively construct our perceptual representations of the world according to psychological principles.

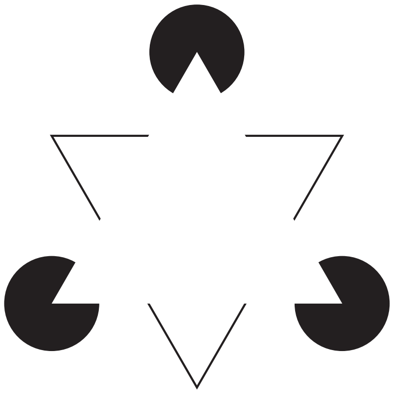
**KEY QUESTIONS**

- How can the Müller-Lyer and moon illusions be explained?
- What do perceptual illusions reveal about perceptual processes?
- What roles do perceptual sets, learning experiences, and culture play in perception?

Our perceptual processes are largely automatic and unconscious. On the one hand, this arrangement is mentally efficient. With a minimum of cognitive effort, we decipher our surroundings, answering important perceptual questions and making sense of the environment. On the other hand, because perceptual processing is largely automatic, we can inadvertently arrive at the wrong perceptual conclusion. When we misperceive the true characteristics of an object or an image, we experience a **perceptual illusion.**

During the past century, well over 200 perceptual illusions have been discovered. One famous perceptual illusion is shown in Figure 3.16. The perceptual contradictions of

**FIGURE 3.16** Illusory Contours: How Many Triangles Do You See? The Gestalt principles of perceptual organization contribute to the illusion of triangular contours in this image. When you look at this ambiguous image, you instantly reverse figure and ground so that the black circular regions become the ground while the white region is visually favored as the figure. The Gestalt principles of closure and good continuation contribute to the perceptual construction of a solid white triangle covering three black disks and an inverted triangle. The images produce a second intriguing illusion: The pure white illusory triangle seems brighter than the surrounding white paper.



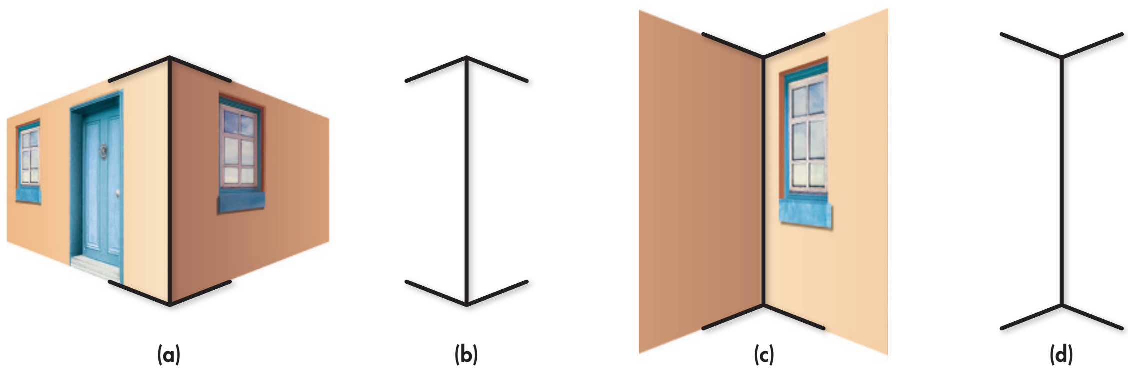



**FIGURE 3.17** The Müller-Lyer Illusion Compare the two drawings of buildings. Which *corner* line is longer? Now compare the two line drawings. Which *center* line is longer? In reality, the center lines in the buildings and the line drawings are all exactly the same length, which you can prove to yourself with a ruler.

illusions are not only fascinating but can also shed light on how the normal processes of perception guide us to perceptual conclusions. Given the basics of perception that we've covered thus far, you're in a good position to understand how and why some famous illusions seem to occur.

## The Müller-Lyer Illusion

Look at the center line made by the corners of the walls in (a) and (c) in Figure 3.17. Which line is longer? If you said (c), then you've just experienced the **Müller-Lyer illusion.** In fact, the two center lines are the same length, even though they *appear* to have different lengths. You can confirm that they are the same length by measuring them. The same illusion occurs when you look at a simple line drawing of the Müller-Lyer illusion, shown in parts (b) and (d) of Figure 3.17.

The Müller-Lyer illusion is caused in part by visual depth cues that promote the perception that the center line in (c) is *farther* from you (Gregory, 1968; Rock, 1995). When you look at (c), the center line is that of a wall jutting away from you. When you look at drawing (d), the outward-pointing arrows create much the same visual effect—a corner jutting away from you. In Figure 3.17 (a) and (b), visual depth cues promote the perception of *lesser* distance—a corner that is jutting toward you.

Size constancy also seems to play an important role in the Müller-Lyer illusion. Because they are the same length, the two center lines in the photographs and the line drawings produce retinal images that are the same size. However, as we noted in our earlier discussion of size constancy, if the retinal size of an object stays the same but the perception of its distance increases, we will perceive the object as being larger. Previously, we demonstrated this with the afterimage of a light bulb that seemed much larger when viewed against a distant wall.

The same basic principle seems to apply to the Müller-Lyer illusion. Although all four center lines produce retinal images that are the same size, the center lines in images (c) and (d) are embedded in visual depth cues that make you perceive them as farther away. Hence, you perceive the center lines in these images as being longer, just as you perceived the afterimage of the light bulb as being larger when viewed on a distant wall.

Keep in mind that the arrows pointing inward or outward are responsible for creating the illusion in the Müller-Lyer illusion. Take away those potent depth cues and the Müller-Lyer illusion evaporates. You perceive the two lines just as they are—the same length.

## The Moon Illusion

Another famous illusion is one you've probably experienced firsthand—the **moon illusion.** When a full moon is rising on a clear, dark night, it appears much larger when viewed on the horizon against buildings and trees than it does when viewed in the clear sky overhead. But the moon, of course, doesn't shrink as it rises. In fact, *the retinal size of the full moon is the same in all positions*. What causes this illusion?

**Müller-Lyer illusion** A famous visual illusion involving the misperception of the identical length of two lines, one with arrows pointed inward, one with arrows pointed outward.

**moon illusion** A visual illusion involving the misperception that the moon is larger when it is on the horizon than when it is directly overhead.

**The Moon Illusion** Why does the moon appear to be much larger when it's viewed on the horizon than when it's viewed higher in the sky?

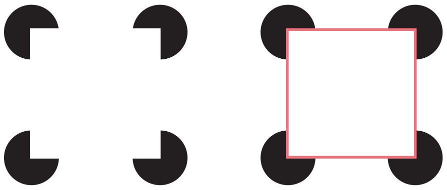
REUTERS/Darryl Webb

Part of the explanation has to do with our perception of the distance of objects at different locations in the sky (Ozkan & Braunstein, 2010). Researchers have found that people perceive objects on the horizon as farther away than objects that are directly overhead in the sky. The horizon contains many familiar distance cues, such as buildings, trees, and the smoothing of the texture of the landscape as it fades into the distance. The moon on the horizon is perceived as being *behind* these depth cues, so the depth perception cue of overlap adds to the perception that the moon on the horizon is farther away.

The moon illusion also involves the misapplication of the principle of size constancy. Like the afterimage of the glowing light bulb, which looked larger on a distant wall, the moon looks larger when the perception of its distance increases. Remember, the retinal image of the moon is the *same* in all locations, as was the afterimage of the light bulb. Thus, even though the retinal image of the moon remains constant, we perceive the moon as being larger because it seems farther away on the horizon (Kaufman & others, 2007).

If you look at a full moon on the horizon through a cardboard tube, you'll remove the distance cues provided by the horizon. The moon on the horizon shrinks immediately—and looks the same size as it does when directly overhead.

## Mike and Perceptual Illusions



Perceptual illusions underscore the fact that what we see is *not* merely a simple reflection of the world, but rather our subjective perceptual interpretation of it. We've been developing and refining our perceptual interpretations from infancy onward. But what about Mike, who regained low vision after more than four decades of blindness?

Psychologist Ione Fine and her colleagues (2003) assessed Mike's perceptual processing with a couple of perceptual illusions. For example, Mike was presented with an image containing illusory contours, shown on the left. It's much like the more complex image we discussed in Figure 3.16. When asked, "What is the 'hidden' shape outlined by the black apertures?" Mike had no response. However, when the form was outlined in red, Mike immediately perceived the red square.

Now look at Figure 3.18. Which tabletop is longer? If you used your keen perceptual skills and confidently said (b), you'd be wrong. If you responded as Mike did and said that the two tabletops are of identical size and shape, you'd be correct.

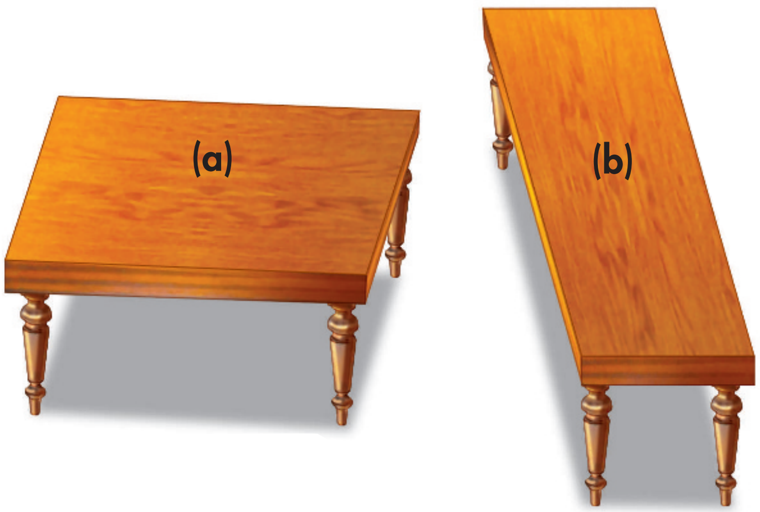



**FIGURE 3.18** Which Tabletop Is Longer? The *Shepard Tables* illusion consists of two tables that are oriented in different directions. By relying on well-learned depth perception cues, most people pick (b) as being the longer tabletop. But the two tabletops are actually the same size and shape. Mike May was oblivious to the perceptual illusion (Fine & others, 2003). You can verify this with a ruler.
Source: Information from Shepard (1990).

You can use a ruler or tracing paper to verify this. This illusion is referred to as the *Shepard Tables,* named after its creator, psychologist Roger Shepard (1990).

Why wasn't Mike susceptible to this compelling visual illusion? Partly, it's because he does not automatically use many of the depth perception cues we discussed earlier (Gregory, 2003). As psychologist Donald MacLeod explained, "Mike is impressively free from some illusions that beset normal vision, illusions that reflect the constructive processes involved in the perception of three-dimensional objects" (Abrams, 2002).

Although seeing is said to be believing, in the case of illusions, believing can lead to seeing something that isn't really there. Like any psychological process, perception can be influenced by many factors, including our expectations. In the final section of this chapter, we'll consider how prior experiences and cultural factors can influence our perceptions of reality.

## The Effects of Experience on Perceptual Interpretations

Our educational, cultural, and life experiences shape what we perceive. As a simple example, consider a climbing wall in a gym. If your knowledge of climbing is limited, the posts, ropes, arrows, and lines look like a meaningless jumble of equipment. But if you are an expert climber, you see handgrips and footgrips, belays, overhangs, and routes of varying difficulty. Our different perceptions of a climbing wall are shaped by our prior learning experiences.

Learning experiences can vary not just from person to person but also from culture to culture. The Culture and Human Behavior box on page 116, "Culture and the Müller-Lyer Illusion," discusses the important role that unique cultural experiences can play in perception.

Perception can also be influenced by an individual's expectations, motives, and interests. The term **perceptual set** refers to the tendency to perceive objects or situations from a particular frame of reference. Perceptual sets usually lead us to reasonably accurate conclusions. If they didn't, we would develop new perceptual sets that were more accurate. But sometimes a perceptual set can lead us astray. For example, someone with an avid interest in UFOs might readily interpret unusual cloud formations as a fleet of alien spacecraft.

**perceptual set** The tendency to perceive objects or situations from a particular frame of reference.

**The $28,000 Grilled Cheese Sandwich: What Do You See?** Is that Madonna on that grilled cheese sandwich? Ten years after she first noticed what she thought was the face of the Virgin Mary on her grilled cheese sandwich, Diana Duyser auctioned it off on eBay. The winning bid? Duyser got $28,000 for her carefully preserved (and partially eaten) relic. Why are we so quick to perceive human faces in ambiguous stimuli?

AFP/Getty Images

People are especially prone to seeing *faces* in ambiguous stimuli, as in the photo here. Why? One reason is that the brain is wired to be uniquely responsive to faces or face-like stimuli (Leopold & Rhodes, 2010; Pascalis & Kelly, 2009). The primate brain has been found to contain individual brain neurons that respond exclusively to faces or face-like images (Tsao, 2006; Tsao & others, 2006). This specialized face-recognition system allows us to identify an individual face out of the thousands that we can recognize (Kanwisher & Yovel, 2009).

But this extraordinary neural sensitivity also makes us more liable to false positives, seeing faces that aren't there. Vague or ambiguous images with face-like blotches and shadows can also trigger the brain's face-recognition system. Thus, we see faces where they don't exist at all—except in our own minds.

**CULTURE AND HUMAN BEHAVIOR**

## Culture and the Müller-Lyer Illusion: The Carpentered-World Hypothesis

Since the early 1900s, it has been known that people in industrialized societies are far more susceptible to the Müller-Lyer illusion than are people in some nonindustrialized societies (Matsumoto & Juang, 2008; Phillips, 2011). How can this difference be explained?

Cross-cultural psychologist Marshall Segall and his colleagues (1963, 1966) proposed the *carpentered-world hypothesis*. They suggested that people living in urban, industrialized environments have a great deal of perceptual experience in judging lines, corners, edges, and other rectangular, manufactured objects. Thus, people in carpentered cultures would be more susceptible to the Müller-Lyer illusion, which involves arrows mimicking a corner that is jutting toward or away from the perceiver.

In contrast, people who live in noncarpentered cultures more frequently encounter natural objects. In these cultures, perceptual experiences with straight lines and right angles are relatively rare. Segall predicted that people from these cultures would be less susceptible to the Müller-Lyer illusion.

To test this idea, Segall and his colleagues (1963, 1966) compared the responses of people living in carpentered societies, such as Evanston, Illinois, with those of people living in noncarpentered societies, such as remote areas of Africa. The results confirmed their hypothesis. The Müller-Lyer illusion was stronger for those living in carpentered societies. Could the difference in illusion susceptibility be due to some sort of biological difference rather than a cultural difference? To address this issue, psychologist V. Mary Stewart (1973) compared groups of white and African American schoolchildren living in Evanston, Illinois. Regardless of race, all of the children living in the city were equally susceptible to the Müller-Lyer illusion. Stewart also compared groups of black African children in five different areas of Zambia—ranging from the very carpentered capital city of Lusaka to rural, noncarpentered areas of the country. Once again, the African children living in the carpentered society of Lusaka were just as susceptible to the illusion as the Evanston children, but the African children living in the noncarpentered countryside were not.

robertharding / Alamy

**A Noncarpentered Environment** People who live in urban, industrialized environments have a great deal of perceptual experience with straight lines, edges, and right angles. In contrast, people who live in a noncarpentered environment, like the village shown here, have little experience with right angles and perfectly straight lines (Phillips, 2011). Are people who grow up in a noncarpentered environment equally susceptible to the Müller-Lyer illusion?

These findings provided some of the first evidence for the idea that culture could shape perception. As Segall (1994) later concluded, "Every perception is the result of an interaction between a stimulus and a perceiver shaped by prior experience." Thus, people who grow up in very different cultures might well perceive aspects of their physical environment differently.

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## Closing Thoughts

From reflections of light waves to perceptual illusions, the world you perceive is the result of complex interactions among distinctly dissimilar elements—environmental stimuli, sensory receptor cells, neural pathways, and brain mechanisms. Equally important are the psychological and cultural factors that help shape your perception of the world. As Mike's story illustrated, the world we experience relies not only on the functioning of our different sensory systems but also on neural pathways sculpted by years of learning experiences from infancy onward (Huber & others, 2015).

Alyson Aliano

**"I Am Mike May. . . ."** "By getting some sight, I gained some new elements of my personality and lifestyle without rejecting the blindness. I am not a blind person or a sighted person. I am not even simply a visually impaired person. I am Mike May with his quirky sense of humor, graying hair, passion for life, and rather unusual combination of sensory skills."

Although he spent more than four decades totally blind, Mike never seemed to lack vision. With conviction, humor, and curiosity, he sought out a life of change and adventure. And he found it. Rather than expecting his surgery to fundamentally change his life, he simply welcomed the opportunity for new experiences. Throughout his life, Mike wrote, "I have sought change and thrive on it. I expected new and interesting experiences from getting vision as an adult but not that it would change my life" (May, 2004). As Mike points out, "My life was incredibly good before I had my operation. I've been very fortunate and had incredible opportunities, and so I can say that life was incredible. It was fantastic as a non-seeing person, and life is still amazing now that I have vision. That's been consistent between not seeing and seeing. Experiencing life to its fullest doesn't depend on having sight" (May, 2002).

We hope that learning about Mike's experiences has provided you with some insights as to how your own life experiences have helped shape your perceptions of the world. In the next section, we'll provide you with some tips that we think you'll find useful in influencing your perceptions of painful stimuli.

PSYCH FOR YOUR LIFE

## Strategies to Control Pain

Pain specialists use a variety of techniques to control pain, including *hypnosis* and *painkilling drugs* (Flor, 2014). We'll discuss both of these topics in the next chapter. Another pain-relieving strategy is *acupuncture*.

Acupuncture is a pain-relieving technique that has been used in traditional Chinese medicine for thousands of years. Acupuncture involves inserting tiny, sterile needles at specific points in the body. The needles are then twirled, heated, or stimulated with a mild electrical current. Exactly how this stimulation diminishes pain signals or the perception of pain has yet to be completely explained (Moffet, 2008, 2009). Some research has shown that acupuncture stimulates the release of endorphins in the brain (Field, 2009). Evidence suggests that psychological factors also play a significant role in the pain-relieving effects of acupuncture. Some early clinical studies found that true acupuncture was only slightly more effective than sham acupuncture in relieving pain (Madsen & others, 2009; Moffet, 2009). However, a meta-analysis of dozens of studies found that acupuncture was significantly more effective than sham acupuncture or usual-care treatment in relieving pain associated with chronic headaches, arthritis, and chronic back, neck, and shoulder pain (Avins, 2012; Vickers & others, 2012). Similar results were found in a meta-analysis of postoperative pain (Wu & others, 2016).


MICHAEL NAGLE/The New York Times/Redux Pictures

**Acupuncture for Pain Relief** Lisa Ripi works on former New York Jets player Tony Richardson, one of dozens of NFL players that she regularly treated with a combination of acupuncture and massage for pain, muscle stiffness, and injuries.

But what about everyday pain, such as the pain that accompanies a sprained ankle or a trip to the dentist? There are several simple techniques that you can use to help cope with minor pain.

## Self-Administered Strategies

### 1. Distraction

By actively focusing your attention on some nonpainful task, you can often reduce pain (Edwards & others, 2009). For example, you can mentally count backward by sevens from 901, draw different geometric figures in your mind, or focus on the details of a picture or other object. Intently listening to an interesting podcast or calming music can also reduce discomfort (Loewy & Spintge, 2011; North & Hargreaves, 2009).

### 2. Imagery

Creating a vivid mental image can help control pain (Pincus & Sheikh, 2009). Usually people create a pleasant and progressive scenario, such as walking along the beach or hiking in the mountains. Try to imagine all the different sensations involved, including the sights, sounds, aromas, touches, and tastes. The goal is to become so absorbed in your fantasy that you distract yourself from sensations of pain.

### 3. Relaxation and meditation

Deep relaxation can be a very effective strategy for deterring pain sensations (Edwards & others, 2009; Turk & Winter, 2006). One simple relaxation strategy is deep breathing: Inhale deeply, then exhale very slowly and completely, releasing tension throughout your body. As you exhale, consciously note the feelings of relaxation and warmth you've produced in your body.

Several studies have shown that practicing meditation is an effective way to minimize pain (see Flor, 2014; Grant & others, 2010, 2011). Meditation may reduce the subjective experience of pain through multiple pathways, including relaxation, distraction, and inducing a sense of detachment from the painful experience (Jacob, 2016; Zeidan & Vago, 2016). Apparently, you do not need to be an expert to benefit from meditation's pain-relieving effects. Fadel Zeidan and his colleagues (2011) found that after just four 20-minute training sessions in a simple meditation technique, participants' ratings of the unpleasantness of a painful stimulus dropped by 57 percent. (We'll discuss meditation in more detail in the next chapter.)

### 4. Positive self-talk and reappraisal

This strategy involves making positive coping statements, either silently or out loud, during a painful episode or procedure. Examples of positive self-talk include statements such as, "It hurts, but I'm okay, I'm in control" and "I'm uncomfortable, but I can handle it."

Self-talk can also include reappraising or redefining the pain (Edwards & others, 2009). Substituting realistic and constructive thoughts about the pain experience for threatening or helpless thoughts can significantly reduce pain. For example, an athlete in training might say, "The pain means my muscles are getting stronger." Or consider the Marine Corps slogan: "Pain is weakness leaving the body."

## Can Magnets Relieve Pain?

Our students frequently ask us about different *complementary and alternative medicines (CAMs)*. Complementary and alternative medicines are a diverse group of health care systems, practices, or products that are *not* currently considered to be part of conventional medicine. Scientific evidence exists for some CAM therapies, such as massage (Moyer & others, 2004). Therapies that are scientifically proven to be safe and effective usually become adopted by the mainstream health care system. However, the effectiveness and safety of many CAMs have not been proven by well-designed scientific studies.

> **MYTH** ◀ ~~SCIENCE~~
> Is it true that magnets can relieve pain?

Magnets are one popular CAM that have been used for many centuries to treat pain. But can magnets relieve pain? To date, there is *no* evidence supporting the idea that magnets relieve pain (National Standard Monographs, 2009). The pain relief that some people experience could be due to a placebo effect, or expectations that pain will decrease. Or the relief could come from whatever holds the magnet in place, such as a warm bandage or the cushioned insole (Weintraub & others, 2003).

One final note: The techniques described here are not a substitute for seeking appropriate medical attention, especially when pain is severe, recurring, or of unknown origin. If pain persists, seek medical attention.

CHAPTER REVIEW

# Sensation and Perception

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## KEY PEOPLE

Max Wertheimer, p. 105

## KEY TERMS

sensation, p. 80
perception, p. 80
sensory receptors, p. 81
transduction, p. 81
absolute threshold, p. 82
difference threshold, p. 82
Weber's law, p. 82
sensory adaptation, p. 82
subliminal perception, p. 83
mere exposure effect, p. 83
wavelength, p. 84
pupil, p. 85
lens, p. 85
accommodation, p. 85
retina, p. 86
rods, p. 86
cones, p. 86
fovea, p. 86
blind spot, p. 86
optic nerve, p. 87
optic chiasm, p. 87
color, p. 89
trichromatic theory of color vision, p. 90
color blindness, p. 90
afterimage, p. 90
opponent-process theory of color vision, p. 90
audition, p. 92
pitch, p. 92
frequency, p. 92
outer ear, p. 93
eardrum, p. 93
middle ear, p. 94
inner ear, p. 94
cochlea, p. 94
basilar membrane, p. 94
hair cells, p. 94
frequency theory, p. 94
place theory, p. 95
olfaction, p. 95
gustation, p. 95
olfactory bulb, p. 96
pheromones, p. 97
taste buds, p. 98
pain, p. 99
nociceptors, p. 100
gate-control theory of pain, p. 100
proprioception, p. 101
bottom-up processing, p. 102
top-down processing, p. 102
ESP (extrasensory perception), p. 103
parapsychology, p. 103
Gestalt psychology, p. 105
figure–ground relationship, p. 105
depth perception, p. 108
monocular cues, p. 108
binocular cues, p. 109
perceptual constancy, p. 110
size constancy, p. 111
color constancy, p. 111
shape constancy, p. 112
perceptual illusion, p. 112
Müller-Lyer illusion, p. 113
moon illusion, p. 113
perceptual set, p. 115

# Sensation and Perception

## Sensation

Stimulation of **sensory receptors** by some form of energy

To be detected, stimulus must exceed **sensory threshold**. Sensory thresholds include:
- **Absolute threshold**
- **Difference threshold** (*just noticeable difference*) as defined by **Weber's law**
- **Sensory adaptation**

**Transduction:** Energy is converted into neural signals and transmitted to the brain.

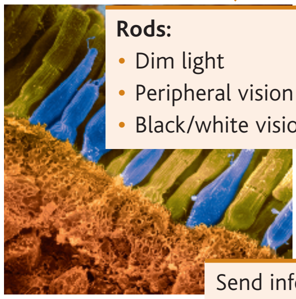

JGI/Getty Images

**Perception:** Signals are interpreted in the brain.

## Vision

Stimulus: Light waves

**Cornea:** Gathers incoming light
**Pupil:** Contracts or dilates to control amount of light entering eye
**Lens:** Process of accommodation focuses light on retina.
**Retina:** Contains sensory receptors


Omikron/Science Source

**Rods:**
- Dim light
- Peripheral vision
- Black/white vision

**Cones:**
- Bright light
- Concentrated in **fovea**
- Fine details (visual acuity)
- Color vision

Send information to:
- Bipolar cells
- Ganglion cells
- **Optic nerve**
  - Exits through optic disk
  - Crosses over at **optic chasm**
- Thalamus
- Visual cortex

**Color vision:** Psychological experience of different **wavelengths**


PicturesWild/Shutterstock

*Hue:* Light wavelength
*Saturation:* Purity of light wavelength
*Brightness:* Amplitude of light wave

**Trichromatic theory:** Describes color processing in cones; explains red–green color blindness
**Opponent-process theory:** Describes color processing in ganglion cells; explains **afterimages**

## Audition (Hearing)

Stimulus: Sound waves
Measured in decibels
*Amplitude* determines loudness.
*Frequency* determines pitch.
*Complexity* determines timbre.

**Outer ear** collects sound waves.
**Middle ear** contains eardrum, which amplifies sound waves.
**Inner ear** contains hair cells on the basilar membrane in the cochlea.


JGI/Jamie Grill/Blend Images/Getty Images

Pitch perception explained by
- **Frequency theory**
- **Place theory**

## Chemical and Body Senses

**Smell (olfaction):** When stimulated by airborne chemicals, receptor cells transmit signals along axons to **olfactory bulb** and on to other brain regions.

Courtesy Noam Sobel

**Taste (gustation):** When stimulated by chemicals in saliva, **taste buds** send neural messages to the thalamus and on to other brain regions.

**Proprioception:** Sensory neurons called *proprioceptors* detect changes in body position and movement.

*Vestibular system:* Receptor cells in semicircular canals and vestibular sacs detect changes in body position and help maintain balance and equilibrium.

**Pain:** Stimulation of free nerve endings, called **nociceptors** trigger:

- Fast pain system—sharp, intense pain
- Slow pain system—dull, chronic pain

**Gate-control theory of pain** describes how psychological and other factors affect the experience of pain.

## Perception

The process of integrating, organizing, and interpreting sensory information

**Top-down processing, Bottom-up processing**

**Gestalt psychology** emphasized perception of whole forms, or gestalts.

Gestalt principles of perception and organization:

- **Figure–ground relationship**
- Law of similarity
- Law of closure
- Law of good continuation
- Law of proximity

**Depth perception**

**Monocular cues:**

- Relative size
- Overlap
- Aerial perspective
- Texture gradient
- Linear perspective
- Motion parallax

**Binocular cues:**

- Convergence
- Binocular disparity

**Perceptual principles**

**Perceptual constancy:** Objects are perceived as stable despite changes in sensory input.

- **Size constancy**
- **Shape constancy**
- **Color constancy**

**Perceptual illusions:**

- **Müller-Lyer illusion**
- **Moon illusion**

Motion perception:

- Induced motion
- Stroboscopic motion

Perception is influenced by experience.
**Perceptual set** is the tendency to perceive objects from a particular frame of reference.

REUTERS/Darryl Webb