3 Sensation and Perception

Key Questions/ Chapter Outline	Core Concepts	Psychology Matters
3.1 How Does Stimulation Become Sensation? Transduction: Changing Stimulation to Sensation Thresholds: The Boundaries of Sensation Signal Detection Theory	The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.	**Sensory Adaptation** We get used to all but the most extreme or obnoxious stimuli because our senses are built to tell us about *change*.
3.2 How Are the Senses Alike? How Are They Different? Vision: How the Nervous System Processes Light Hearing: If a Tree Falls in the Forest . . . How the Other Senses Are Like Vision and Hearing Synesthesia: Sensations across the Senses	The senses all operate in much the same way, but each extracts different information and sends it to its own specialized processing region in the brain.	**The Experience of Pain** Pain is more than just a stimulus; it is an experience that varies from person to person. Pain control methods include drugs, hypnosis, and—for some—placebos.
3.3 What Is the Relationship between Sensation and Perception? Perceptual Processing: Finding Meaning in Sensation Perceptual Ambiguity and Distortion Theoretical Explanations for Perception Seeing and Believing	Perception brings *meaning* to sensation, so perception produces an interpretation of the world, not a perfect representation of it.	**Using Psychology to Learn Psychology** Don't set aside a certain amount of *time* for studying. Instead, study for the Gestalt.

CHAPTER PROBLEM Is there any way to tell whether the world we "see" in our minds is the same as the external world—and whether we see things as most others do?

CRITICAL THINKING APPLIED Subliminal Perception and Subliminal Persuasion

CAN YOU IMAGINE WHAT YOUR WORLD WOULD BE LIKE IF YOU COULD NO LONGER see colors—but merely black, white, and gray? Such a bizarre sensory loss befell Jonathan I., a 65-year-old New Yorker, following an automobile accident. Details of his case appear in neurologist Oliver Sacks's 1995 book, *An Anthropologist on Mars*.

The accident caused damage to a region in Jonathan's brain that processes color information. At first, he also experienced amnesia for reading letters of the alphabet, which all seemed like a jumble of nonsensical markings. But, after five days, his inability to read disappeared. His loss of color vision, however, persisted as a permanent condition, known as *cerebral achromatopsia* (pronounced *ay-kroma-TOP-see-a*). Curiously, Jonathan also lost his memory for colors: He could no longer imagine, for instance, what "red" once looked like.

As you might expect, Jonathan became depressed by this turn in his life. And the problem was aggravated by his occupation. You see, Jonathan was a painter who had based his livelihood on representing his visual images of the world in vivid colors. Now this whole world of color was gone. Everything was drab—all "molded in lead." When he looked at his own paintings now, paintings that had seemed bursting with special meaning and emotional associations, all he could see were unfamiliar and meaningless objects on canvas.

Still, Jonathan's story has a more or less happy ending, one that reveals much about the resilience of the human spirit. Jonathan became a "night person," traveling and working at night and socializing with other night people. (As we will see in this chapter, good color vision depends on bright illumination such as daylight; most people's color vision is not as acute in the dark of night.) He also became aware that what remained of his vision was remarkably good, enabling him to read license plates from four blocks away at night. Jonathan began to reinterpret his "loss" as a "gift" in which he was no longer distracted by color so that he could now focus his work more intensely on shape, form, and content. Finally, he switched to painting only in black and white. Critics acclaimed his "new phase" as a success. He has also become a skilled sculptor, which he had never attempted before his accident. So, as Jonathan's world of color died, a new world of "pure forms" was born in his perception of the people, objects, and events in his environment.

What lessons can we learn from Jonathan's experience? His unusual sensory loss tells us that our picture of the world around us depends on an elaborate sensory system that processes incoming information. In other words, we don't experience the world directly, but instead through a series of "filters" that we call our *senses.* By examining such cases of sensory loss, psychologists have learned much about how the sensory processing system works. And, on a more personal level, case studies like Jonathan's allow us momentarily to slip outside our own experience to see more clearly how resilient humans can be in the face of catastrophic loss.

But Jonathan's case also raises some deeper issues. Many conditions can produce the inability to see colors: abnormalities in the eyes, the optic nerve, or the brain can interfere with vision and, specifically, with the ability to see colors, as Jonathan's case illustrates. But do colors exist in the world outside us—or is it possible that color is a creation of our brains?

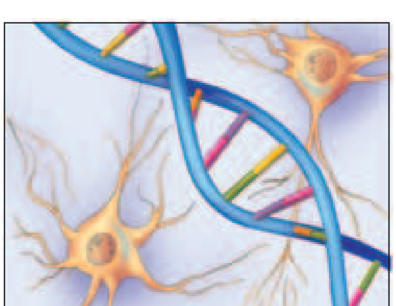
At first, such a question may seem absurd. But let's look a little deeper. Yes, we will argue that color—and, in fact, all sensation—is a creation of the brain. But perhaps the more profound issue is this:

PROBLEM: Is there any way to tell whether the world we "see" in our minds is the same as the external world—and whether we see things as most others do?

This chapter will show you how psychologists have addressed such questions. The chapter also takes us the next logical step beyond our introduction to the brain to a consideration of how information from the outside world gets into the brain and how the brain makes sense of it.

Although the very private processes that connect us with the outside world extend deep into the brain, we will begin our chapter at the surface—at the sense organs. This is the territory of *sensory psychology.* We will define **sensation** simply as the process by which a stimulated receptor (such as the eyes or ears) creates a pattern of neural messages that represent the stimulus in the brain, giving rise to our initial experience of the stimulus. An important idea to remember is that sensation involves converting stimulation (such as a pinprick, a sound, or a flash of light) into a form the brain can understand (neural signals)—much as a cell phone converts an electronic signal into sound waves you can hear.

sensation The process by which stimulation of a sensory receptor produces neural impulses that the brain interprets as a sound, a visual image, an odor, a taste, a pain, or other sensory image. Sensation represents the first series of steps in processing of incoming information.



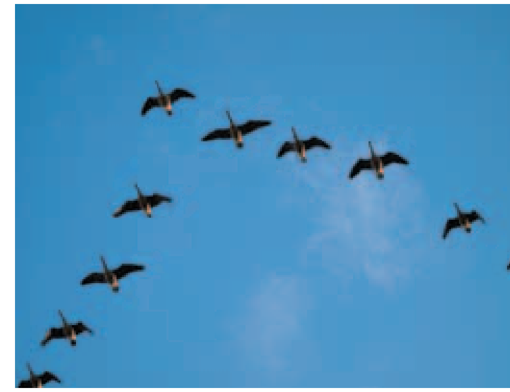
Psychologists study sensation primarily from a biological perspective.

Psychologists who study sensation do so primarily from a biological perspective. As you will see, they have found that all our sense organs are, in some very basic ways, much alike. All the sense organs transform physical stimulation (such as light waves or sound waves) into the neural impulses that give us sensations (such as the experience of light or sound). In this chapter, you will also learn about the biological and psychological bases for color, odor, sound, texture, and taste. By the end of our excursion, you will know why tomatoes and limes have different hues, why a pinprick feels different from a caress, and why seeing doesn't always give us an accurate basis for believing.

Happily, under most conditions, our sensory experience is highly reliable. So when you catch sight of a friend, the sensation usually registers clearly, immediately, and accurately. Yet, we humans do have our sensory limitations—just as other creatures do. In fact, we lack the acute senses so remarkable in many other species: the vision of hawks, the hearing of bats, the sense of smell of rodents, or the sensitivity to magnetic fields found in migratory birds. So do we humans excel at anything? Yes. Our species has evolved the sensory equipment that enables us to process a wider range and variety of sensory input than any other.

But sensation is only half the story. Our ultimate destination in this chapter lies, beyond mere sensation, in the amazing realm of *perception*. There we will uncover the psychological processes that attach meaning and personal significance to the sensory messages entering our brains. *Perceptual psychology* will help you understand how we assemble a series of tones into a familiar melody or a collage of shapes and shadings into a familiar face. More generally, we will define **perception** as a mental process that elaborates and assigns meaning to the incoming sensory patterns. Thus, *perception creates an interpretation of sensation.* Perception gives answers to such questions as: What do I see—a tomato? Is the sound I hear a church bell or a doorbell? Does the face belong to someone I know? Until quite recently, the study of perception was primarily the province of psychologists using the cognitive perspective. Now that brain scans have opened new "windows" on perceptual processes in the brain, neuroscientists have joined them in the quest to find biological explanations for perception.

As you can see, the boundary of sensation blurs into that of perception. Perception is essentially an interpretation and elaboration of sensation. Seen in these terms, sensation refers just to the initial steps in the processing of a stimulus. It is to these first sensory steps that we now turn our attention.



Human senses do not detect the earth's magnetic fields that migratory birds use for navigation.

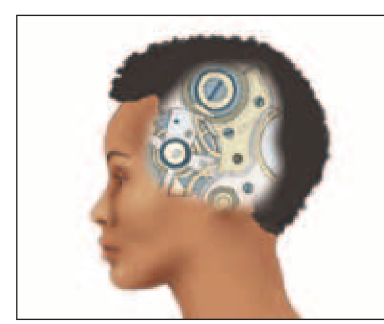
perception A process that makes sensory patterns meaningful. It is perception that makes these words meaningful, rather than just a string of visual patterns. To make this happen, perception draws heavily on memory, motivation, emotion, and other psychological processes.

3.1 KEY QUESTION
How Does Stimulation Become Sensation?

A thunderstorm is approaching, and you feel the electric charge in the air make the hair stand up on your neck. Lightning flashes, and a split second later, you hear the thunderclap. It was close by, and you smell the ozone left in the wake of the bolt as it sizzled through the air. Your senses are warning you of danger.

Our senses have other adaptive functions, too. They aid our survival by directing us toward certain stimuli, such as tasty foods, which provide nourishment. Our senses also help us locate mates, seek shelter, and recognize our friends. Incidentally, our senses also give us the opportunity to find pleasure in music, art, athletics, food, and sex.

How do our senses accomplish all this? The complete answer is complex, but it involves one elegantly simple idea that applies across the sensory landscape: Our sensory impressions of the world involve *neural representations* of stimuli—not the actual stimuli themselves. The Core Concept puts it this way:



Until recently, psychologists studied perception primarily from a cognitive perspective.

Core Concept 3.1

The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.

The brain never receives stimulation directly from the outside world. Its experience of a tomato is not the same as the tomato itself—although we usually assume that the two are identical. Neither can the brain receive light from a sunset, reach out and touch velvet, or inhale the fragrance of a rose. It must always rely on secondhand

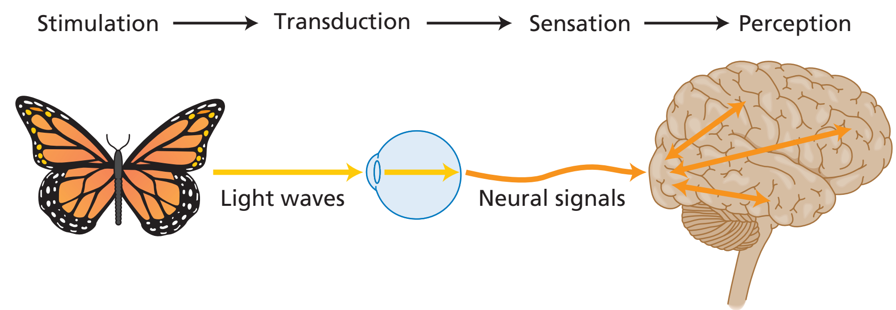


FIGURE 3.1

Stimulation Becomes Perception

For visual stimulation to become meaningful perception, it must undergo several transformations. First, physical stimulation (light waves from the butterfly) is transduced by the eye, where information about the wavelength and intensity of the light is coded into neural signals. Second, the neural messages travel to the sensory cortex of the brain, where they become sensations of color, brightness, form, and movement. Finally, the process of perception interprets these sensations by making connections with memories, expectations, emotions, and motives in other parts of the brain. Similar processes operate on the information taken in by the other senses.

information from the go-between sensory system, which delivers only a coded neural message, out of which the brain must create its own experience (see Figure 3.1). Just as you cannot receive phone messages without a telephone receiver to convert the electronic energy into sound you can hear, your brain also needs its sensory system to convert the stimuli from the outside world into neural signals that it can comprehend.

To understand more deeply how the world's stimulation becomes the brain's sensation, we need to think about three attributes common to all the senses: *transduction, sensory adaptation,* and *thresholds*. They determine which stimuli will actually become sensation, what the quality and impact of that sensation will be, and whether it grabs our interest. These attributes determine, for example, whether a tomato actually registers in the sensory system strongly enough to enter our awareness, what its color and form appear to be, and how strongly it bids for our attention.

Transduction: Changing Stimulation to Sensation

It may seem incredible that basic sensations, such as the redness and flavor of our tomato—or the colors Jonathan could see before his accident—are entirely creations of the sense organs and brain. But remember that all sensory communication with the brain flows through neurons in the form of neural signals: Neurons cannot transmit light or sound waves or any other external stimulus. Accordingly, none of the light bouncing off the tomato ever actually reaches the brain. In fact, incoming light only travels as far as the back of the eyes. There the information it contains is converted to neural messages. Likewise, the chemicals that signal taste make their way only as far as the tongue, not all the way to the brain.

In all the sense organs, it is the job of the *sensory receptors,* such as the eyes and ears, to convert incoming stimulus information into electrochemical signals—neural activity—the only language the brain understands. As Jonathan I.'s case suggests, sensations, such as "red" or "sweet" or "cold," occur only when the neural signal reaches the cerebral cortex. The whole process seems so immediate and direct that it fools us into assuming that the sensation of redness is characteristic of a tomato or the sensation of cold is a characteristic of ice cream. But they are not! (You can discover how light is not necessary for sensations of light with the demonstration in the *Do It Yourself!* box, "Phosphenes Show That Your Brain Creates Sensations.")

transduction Transformation of one form of information into another—especially the transformation of stimulus information into nerve signals by the sense organs. As a result of transduction, the brain interprets the incoming light waves from a ripe tomato as red.

Psychologists use the term **transduction** for the sensory process that converts the information carried by a physical stimulus, such as light or sound waves, into the form of neural messages. Transduction begins when a sensory neuron detects a physical stimulus (such as the sound wave made by a vibrating guitar string). When the appropriate stimulus reaches a sense organ, it activates specialized neurons, called *receptors,* that respond by converting their excitation into a nerve signal. This happens in much the same way that a bar-code reader (which is, after all, merely an electronic receptor) converts the series of lines on a frozen pizza box into an electronic signal that a computer can match with a price.

In our own sensory system, neural impulses carry the codes of sensory events in a form that can be further processed by the brain. To get to its destination, this information-carrying signal travels from the receptor cells along a *sensory pathway*—usually by way

Do It Yourself! PHOSPHENES SHOW THAT YOUR BRAIN CREATES SENSATIONS

One of the simplest concepts in perceptual psychology is among the most difficult for most people to grasp: The brain and its sensory systems create the colors, sounds, tastes, odors, textures, and pains that you sense. You can demonstrate this to yourself in the following way.

Close your eyes and press gently with your finger on the inside corner of one eye. On the opposite side of your visual field, you will "see" a pattern caused by the pressure of your finger—not by light. These light sensations are *phosphenes,* visual images caused by fooling your visual system with pressure, which stimulates the optic nerve in much the same way light does. Direct electrical stimulation of the occipital lobe, sometimes done during brain surgery, can have the same effect. This shows that light waves are not absolutely necessary for the sensation of light. The sensory experience of light, therefore, must be a creation of the brain rather than a property of objects in the external world.

Phosphenes may have some practical value, too. Several laboratories are working on ways to use phosphenes, created by stimulation sent from a TV camera to the occipital cortex to create visual sensations for people who have lost their sight (Wickelgren, 2006). Another promising approach under development involves replacing a section of the retina with an electronic microchip (Boahen, 2005; Liu et al., 2000). We hasten to add, however, that this technology is in its infancy (Cohen, 2002).

of the thalamus and on to specialized sensory processing areas in the brain. From the coded neural impulses arriving from these pathways, the brain then extracts information about the basic qualities of the stimulus, such as its intensity and direction. Please keep in mind, however, that the stimulus itself terminates in the receptor: The only thing that flows into the nervous system is *information* carried by the neural impulse.

Let's return now to the problem we set out at the beginning of the chapter: How could we tell whether the world we "see" in our minds is the same as the external world—and whether we see the world as others do? The idea of transduction gives us part of the answer. Because we do *not* see (or hear, or smell . . .) the external world directly, what we sense is an electrochemical rendition of the world created by the sensory receptors and the brain. To give an analogy: Just as digital photography changes a scene first into electronic signals and then into drops of ink on a piece of paper, so the process of sensation changes the world into a pattern of neural impulses realized in the brain.

Thresholds: The Boundaries of Sensation

What is the weakest stimulus an organism can detect? How dim can a light be and still be visible? How soft can music be and still be heard? These questions refer to the **absolute threshold** for different types of stimulation, which is the minimum amount of physical energy needed to produce a sensory experience. In the laboratory, a psychologist would define this operationally as the intensity at which the stimulus is detected accurately half of the time over many trials. This threshold will also vary from one person to another. So if you point out a faint star to a friend who says he cannot see it, the star's light is above your absolute threshold (you can see it) but below that of your friend (who cannot).

absolute threshold The amount of stimulation necessary for a stimulus to be detected. In practice, this means that the presence or absence of a stimulus is detected correctly half the time over many trials.

CONNECTION CHAPTER 1

An *operational definition* describes a concept in terms of the operations required to produce, observe, or measure it (p. XXX).

A faint stimulus does not abruptly become detectable as its intensity increases. Because of the fuzzy boundary between detection and nondetection, a person's absolute threshold is not absolute! In fact, it varies continually with our mental alertness and physical condition. Experiments designed to determine thresholds for various types of stimulation were among the earliest studies done by psychologists—who called this line of inquiry *psychophysics*. Table 3.1 shows some typical absolute threshold levels for several familiar natural stimuli.

We can illustrate another kind of threshold with the following imaginary experiment. Suppose you are relaxing by watching television on the one night you don't need

TABLE 3.1 Approximate Sensory Thresholds of Five Senses

Sense	Detection Threshold
Vision	A candle flame at 30 miles on a dark, clear night
Hearing	The tick of a mechanical watch under quiet conditions at 20 feet
Taste	One teaspoon of sugar in 2 gallons of water
Smell	One drop of perfume diffused into the entire volume of a three-bedroom apartment
Touch	The wing of a bee falling on your cheek from a distance of 1 centimeter

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to study, while a roommate busily prepares for an early morning exam. Your roommate asks you to "turn it down a little" to eliminate the distraction. You feel that you should make some effort to comply but really wish to leave the volume as it is. What is the least amount you can lower the volume to prove your good intentions to your roommate while still keeping the sound clearly audible? Your ability to make judgments like this one depends on your **difference threshold** (also called the *just noticeable difference* or *JND*), the smallest physical difference between two stimuli that a person can reliably detect 50 percent of the time.

difference threshold The smallest amount by which a stimulus can be changed and the difference be detected half the time.

If you turn down the volume as little as possible, your roommate might complain, "I don't hear any difference." By this, your roommate probably means that the change in volume does not match his or her difference threshold. By gradually lowering the volume until your roommate says "when," you will be able to find the difference threshold that keeps the peace in your relationship.

Investigation of the difference thresholds across the senses has yielded some interesting insights into how human stimulus detection works. It turns out that *the JND is always large when the stimulus intensity is high and small when the stimulus intensity is low.* Psychologists refer to this idea—that the size of the JND is proportional to the intensity of the stimulus—as **Weber's law.** And what does Weber's law tell us about adjusting the TV volume? If you have the volume turned up very high, you will have to turn it down a lot to make the difference noticeable. On the other hand, if you already have the volume set to a very low level, a small adjustment will probably be noticeable enough for your roommate. The same principle operates across all our senses. Knowing this, you might guess that a weight lifter would notice the difference when small amounts are added to light weights, but it would take a much larger addition to be noticeable with heavy weights.

Weber's law The concept that the size of a JND is proportional to the intensity of the stimulus; the JND is large when the stimulus intensity is high and small when the stimulus intensity is low.

What does all this mean for our understanding of human sensation? The general principle is this: We are built to detect *changes* in stimulation and *relationships* among stimuli. You can see how this works in the box, *Do It Yourself! An Enlightening Demonstration of Sensory Relationships.*

Do It Yourself! AN ENLIGHTENING DEMONSTRATION OF SENSORY RELATIONSHIPS

In this simple demonstration, you will see how detection of change in brightness is relative, not absolute. Find a three-way lamp equipped with a bulb having equal wattage increments, such as a 50-100-150-watt bulb. (Wattage is closely related to brightness.) Then, in a dark room, switch the light on to 50 watts, which will seem like a *huge* increase in brightness relative to the dark. Next, turn the switch to change from 50 to 100 watts: This will also seem like a large increase—but not so much as it did when you originally turned on the light in the dark. Finally, switch from 100 to 150 watts. Why does this last 50-watt increase, from 100 to 150 watts, appear only slightly brighter?

Your visual system does not give you an *absolute* sensation of brightness; rather, it provides information about the *relative* change. That is, it compares the stimulus change to the background stimulation, translating the jump from 100 to 150 watts as a mere 50 percent increase (50 watts added to 100) compared to the earlier 100 percent increase (50 watts added to 50). This illustrates how your visual system computes sensory relationships rather than absolutes—and it is essentially the same with your other senses.

Signal Detection Theory

A deeper understanding of absolute and difference thresholds comes from *signal detection theory* (Green & Swets, 1966). Originally developed for engineering electronic sensors, signal detection theory uses the same concepts to explain both the electronic sensing of stimuli by devices, such as your TV set, and by the human senses, such as vision and hearing.

According to **signal detection theory,** sensation depends on the *characteristics of the stimulus,* the *background stimulation,* and the *detector*. Thus, how well you receive a stimulus, such as a professor's lecture, depends on the presence of competing stimuli in the background—the clacking keys of a nearby laptop or intrusive fantasies about a classmate. It will also depend on the condition of your "detector"—your brain—and, perhaps, whether it has been aroused by a strong cup of coffee or dulled by drugs or lack of sleep.

signal detection theory Explains how we detect "signals," consisting of stimulation affecting our eyes, ears, nose, skin, and other sense organs. Signal detection theory says that sensation is a judgment the sensory system makes about incoming stimulation. Often, it occurs outside of consciousness. In contrast to older theories from psychophysics, signal detection theory takes observer characteristics into account.

Signal detection theory also helps us understand why thresholds vary—why, for example, you might notice a certain sound one time and not the next. The classical theory of thresholds ignored the effects of the perceiver's physical condition, judgments, or biases. Thus, in classical psychophysics (as the study of stimulation, thresholds, and sensory experience was called before signal-detection theory came along), if a signal were intense enough to exceed one's absolute threshold, it would be sensed; if below the threshold, it would be missed. In the view of modern signal detection theory, sensation is not a simple yes-or-no experience but a *probability* that the signal will be detected and processed accurately.

So, what does signal detection theory offer psychology that was missing in classical psychophysics? One factor is the variability in human judgment. Another involves the conditions in which the signal occurs. Signal detection theory recognizes that the observer, whose physical and mental status is always in flux, must compare a sensory experience with ever-changing expectations and biological conditions. When something "goes bump in the night" after you have gone to bed, you must decide whether it is the cat, an intruder, or just your imagination. But what you decide it is depends on factors such as the keenness of your hearing and what you expect to hear, as well as other noises in the background. By taking into account the variable conditions that affect detection of a stimulus, signal detection theory provides a more accurate portrayal of sensation than did classical psychophysics.

Signal detection theory says that the background stimulation would make it less likely for you to hear someone calling your name on a busy downtown street than in a quiet park.

[PSYCHOLOGY MATTERS]

Sensory Adaptation

If you have ever jumped into a cool pool on a hot day, you know that sensation is critically influenced by *change*. In fact, a main role of our stimulus detectors is to announce changes in the external world—a flash of light, a splash of water, a clap of thunder, the approach of a lion, the prick of a pin, or the burst of flavor from a dollop of salsa. Thus, our sense organs are *change detectors*. Their receptors specialize in gathering information about new and changing events.

The great quantity of incoming sensation would quickly overwhelm us, if not for the ability of our sensory systems to adapt. **Sensory adaptation** is the diminishing responsiveness of sensory systems to prolonged stimulation, as when you adapt to the feel of swimming in cool water. In fact, any unchanging stimulation usually shifts into the background of our awareness unless it is quite intense or painful. On the other hand, any change in stimulation (as when a doorbell rings) will immediately draw your attention.

sensory adaptation Loss of responsiveness in receptor cells after stimulation has remained unchanged for a while, as when a swimmer becomes adapted to the temperature of the water.

Incidentally, sensory adaptation accounts for the background music often played in stores being so forgettable: It has been deliberately selected and filtered to remove any large changes in volume or pitch that might distract attention from the merchandise. (On the other hand, do you see why it's not a good idea to listen to your favorite music while studying?)

Check Your Understanding

Study and Review on **mypsychlab.com**

1. **RECALL:** The sensory pathways carry information from ________ to ________.
2. **RECALL:** Why do sensory psychologists use the standard of *the amount of stimulation that your sensory system can detect about half the time* for identifying the absolute threshold?
3. **APPLICATION:** Which one would involve sensory adaptation?
   - **a.** The water in a swimming pool seems warmer after you have been in it for a while than it did when you first jumped in.
   - **b.** The flavor of a spicy salsa on your taco seems hot by comparison with the blandness of the sour cream.
   - **c.** You are unaware of a stimulus flashed on the screen at 1/100 of a second.
   - **d.** You prefer the feel of silk to the feel of velvet.
4. **RECALL:** What is the psychological process that adds *meaning* to information obtained by the sensory system?
5. **UNDERSTANDING THE CORE CONCEPT:** Use the concept of *transduction* to explain why the brain never directly senses the outside world.

Answers 1. The sense organs; the brain. **2.** The amount of stimulation that we can detect is not fixed. Rather, it varies depending on ever-changing factors such as our level of arousal, distractions, fatigue, and motivation. **3.** a **4.** Perception **5.** The senses transduce stimulation from the external world into the form of neural impulses, which is the only form of information that the brain can use. Therefore, the brain does not deal directly with light, sound, odors, and other stimuli but only with information that has been changed (transduced) into neural messages.

3.2 KEY QUESTION
How Are the Senses Alike? And How Are They Different?

Vision, hearing, smell, taste, touch, pain, body position: In certain ways, all these senses are the same. We have seen that they all transduce stimulus energy into neural impulses. They are all more sensitive to change than to constant stimulation. And they all provide us information about the world—information that has survival value. But how are they *different?* With the exception of pain, each sense taps a different form of stimulus energy, and each sends the information it extracts to a different part of the brain. These contrasting ideas lead us to the Core Concept of this section:

Core Concept 3.2

The senses all operate in much the same way, but each extracts different information and sends it to its own specialized processing region in the brain.

As a result, *different sensations occur because different areas of the brain become activated*. Whether you hear a bell or see a bell depends ultimately on which part of the brain receives stimulation. We will explore how this all works by looking at each of the senses in turn. First, we will explore the visual system—the best understood of the senses—to discover how it transduces light waves into visual sensations of color and brightness.

Vision: How the Nervous System Processes Light

Animals with good vision have an enormous biological advantage. This fact has exerted evolutionary pressure to make vision the most complex, best-developed, and important sense for humans and most other highly mobile creatures. Good vision helps us detect desired targets, threats, and changes in our physical environment and to adapt our behavior accordingly. So, how does the visual system accomplish this?

The Anatomy of Visual Sensation You might think of the eye as a sort of "video camera" that the brain uses to make motion pictures of the world (see Figure 3.2). Like a camera, the eye gathers light through a lens, focuses it, and forms an image in the *retina* at the back of the eye. The lens, incidentally, turns the image left to right and upside down. (Because vision is so important, this visual reversal may have influenced the very structure of the brain, which, you will remember, tends to maintain this reversal in its sensory processing regions. Thus, most information from the sense organs crosses over to the opposite side of the brain. Likewise, "maps" of the body in the brain's sensory areas are typically reversed and inverted.)

But while a digital camera simply forms an electronic image, the eye forms an image that gets extensive further processing in the brain. The unique characteristic of the eye—what makes the eye different from other sense organs—lies in its ability to extract the information from light waves, which are simply a form of electromagnetic energy. The eye, then, *transduces* the characteristics of light into neural signals that the brain can process. This transduction happens in the **retina**, the light-sensitive layer of cells at the back of the eye that acts much like the light-sensitive chip in a digital camera.

And, as with a camera, things can go wrong. For example, the lenses of those who are "nearsighted" focus images short of (in front of) the retina; in those who are "farsighted," the focal point extends behind the retina. Either way, images are not sharp without corrective lenses.

The real work in the retina is performed by light-sensitive cells known as **photoreceptors**, which operate much like the tiny pixel receptors in a digital camera. These photoreceptors consist of two different types of specialized neurons—the *rods* and *cones* that absorb light energy and respond by creating neural impulses (see Figure 3.3). But why are there two sorts of photoreceptors?

Because we function sometimes in near darkness and sometimes in bright light, we have evolved two types of processors involving two distinct receptor cell types named for their shapes. The 125 million tiny **rods** "see in the dark"—that is, they detect low

retina The thin light-sensitive layer at the back of the eyeball. The retina contains millions of photoreceptors and other nerve cells.

photoreceptors Light-sensitive cells (neurons) in the retina that convert light energy to neural impulses. The photoreceptors are as far as light gets into the visual system.

rods Photoreceptors in the retina that are especially sensitive to dim light but not to colors. Strange as it may seem, they are rod-shaped.

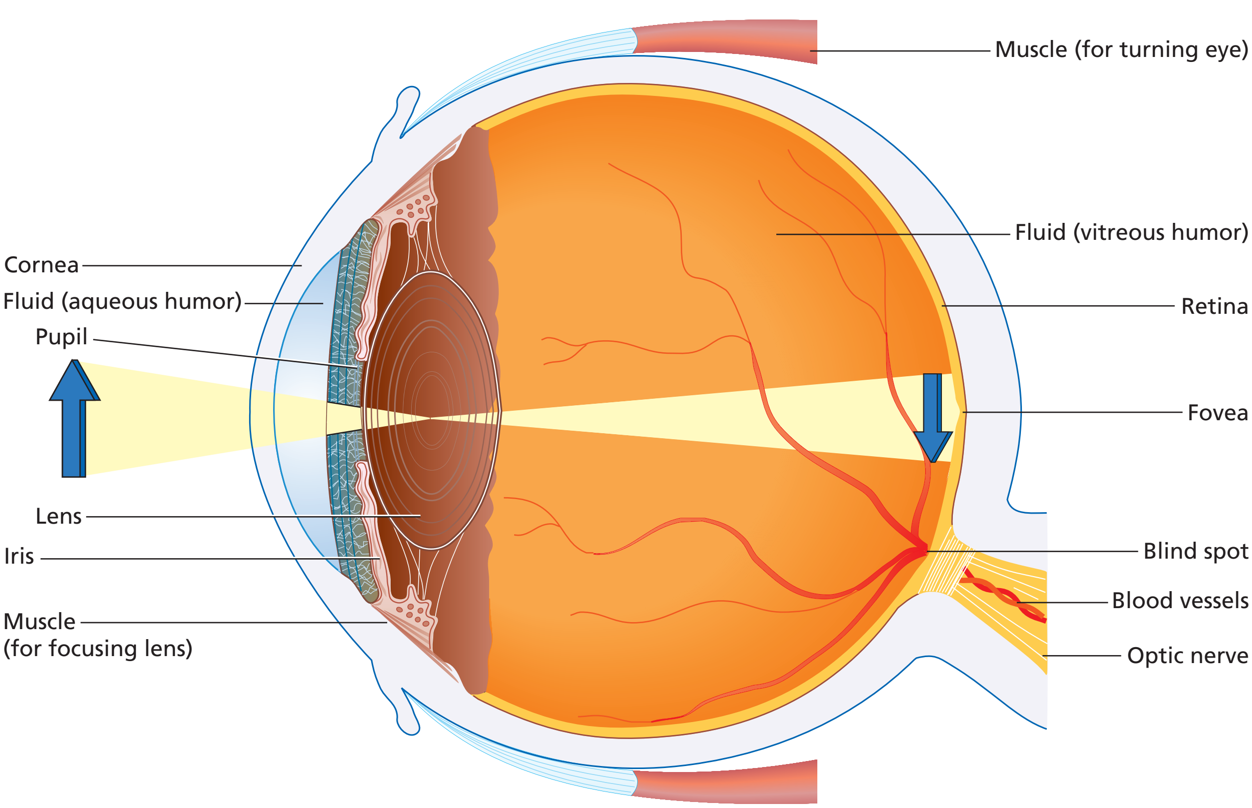
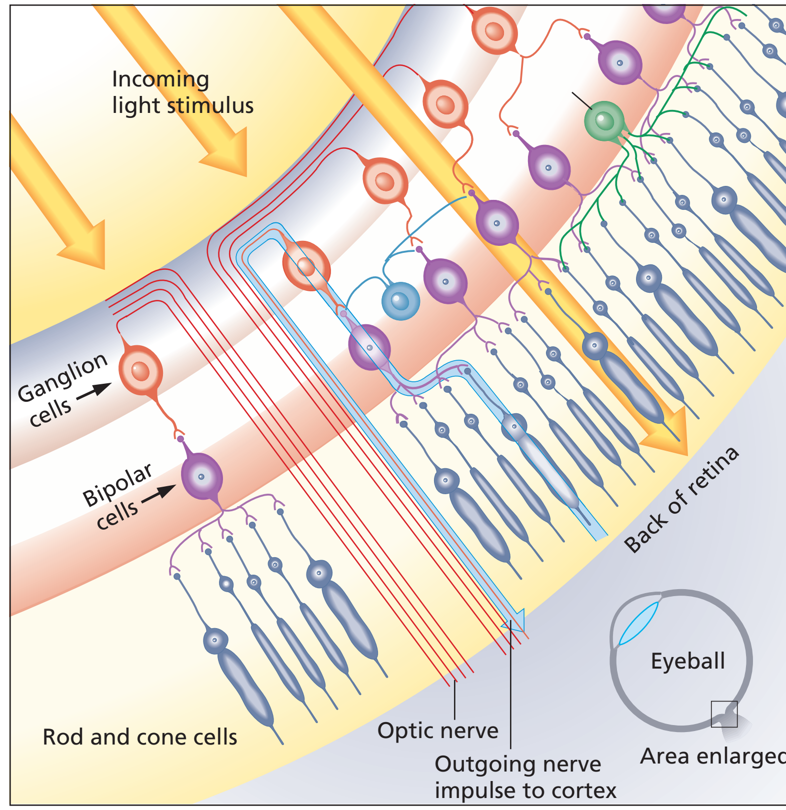


FIGURE 3.2
Structures of the Human Eye

FIGURE 3.3

Transduction of Light in the Retina

This simplified diagram shows the pathways that connect three layers of nerve cells in the retina. Incoming light passes through the ganglion cells and bipolar cells first before striking the photoreceptors at the back of the eyeball. Once stimulated, the rods and cones then transmit information to the bipolar cells (note that one bipolar cell combines information from several receptor cells). The bipolar cells then transmit neural impulses to the ganglion cells. Impulses travel from the ganglia to the brain via axons that make up the optic nerve.



intensities of light at night, though they cannot make the fine distinctions that give rise to our sensations of color. Rod cells enable you to find a seat in a darkened movie theater.

Making the fine distinctions necessary for color vision is the job of the seven million **cones** that come into play in brighter light. Each cone is specialized to detect the light waves we sense either as blue, red, or green. In good light, then, we can use these cones to distinguish ripe tomatoes (sensed as red) from unripe ones (sensed as green). The cones concentrate in the very center of the retina, in a small region called the **fovea,** which gives us our sharpest vision. With movements of our eyeballs, we use the fovea to scan whatever interests us visually—the features of a face or, perhaps, a flower.

cones Photoreceptors in the retina that are especially sensitive to colors but not to dim light. You may have guessed that the cones are cone-shaped.

fovea The tiny area of sharpest vision in the retina.

There are other types of cells in the retina that do not respond directly to light. The *bipolar cells* handle the job of collecting impulses from many photoreceptors (rods and cones) and shuttling them on to the *ganglion cells,* much as an airline hub collects passengers from many regional airports and shuttles them on to other destinations. The retina also contains receptor cells sensitive to edges and boundaries of objects; other cells respond to light and shadow and motion (Werblin & Roska, 2007).

Bundled together, the axons of the ganglion cells make up the **optic nerve,** which transports visual information from the eye to the brain (refer to Figures 3.2 and 3.3). Again, it is important to understand that the optic nerve carries no light—only patterns of nerve impulses conveying *information* derived from the incoming light.

optic nerve The bundle of neurons that carries visual information from the retina to the brain.

Just as strangely, there is a small area of the retina in each eye where everyone is blind, because that part of the retina has no photoreceptors. This **blind spot** is located at the point where the optic nerve exits each eye, and the result is a gap in the visual field. You do not experience blindness there because what one eye misses is registered by the other eye, and the brain "fills in" the spot with information that matches the background. You can find your own blind spot by following the instructions in the *Do It Yourself!* box.

blind spot The point where the optic nerve exits the eye and where there are no photoreceptors. Any stimulus that falls on this area cannot be seen.

We should clarify that the visual impairment we call *blindness* can have many causes, which are usually unrelated to the blind spot. Blindness can result, for example, from damage to the retina, cataracts that make the lens opaque, damage to the optic nerve, or from damage to the visual processing areas in the brain.

Do It Yourself! FIND YOUR BLIND SPOT

The "blind spot" occurs at the place on the retina where the neurons from the retina bunch together to exit the eyeball and form the optic nerve. There are no light-sensitive cells at this point on the retina. Consequently, you are "blind" in this small region of your visual field. The following demonstrations will help you determine where this blind spot occurs in your visual field.

Demonstration 1

Hold the text at arm's length, close your right eye, and fix your left eye on the "bank" figure. Keep your right eye closed and bring the book slowly closer. When it is about 10 to 12 inches away and the dollar sign is in your blind spot, the dollar sign will disappear—but you will not see a "hole" in your visual field. Instead, your visual system "fills in" the missing area with information from the white background. You have "lost" your money!

Demonstration 2

To convince yourself that the brain fills in the missing part of the visual field with appropriate background, close your right eye again and focus on the cross in the lower part of the figure. Once again, keeping the right eye closed, bring the book closer to you as you focus your left eye on the cross. This time, the gap in the line will disappear and will be filled in with a continuation of the line on either side. This shows that what you see in your blind spot may not really exist!

Processing Visual Sensation in the Brain We *look* with our eyes, but we *see* with the brain. That is, a special brain area called the *visual cortex* creates visual images from the information imported from the eyes through the optic nerve (see Figure 3.4). There in the visual cortex, the brain begins working its magic by transforming the incoming neural impulses into visual sensations of color, form, boundary, and

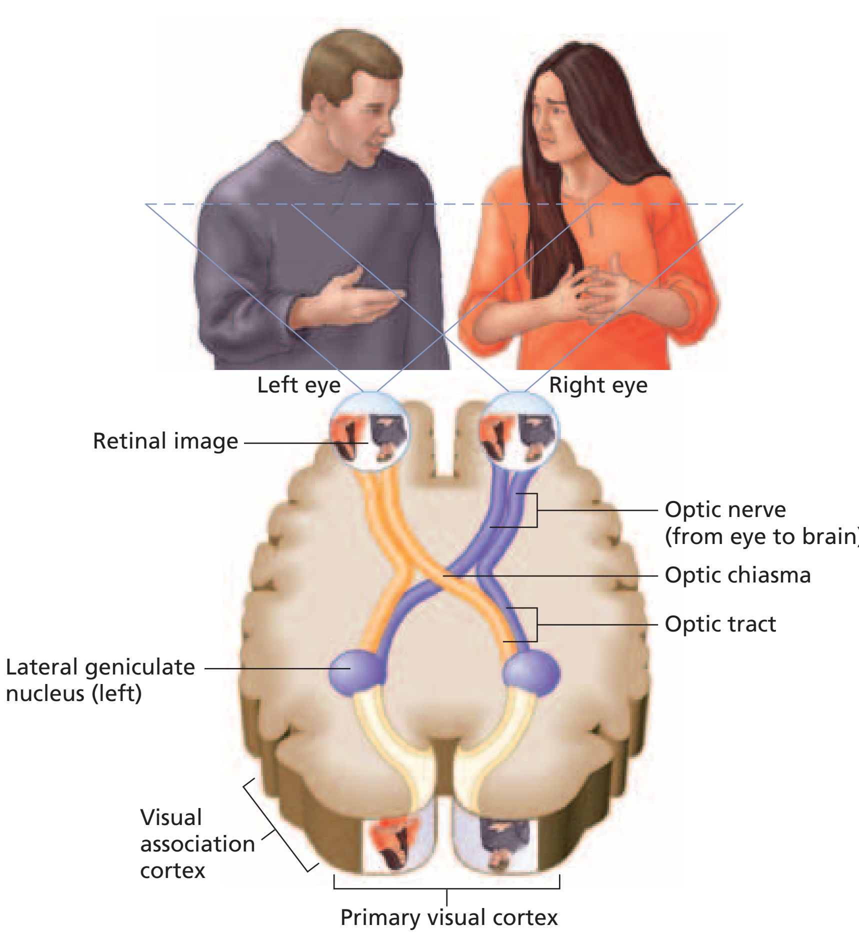


FIGURE 3.4

How Visual Stimulation Goes from the Eyes to the Brain

Light from objects in the visual field projects images on the retinas of the eyes. Please note two important things. First, the lens of the eye reverses the image on the retina—so the image of the man falls on the right side of the retina, and the image of the woman falls on the left. Second, the visual system splits the retinal image coming from each eye so that part of the image coming from each eye crosses over to the opposite side of the brain. (Note how branches of the optic pathway cross at the *optic chiasma.*) As a result, objects appearing in the *left* part of the visual field *of both eyes* (the man, in this diagram) are sent to the *right* hemisphere's visual cortex for processing, while objects in the *right* side of the visual field *of both eyes* (the woman, in this diagram) are sent to the *left* visual cortex. In general, the right hemisphere "sees" the left visual field, while the left hemisphere "sees" the right visual field.

Source: *SEEING: Illusion, Brain and Mind*, by J. P. Frisby. Copyright © 1979. Reprinted by permission of J. P. Frisby.

TABLE 3.2 Visual Stimulation Becomes Sensation

Color and brightness are the psychological counterparts of the wavelength and intensity of a light wave. Wavelength and intensity are physical characteristics of light waves, while color and brightness are psychological characteristics that exist only in the brain.

Physical Stimulation	Psychological Sensation
Wavelength	Color
Intensity (amplitude)	Brightness

CONNECTION CHAPTER 2

Note that part of the visual pathway of each eye crosses over to the cortex on the opposite side of the brain. This produced some of the bizarre responses that we saw in the tests of *split-brain* patients (p. XXX).

movement. Amazingly, the visual cortex also manages to take the two-dimensional patterns from each eye and assemble them into our three-dimensional world of depth (Barinaga, 1998; Dobbins et al., 1998). With further processing, the cortex ultimately combines these visual sensations with memories, motives, emotions, and sensations of body position and touch to create a representation of the visual world that fits our current concerns and interests (de Gelder, 2000; Vuilleumier & Huang, 2009). These associations explain why, for example, you feel so strongly attracted by displays of appetizing foods if you go grocery shopping when you are hungry.

Let's return for a moment to the chapter problem and to the question, Do we "see" the world as others do? As far as sensation is concerned, we will find that the answer is a qualified "yes." That is, different people have essentially the same sensory apparatus (with the exceptions of a few individuals who, like Jonathan, cannot distinguish colors or who have other sensory deficits). Therefore, it is reasonable to assume that most people *sense* colors, sounds, textures, odors, and tastes in much the same way—although, as we will see, they do not necessarily *perceive* them in the same way. To see what we mean, let's start with the visual sensation of *brightness*.

brightness A psychological sensation caused by the intensity (amplitude) of light waves.

How the Visual System Creates Brightness Sensations of **brightness** come from the intensity or *amplitude* of light, determined by how much light reaches the retina (see Table 3.2). Bright light, as from the sun, involves a more intense light wave, which creates much neural activity in the retina, while relatively dim light, as from the moon, produces relatively little retinal activity. Ultimately, the brain senses brightness by the volume of neural activity it receives from the eyes.

color Also called *hue.* Color is not a property of things in the external world. Rather, it is a *psychological sensation* created in the brain from information obtained by the eyes from the wavelengths of visible light.

How the Visual System Creates Color You may have been surprised to learn that a flower or a ripe tomato, itself, has no **color,** or *hue*. Physical objects seen in bright light seem to have the marvelous property of being awash with color; but, as we have noted, the red tomatoes, yellow flowers, green trees, blue oceans, and multihued rainbows are, in themselves, actually quite colorless. Nor does the light reflected from these objects have color. Despite the way the world appears to us, color does not exist outside the brain because color is a *sensation* that the brain creates based on the wavelength of light striking our eyes. Thus, color exists only in the mind of the viewer—a *psychological* property of our sensory experience. To understand more fully how this happens, you must first know something of the nature of light.

The eyes detect the special form of energy that we call *visible light*. Physicists tell us that this light is pure energy—fundamentally the same as radio waves, microwaves, infrared light, ultraviolet light, X-rays, and cosmic rays. All are forms of *electromagnetic energy*. These waves differ in their wavelength (the distance they travel in making one wave cycle) as they vibrate in space, like ripples on a pond (see Figure 3.5). The light we see occupies but a tiny segment somewhere near the middle of the vast **electromagnetic spectrum.** Our only access to this electromagnetic spectrum lies through a small visual "window" called the **visible spectrum.** Because we have no biological receptors sensitive to the other portions of the electromagnetic spectrum, we must detect these waves through devices, such as radios and TVs, that convert the energy into signals we can use.

electromagnetic spectrum The entire range of electromagnetic energy, including radio waves, X-rays, microwaves, and visible light.

visible spectrum The tiny part of the electromagnetic spectrum to which our eyes are sensitive. The visible spectrum of other creatures may be slightly different from our own.

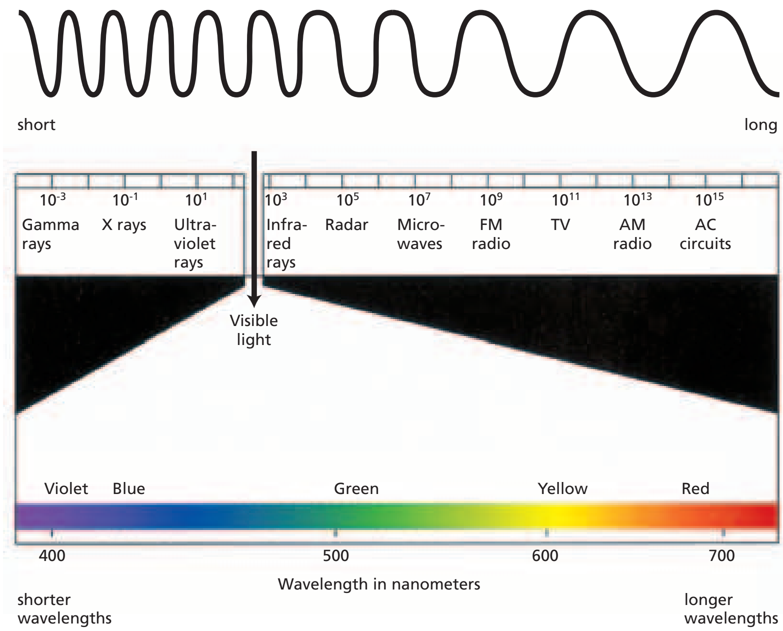


FIGURE 3.5

The Electromagnetic Spectrum

The only difference between visible light and other forms of electromagnetic energy is *wavelength.* The receptors in our eyes are sensitive to only a tiny portion of the electromagnetic spectrum.

Source: *Perception,* 3rd ed., by Sekuler & Blake. Copyright © 1994. Reprinted by permission of McGraw-Hill.

Within the narrow visible spectrum, light waves of different wavelengths give rise to our sensations of different colors. Longer waves make us see a tomato as red, and medium-length waves give rise to the sensations of yellow and green we see in lemons and limes. The shorter waves from a clear sky stimulate sensations of blue. Thus, the eye extracts information from the wavelength of light, and the brain uses that information to construct the sensations we see as colors (see Table 3.2).

Remarkably, our visual experiences of color, form, position, and depth are based on processing the stream of visual sensory information in different parts of the cortex. Colors themselves are realized in a specialized area, where humans are capable of discriminating among about five million different hues. It was damage in this part of the cortex that shut down Jonathan's ability to see colors. Other nearby cortical areas take responsibility for processing information about boundaries, shapes, and movements.

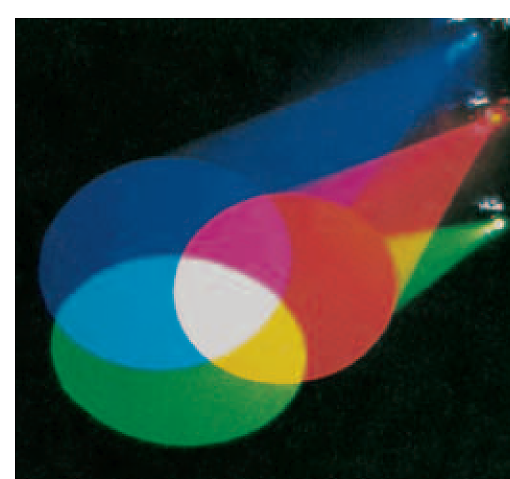
trichromatic theory The idea that colors are sensed by three different types of cones sensitive to light in the red, blue, and green wavelengths. The trichromatic (three-color) theory explains the earliest stage of color sensation. In honor of its originators, this is sometimes called the Young-Helmholtz theory.

opponent-process theory The idea that cells in the visual system process colors in complementary pairs, such as red or green or as yellow or blue. The opponent-process theory explains color sensation from the bipolar cells onward in the visual system.

afterimages Sensations that linger after the stimulus is removed. Most visual afterimages are *negative afterimages,* which appear in reversed colors.

Two Ways of Sensing Colors Even though color is realized in the cortex, color processing begins in the retina. There, three different types of cones sense different parts of the visible spectrum—light waves that we sense as red, green, and blue. This three-receptor explanation for color vision is known as the **trichromatic theory,** and for a time it was considered to account for color vision completely. We now know that the trichromatic theory best explains the initial stages of color vision in the cone cells.

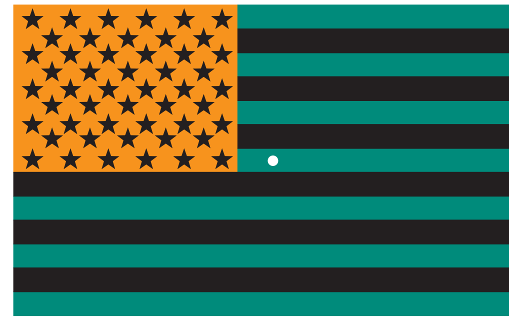
Another explanation, called the **opponent-process theory,** better explains negative **afterimages** (see the *Do It Yourself!* box), phenomena that involve *opponent,* or complementary, colors. According to the opponent-process theory, the visual system processes colors, from the bipolar cells onward, in complementary pairs: red-green or yellow-blue. Thus, the sensation of a certain color, such as red, inhibits, or interferes with, the sensation of its complement, green. Taken together, the two theories explain two different aspects of color vision involving the retina and visual pathways. While all that may sound complicated, here is the take-home message: *The trichromatic theory explains color processing in the cones of the retina, while the opponent-process theory explains what happens in the bipolar cells and beyond.*



The combination of any two primary colors of light yields the complement of a third color. The combination of all three wavelengths produces white light. (The mixture of pigments, as in print, works differently, because pigments are made to absorb some wavelengths of light falling on them.)

Color Blindness Not everyone sees colors in the same way, because some people are born with a deficiency in distinguishing colors. The incidence varies among

Do It Yourself! THE AMAZING AFTERIMAGE



After you stare at a colored object for a while, ganglion cells in your retina will become fatigued, causing an interesting visual effect. When you shift your gaze to a blank, white surface, you can "see" the object in complementary colors—as a visual afterimage. The "phantom flag" demonstration will show you how this works.

Stare at the dot in the center of the green, black, and orange flag for at least 30 seconds. Take care to hold your eyes steady and not to let them scan over the image during this time. Then quickly shift your gaze to the center of a sheet of white paper or to a light-colored blank wall. What do you see? Have your friends try this, too. Do they see the same afterimage? (The effect may not be the same for people who are color blind.)

Afterimages may be negative or positive. Positive afterimages are caused by a continuation of the receptor and neural processes following stimulation. They are brief. An example of positive afterimages occurs when you see the trail of a sparkler twirled by a Fourth of July reveler. Negative afterimages are the opposite or the reverse of the original experience, as in the flag example. They last longer. Negative afterimages operate according to the *opponent-process theory* of color vision, which involves ganglion cells in the retina and the optic nerve. Apparently, in a negative afterimage, the fatigue in these cells produces sensations of a complementary color when they are exposed to white light.

racial groups (highest in Whites and lowest in Blacks). Overall about 8 percent of males in the United States are affected. Women rarely have the condition.

color blindness Typically a genetic disorder (although sometimes the result of trauma, as in the case of Jonathan) that prevents an individual from discriminating certain colors. The most common form is red–green color blindness.

At the extreme, complete **color blindness** is the total inability to distinguish colors. More commonly, people merely have a color weakness that causes minor problems in distinguishing colors, especially under low-light conditions. People with one form of color weakness can't distinguish pale colors, such as pink or tan. Most color weakness or blindness, however, involves a problem in distinguishing red from green, especially at weak saturations. Those who confuse yellows and blues are rare, about one or two people per thousand. Rarest of all are those who see no color at all but see only variations in brightness. In fact, only about 500 cases of this total color blindness have ever been reported—including Jonathan I., whom we met at the beginning of this chapter. To find out whether you have a deficiency in color vision, look at Figure 3.6. If you see the number 29 in the dot pattern, your color vision is probably normal. If you see something else, you are probably at least partially color blind.

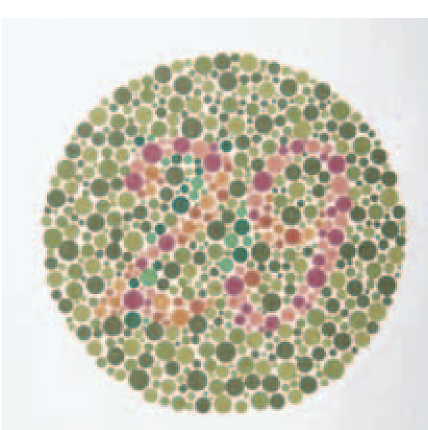


FIGURE 3.6
The Ishihara Color Blindness Test
Someone who cannot discriminate between red and green hues will not be able to identify the number hidden in the figure. What do you see? If you see the number 29 in the dot pattern, your color vision is probably normal.

Hearing: If a Tree Falls in the Forest . . .

Imagine how your world would change if your ability to hear were suddenly diminished. You would quickly realize that hearing, like vision, provides you with the ability to locate objects in space, such as the source of a voice calling your name. In fact, hearing may be even more important than vision in orienting us toward distant events. We often hear things, such as footsteps coming up behind us, before we see the source of the sounds. Hearing may also tell us of events that we cannot see, including speech, music, or an approaching car.

But there is more to hearing than its function. Accordingly, we will look a little deeper to learn *how* we hear. In the next few pages, we will review what sensory psychologists have discovered about how sound waves are produced, how they are sensed, and how these sensations of sound are interpreted.

The Physics of Sound: How Sound Waves Are Produced If Hollywood gave us an honest portrayal of exploding spaceships or planets, there would be absolutely no sound! In space, there is no air or other medium to carry sound waves, so if you were a witness to an exploding star, the experience would be eerily silent. On Earth, the energy of exploding objects, such as firecrackers, transfers to the surrounding medium—usually

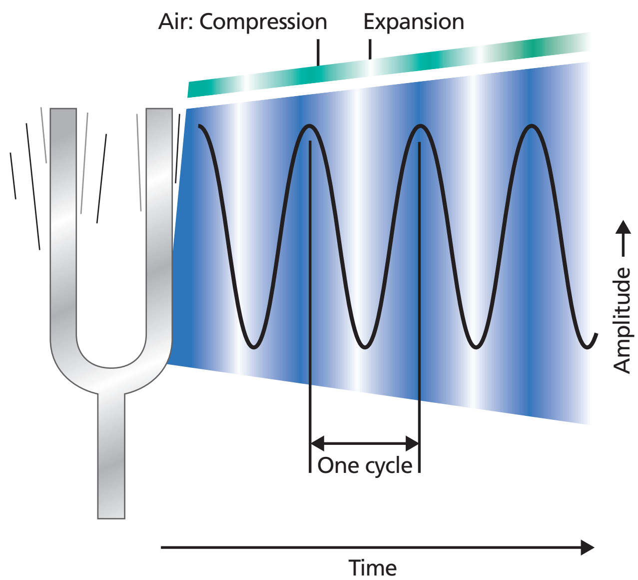


FIGURE 3.7

Sound Waves

Sound waves produced by the vibration of a tuning fork create waves of compressed and expanded air. The pitch that we hear depends on the *frequency* of the wave (the number of cycles per second). High pitches are the result of high-frequency waves. The *amplitude* or strength of a sound wave depends on how strongly the air is affected by the vibrations. In this diagram, amplitude is represented by the height of the graph.

air—in the form of sound waves. Essentially the same thing happens with rapidly vibrating objects, such as guitar strings, bells, and vocal cords, as the vibrations push the molecules of air back and forth. The resulting changes in pressure spread outward in the form of sound waves that can travel 1,100 feet per second.

The purest tones are made by a tuning fork (see Figure 3.7). When struck with a mallet, a tuning fork produces an extremely clean sound wave that has only two characteristics, *frequency* and *amplitude*. These are the two physical properties of any sound wave that determine how it will be sensed by the brain. **Frequency** refers to the number of vibrations or cycles the wave completes in a given amount of time, which in turn determines the highness or lowness of a sound (the *pitch*). Frequency is usually expressed in *cycles per second (cps)* or *hertz (Hz)*. **Amplitude** measures the physical strength of the sound wave (shown in graphs as the height of the wave); it is defined in units of sound pressure or energy. When you turn down the volume on your music system, you are decreasing the amplitude of the sound waves emerging from the speakers or ear buds.

frequency The number of cycles completed by a wave in a second.

amplitude The physical strength of a wave. This is shown on graphs as the height of the wave.

Sensing Sounds: How We Hear Sound Waves Much like vision, the psychological sensation of sound requires that waves be transduced into neural impulses and sent to the brain. This happens in four steps:

1. **Airborne sound waves are relayed to the inner ear.** In this initial transformation, vibrating waves of air enter the outer ear (also called the *pinna*) and move through the ear canal to the *eardrum,* or **tympanic membrane** (see Figure 3.8). This tightly stretched sheet of tissue transmits the vibrations to three tiny bones in the

tympanic membrane The eardrum.

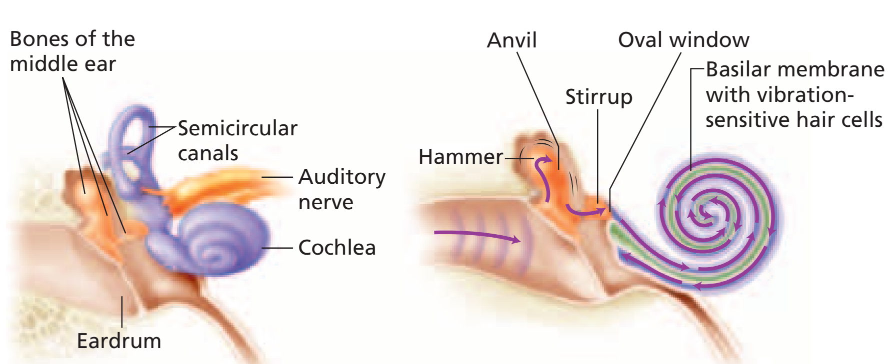


FIGURE 3.8

Structures of the Human Ear

Sound waves are channeled by the outer ear *(pinna)* through the external canal, causing the tympanic membrane to vibrate. The vibration activates the tiny bones in the middle ear (*hammer, anvil,* and *stirrup*). These mechanical vibrations pass from the oval window to the cochlea, where they set an internal fluid in motion. The fluid movement stimulates tiny hair cells along the basilar membrane, inside the cochlea, to transmit neural impulses from the ear to the brain along the auditory nerve.

cochlea The primary organ of hearing; a coiled tube in the inner ear, where sound waves are transduced into nerve messages.

basilar membrane A thin strip of tissue sensitive to vibrations in the cochlea. The basilar membrane contains hair cells connected to neurons. When a sound wave causes the hair cells to vibrate, the associated neurons become excited. As a result, the sound waves are converted (transduced) into nerve activity.

CONNECTION CHAPTER 2

The brain's primary auditory cortex lies in the *temporal lobes* (p. XXX).

pitch A sensory characteristic of sound produced by the *frequency* of the sound wave.

middle ear: the *hammer, anvil,* and *stirrup,* named for their shapes. These bones pass the vibrations on to the primary organ of hearing, the **cochlea,** located in the inner ear.

2. **The cochlea focuses the vibrations on the basilar membrane.** Here in the cochlea, the formerly airborne sound wave becomes "seaborne," because the coiled tube of the cochlea is filled with fluid. As the bony stirrup vibrates against the *oval window* at the base of the cochlea, the vibrations set the fluid into wave motion, much as a submarine sends a sonar "ping" through the water. As the fluid wave spreads through the cochlea, it causes vibration in the **basilar membrane,** a thin strip of hairy tissue running through the cochlea.
3. **The basilar membrane converts the vibrations into neural messages.** The swaying of tiny hair cells on the vibrating basilar membrane stimulates sensory nerve endings connected to the hair cells. The excited neurons, then, transform the mechanical vibrations of the basilar membrane into neural activity.
4. Finally, *the neural messages travel to the auditory cortex in the brain.* Neural signals leave the cochlea in a bundle of neurons called the *auditory nerve.* The neurons from the two ears meet in the brain stem, which passes the auditory information to both sides of the brain. Ultimately, the signals arrive in the *auditory cortex* for higher-order processing.

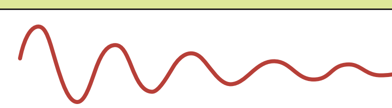
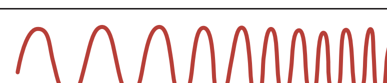
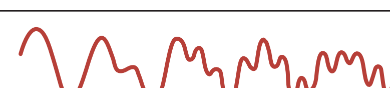
If the auditory system seems complicated, you might think of it as a sensory "relay team." Sound waves are first funneled in by the outer ear, then handed off from the eardrum to bones in the middle ear. These bones then hand off their mechanical vibrations to the cochlea and basilar membrane in the inner ear, where they finally become neural signals, which are, in turn, passed along to the brain. This series of steps transforms commonplace vibrations into experiences as exquisite and varied as music, doorbells, whispers, and shouts—and psychology lectures.

Psychological Qualities of Sound: How We Distinguish One Sound from Another No matter where they come from, sound waves—like light waves—have only two *physical* characteristics: *frequency* and *amplitude.* In the following discussion, we will show you how the brain converts these two characteristics into three *psychological sensations: pitch, loudness,* and *timbre.*

Sensations of Pitch A sound wave's *frequency* determines the highness or lowness of a sound—a quality known as **pitch.** High frequencies produce high-pitched sounds, and low frequencies produce low-pitched sounds, as you see in Table 3.3. As with light, our sensitivity to sound spans only a limited range of the sound waves that occur in nature. The range of human auditory sensitivity extends from frequencies as low as about 20 cps (the lowest range of a subwoofer in a good sound system) to frequencies as high as

TABLE 3.3 Auditory Stimulation Becomes Sensation

Pitch and loudness are the psychological counterparts of the frequency and amplitude (intensity) of a sound wave. Frequency and amplitude are characteristics of the physical sound wave, while sensations of pitch and loudness exist only in the brain. In addition, sound waves can be complex combinations of simpler waves. Psychologically, we experience this complexity as *timbre.* Compare this table with Table 3.2 for vision.

Physical stimulation	Waveform	Psychological sensation
Amplitude (intensity)	 Loud … Soft	Loudness
Frequency (wavelength)	 Low … High	Pitch
Complexity	 Pure … Complex	Timbre

20,000 cps (produced by the high-frequency tweeter in a high-quality audio system). Other creatures can hear sounds both higher (dogs, for example) and lower (elephants).

How does the auditory apparatus produce sensations of pitch? Two distinct auditory processes share the task, affording us much greater sensory precision than either could provide alone. Here's what happens:

- When sound waves pass through the inner ear, the basilar membrane vibrates (see Figure 3.8). Different frequencies activate different locations on the membrane. Thus, the pitch one hears depends, in part, on which region of the basilar membrane is receiving the greatest stimulation. This *place theory* explanation of pitch perception says that different *places* on the basilar membrane send neural codes for different pitches to the auditory cortex of the brain—much as keys in different places on a piano keyboard can produce different notes. It turns out that the place theory accounts for our ability to hear high tones—above about 1,000 Hz (cycles per second).
- Neurons on the basilar membrane respond with different firing rates to different sound wave *frequencies,* much as guitar strings vibrating at different frequencies produce different notes. And so, the rate of firing provides another code for pitch perception in the brain. This *frequency theory* explains how the basilar membrane deals with frequencies below about 5,000 Hz.
- Between 1,000 and 5,000 Hz, hearing relies on both place and frequency.

What is so special about the range of 1,000 to 5,000 Hz? This interval spans the upper frequency range of human speech, which is crucial for discriminating the high-pitched sounds that distinguish consonants, such as p, s, and t. These are the subtle sounds that allow us to distinguish among many common words, such as *pie*, *sigh*, and *tie*. Coincidentally, the auditory canal is specially shaped to amplify sounds within this speech range.

Sensations of Loudness Much as the intensity of light determines brightness, the physical strength or *amplitude* of a sound wave determines **loudness,** as shown in Table 3.3. More intense sound waves (a shout) produce louder sounds, while we experience sound waves with small amplitudes (a whisper) as soft. *Amplitude,* then, refers to the *physical* characteristics of a sound wave, while *loudness* is a *psychological sensation*.

Because we can hear sound waves across a great range of intensity, the loudness of a sound is usually expressed as a ratio rather than an absolute amount. More specifically, sound intensity is expressed in units called decibels (dB). Figure 3.9 shows the levels of some representative natural sounds in decibel units.

Sensations of Timbre The bark of a dog, a toot of a train whistle, the wail of an oboe, the clink of a spoon in a cup—all sound distinctively different, not just because they have different pitches or loudness but because they are peculiar mixtures of tones. In fact, most natural sound waves are mixtures rather than pure tones, as shown in Figure 3.10. This complex quality of a sound wave is known as **timbre** (pronounced *TAM—b'r*). Timbre is the property that enables you to recognize a friend's voice on the phone or distinguish between the same song sung by different artists.

Hearing Loss Aging commonly involves loss of hearing acuity, especially for high-frequency sounds so crucial for understanding speech. If you think about the tiny difference between the sounds *b* and *p,* you can see why speech perception depends so heavily on high frequency sounds. But hearing loss is not always the result of aging. It can come from diseases, such as mumps, that may attack the auditory nerves. And it can result from exposure to loud noises (see Figure 3.9), such as gunshots, jet engines, or loud music, that damage the hair cells in the cochlea.

How Are Auditory and Visual Sensations Alike? Earlier, we discussed how visual information is carried to the brain by the optic nerve in the form of neural impulses. Now we find that, in a similar fashion, auditory information is also conveyed to the

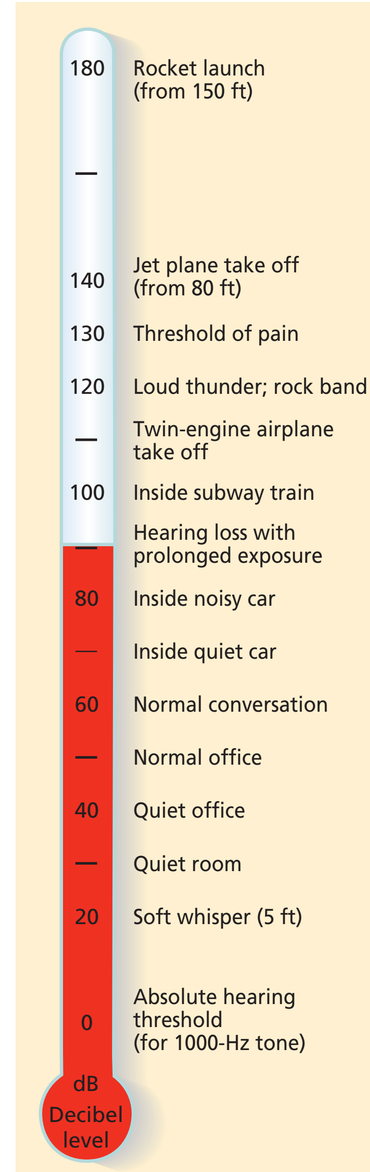


FIGURE 3.9
Intensities of Familiar Sounds

loudness A sensory characteristic of sound produced by the *amplitude* (intensity) of the sound wave.

timbre The quality of a sound wave that derives from the wave's complexity (combination of pure tones). *Timbre* comes from the Greek word for "drum," as does the term *tympanic membrane,* or eardrum.

Watch Cochlear Implants on **mypsychlab.com**

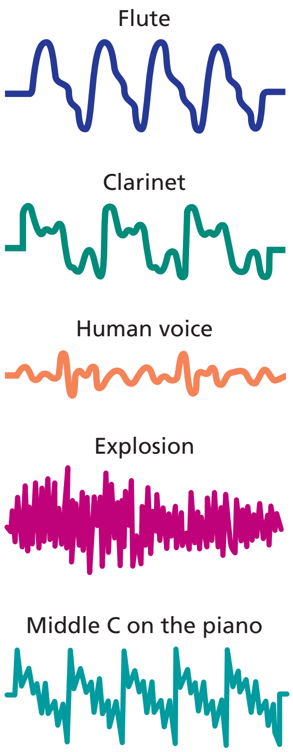


FIGURE 3.10
Waveforms of Familiar Sounds

Each sound is a distinctive combination of several pure tones.

Source: The Science of Musical Sounds, by D. C. Miller. Reprinted by permission of Case Western Reserve University.

brain as neural signals—but by a different pathway and to a different location in the brain. Please note the similarity in the ways vision and hearing make use of frequency and amplitude information found in light and sound waves.

But why do we "see" visual information and "hear" auditory information? As our Core Concept suggested, the answer lies in the region of the cortex receiving the neural message—not on some unique quality of the message itself. In brief, different regions of the brain, when activated, produce different sensations.

How the Other Senses Are Like Vision and Hearing

Of all our senses, vision and hearing have been studied the most. However, our survival and well-being depend on other senses, too. So, to conclude this discussion of sensation, we will briefly review the processes involved in our sense of body position and movement, smell, taste, the skin senses, and pain (see Table 3.4). You will note that each gives us information about a different aspect of our internal or external environment. Yet each operates on similar principles. Each transduces physical stimuli into neural activity, and each is more sensitive to change than to constant stimulation. And, as was the case with vision and hearing, each of these senses is distinguished by the type of information it extracts and by the specialized regions of the brain devoted to it. Finally, the senses often act in concert, as when we see a lightning strike and hear the ensuing clap of thunder or when the sensation we call "taste" really encompasses a combination of flavor, odor, sight, and texture of food. Other common sensory combinations occur in sizzling steaks, fizzing colas, and bowls of Rice Krispies®.

Position and Movement To act purposefully and gracefully, we need constant information about the position of our limbs and other body parts in relation to each other and to objects in the environment. Without this information, even our simplest actions

TABLE 3.4 Fundamental Features of the Human Senses

Sense	Stimulus	Sense Organ	Receptor	Sensation
Vision	Light waves	Eye	Rods and cones of retina	Colors, brightness, patterns, motion, textures
Hearing	Sound waves	Ear	Hair cells of the basilar membrane	Pitch, loudness, timbre
Skin senses	External contact	Skin	Nerve endings in skin	Touch, warmth, cold
Smell	Volatile substances	Nose	Hair cells of olfactory epithelium	Odors
Taste	Soluble substances	Tongue	Taste buds of tongue	Flavors
Pain	Many intense or extreme stimuli: temperature, chemicals, mechanical stimuli, etc.	Net of pain fibers all over the body	Specialized pain receptors, overactive or abnormal neurons	Acute pain, chronic pain
Kinesthetic and vestibular senses	Body position, movement, and balance	Semicircular canals, skeletal muscles, joints, tendons	Hair cells in semicircular canals; neurons connected to skeletal muscles, joints, and tendons	Position of body parts in space

would be hopelessly uncoordinated. (You have probably had just this experience when you tried to walk on a leg that had "gone to sleep.") The physical mechanisms that keep track of body position, movement, and balance actually consist of two different systems, the *vestibular sense* and the *kinesthetic sense*.

The **vestibular sense** is the body position sense that orients us with respect to gravity. It tells us the posture of our bodies—whether straight, leaning, reclining, or upside down. The vestibular sense also tells us when we are moving or how our motion is changing. The receptors for this information are tiny hairs (much like those we found in the basilar membrane) in the *semicircular canals* of the inner ear (refer to Figure 3.8). These hairs respond to our movements by detecting corresponding movements in the fluid of the semicircular canals. Disorders of this sense can cause extreme dizziness and disorientation.

vestibular sense The sense of body orientation with respect to gravity. The vestibular sense is closely associated with the inner ear and, in fact, is carried to the brain on a branch of the auditory nerve.

The **kinesthetic sense,** the other sense of body position and movement, keeps track of body parts relative to each other. Your kinesthetic sense makes you aware of crossing your legs, for example, and tells you which hand is closer to your cell phone when it rings. Kinesthesis provides constant sensory feedback about what the muscles in your body are doing during motor activities, such as whether to continue reaching for your cup of coffee or to stop before you knock it over (Turvey, 1996).

kinesthetic sense The sense of body position and movement of body parts relative to each other (also called *kinesthesis*)

Receptors for kinesthesis reside in the joints, muscles, and tendons. These receptors, as well as those for the vestibular sense, connect to processing regions in the brain's parietal lobes—which help us make a sensory "map" of the spatial relationship among objects and events. This processing usually happens automatically and effortlessly, outside of conscious awareness, except when we are deliberately learning the movements for a new physical skill, such as swinging a golf club or playing a musical instrument.

Gymnasts and dancers rely on their vestibular and kinesthetic senses to give them information about the position and movement of their bodies.

Smell

Smell serves a protective function by sensing the odor of possibly dangerous food or, for some animals, the scent of a predator. We humans seem to use the sense of smell primarily in conjunction with taste to locate and identify calorie-dense foods, avoid tainted foods, and, it seems, to identify potential mates—a fact capitalized on by the perfume and cologne industry (Benson, 2002; Martins et al., 2005; Miller & Maner, 2010).

Many animals take the sense of smell a step farther by exploiting it for communication. For example, insects such as ants and termites and vertebrates such as dogs and cats communicate with each other by secreting and detecting odorous signals called **pheromones**—especially to signal not only sexual receptivity but also danger, territorial boundaries, food sources, and family members. It appears that the human use of the sense of smell is much more limited.

pheromones Chemical signals released by organisms to communicate with other members of their species. Pheromones are often used by animals as sexual attractants. It is unclear whether or not humans employ pheromones.

The Biology of Olfaction Biologically, the sense of smell, or **olfaction,** begins with chemical events in the nose. There, odors (in the form of airborne chemical molecules) interact with receptor proteins associated with specialized nerve cells (Axel, 1995; Turin, 2006). These cells, incidentally, are the body's only nerve cells that come in direct contact with the outside environment.

olfaction The sense of smell.

Odor molecules can be complex and varied. For example, freshly brewed coffee owes its aroma to as many as 600 volatile compounds (Wilson & Stevenson, 2006). More broadly, scientists have cataloged at least 1,500 different odor-producing molecules (Zimmer, 2010). Exactly how the nose makes sense of this cacophony of odors is not completely understood, but we do know that nasal receptors sense the shape of odor molecules (Foley & Matlin, 2010).

We also know that the nose's receptor cells transduce information about the stimulus and convey it to the brain's *olfactory bulbs,* located on the underside of the brain just below the frontal lobes (see Figure 3.11). There, our sensations of smell are initially processed and then passed on to many other parts of the brain (Mori et al., 1999). Unlike all the other senses, smell signals are *not* relayed through the thalamus, suggesting that smell has very ancient evolutionary roots.

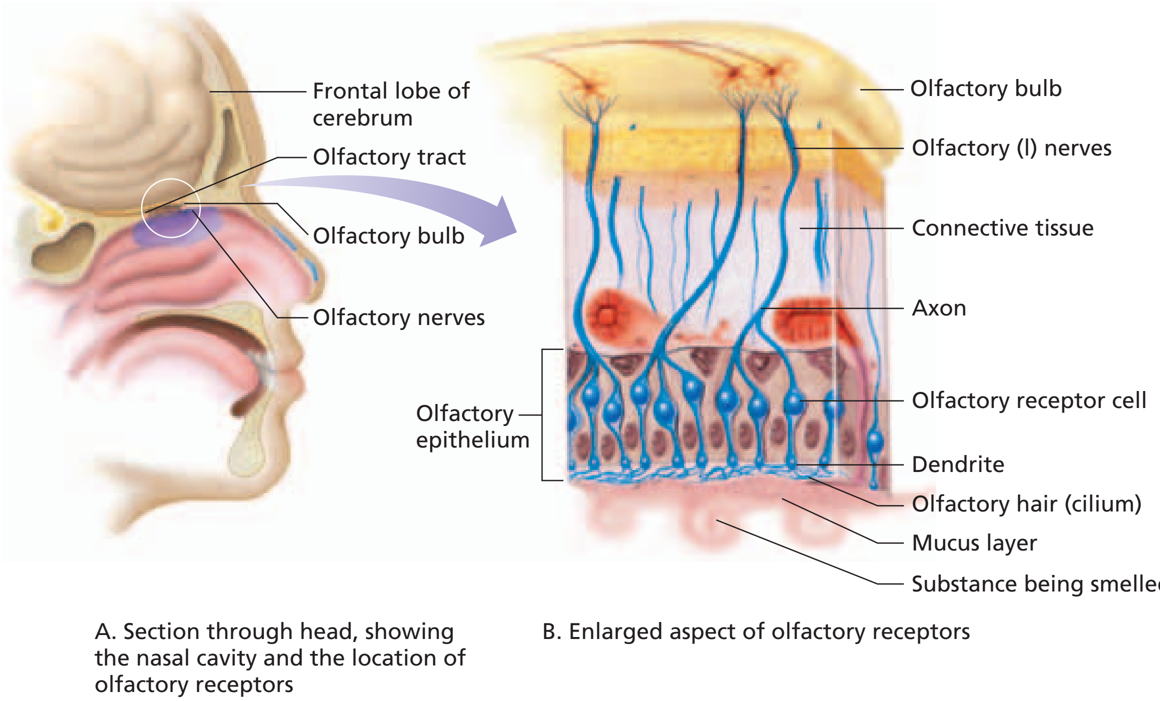


FIGURE 3.11

Receptors for Smell

Source: P. G. Zimbardo and R. J. Gerrig. Copyright, *Psychology and Life,* 15th ed. Published by Allyn and Bacon, Boston, MA © 1999 by Pearson Education. Reprinted by permission of the publisher.

The Psychology of Smell Olfaction has an intimate connection with both emotion and memory. This may explain why the olfactory bulbs lie very close to, and communicate directly with, structures in the limbic system and temporal lobes that are associated with emotion and memory. Therefore, it is not surprising that both psychologists and writers have noticed that certain smells can evoke emotion-laden memories, sometimes of otherwise-forgotten events (Dingfelder, 2004a). If you think about it for a moment, you can probably recall a vivid memory "image" of the aroma associated with a favorite food—perhaps fresh bread or a spicy dish—from your childhood.

Taste Like smell, taste is a sense based on chemistry. But the similarity doesn't end there: The senses of taste and smell have a close and cooperative working relationship—so many of the subtle distinctions you may think of as flavors really come from odors. (Much of the "taste" of an onion is odor, not flavor. And when you have a cold, you'll notice that food seems tasteless because your nasal passages are blocked.)

gustation The sense of taste, from the same word root as "gusto;" also called the *gustatory sense.*

Most people know that our sense of taste, or **gustation,** involves four primary qualities or dimensions: sweet, sour, bitter, and salty. Less well known, however, is a fifth taste called *umami* (Chaudhari et al., 2000). Umami is the savory flavor found in protein-rich foods, such as meat, seafood, and cheese. It is also associated with monosodium glutamate (MSG), often used in Asian cuisine.

The taste receptor cells, located in the *taste buds* on the top and side of the tongue, sample flavors from food and drink as they pass by on the way to the stomach. These taste receptors cluster in small mucous-membrane projections called *papillae,* shown in Figure 3.12. Each is especially sensitive to molecules of a particular shape.

Moving beyond the receptors on the tongue, a specialized nerve "hotline" carries nothing but taste messages to specialized regions of the cortex. There, tastes are realized in the parietal lobe's somatosensory area. Conveniently, this region lies next to the patch of cortex that receives touch stimulation from the face (Gadsby, 2000).

Developmental Changes in Taste Infants have heightened taste sensitivity, which is why babies universally cringe at the bitter taste of lemon. This supersensitivity, however, decreases with age. As a result, many elderly people complain that food has lost its

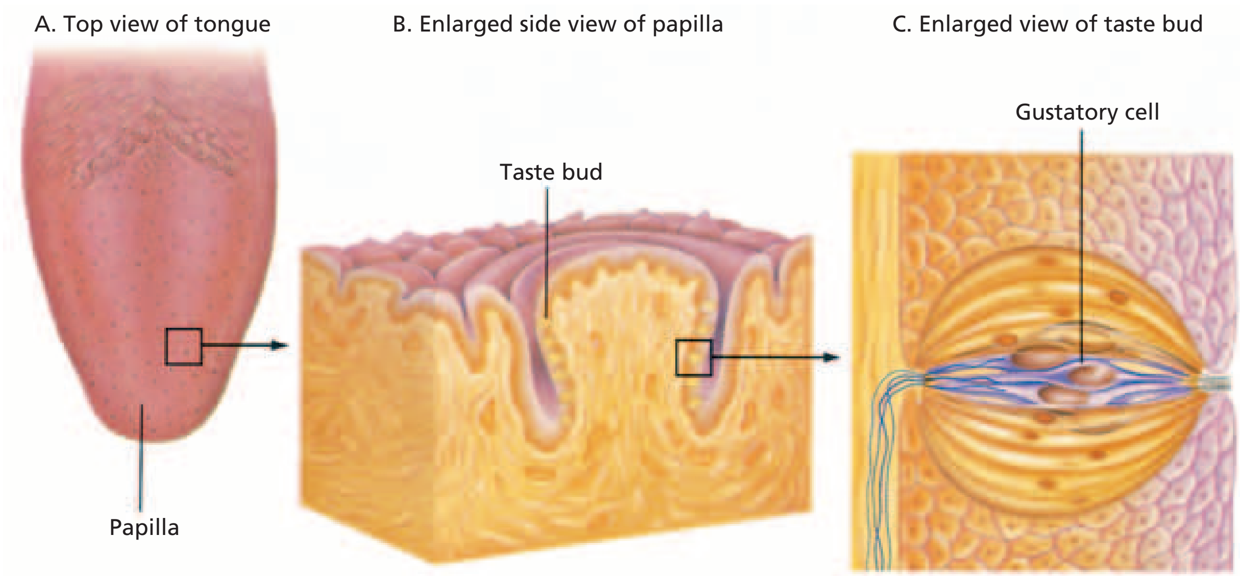


FIGURE 3.12

Receptors for Taste

(A) Taste buds are clustered in papillae on the upper side of the tongue; **(B)** an enlarged view with individual papillae and taste buds visible; **(C)** one of the taste buds enlarged.

taste—which really means that they have lost much of their sensory ability to detect differences in the taste and smell of food. Compounding this effect, taste receptors can be easily damaged by alcohol, smoke, acids, or hot foods. Fortunately, we frequently replace our gustatory receptors—as we do our smell receptors. Because of this constant renewal, the taste system boasts the most resistance to permanent damage of all our senses, and a total loss of taste is extremely rare (Bartoshuk, 1990).

Supertasters Individuals of any age vary in their sensitivity to taste sensations, a function of the density of papillae on the tongue (Bartoshuk, 2000, 2009; Bartoshuk et al., 1994). Those with the most taste buds are *supertasters* who live in a "neon" taste world relative to the rest of us—which accounts for their distaste for certain foods, such as broccoli or "diet" drinks, in which they detect a disturbingly bitter flavor (Duenwald, 2005). Is there any advantage to being a supertaster? Taste expert Linda Bartoshuk (1993) speculates that, because most poisons are bitter, supertasters have a survival advantage.

Such differences also speak to the problem with which we began the chapter—in particular, the question of whether different people sense the world in the same way. Bartoshuk's research suggests that, to the extent that the sense receptors exhibit some variation from one person to another, so does our sensory experience of the world. This variability is not so bizarre as to make one person's sensation of sweet the same as another person's sensation of sour. Rather, the variations observed involve simply the *intensity* of taste sensations, such as the bitter detected by supertasters. One big unknown, according to Bartoshuk, is whether people differ in their sensitivities to different taste sensations: for example, whether a person could be a supertaster for bitter while having only normal sensations for sweet or salt (personal communication, January 4, 2011).

On the other hand, taste researchers have detected differences in taste *preferences* between supertasters and those with normal taste sensations. In particular, supertasters more often report disliking foods that they find too sweet or too fatty. Although the significance of this remains to be determined, researchers have observed that supertasters, on the average, weigh less than their nonsupertasting counterparts (Bartoshuk, 2000).

The Skin Senses Consider the skin's remarkable versatility: It protects us against surface injury, holds in body fluids, and helps regulate body temperature. The skin also contains nerve endings that, when stimulated, produce sensations of touch, pain,

skin senses Sensory systems for processing touch, warmth, cold, texture, and pain.

warmth, and cold. Like several other senses, these **skin senses** are connected to the somatosensory cortex located in the brain's parietal lobes.

The skin's sensitivity to stimulation varies tremendously over the body, depending in part on the number of receptors in each area. For example, we are ten times more accurate in sensing stimulation on our fingertips than stimulation on our backs. In general, our sensitivity is greatest where we need it most—on our face, tongue, and hands. Precise sensory feedback from these parts of the body permits effective eating, speaking, and grasping.

One important aspect of skin sensitivity—touch—plays a central role in human relationships. Through touch, we communicate our desire to give or receive comfort, support, and love (Fisher, 1992; Harlow, 1965). Touch also serves as a primary stimulus for sexual arousal in humans. And it is essential for healthy mental and physical development; the lack of touch stimulation can stunt mental and motor development (Anand & Scalzo, 2000).

Synesthesia: Sensations across the Senses

synesthesia The mixing of sensations across sensory modalities, as in tasting shapes or seeing colors associated with numbers.

A small minority of otherwise "normal" people have a condition called **synesthesia,** which allows them to sense their worlds across sensory domains. Some actually taste shapes—so that pears may taste "round" and grapefruit "pointy" (Cytowic, 1993). Other synesthetes associate days of the week with colors—so that Wednesday may be "green" and Thursday may be "red." Their defining characteristic involves sensory experience that links one sense with another.

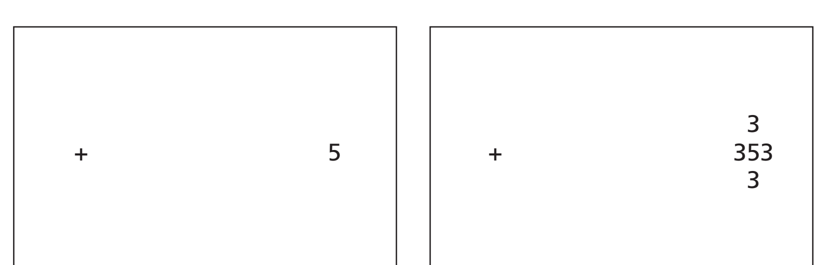
Through clever experiments, V. S. Ramachandran and his colleagues have shown that the cross-sensory sensations reported in synesthesia are real, not just metaphors (Ramachandran & Hubbard, 2001). You can take one of their tests in the accompanying *Do It Yourself!* box. Research also shows that this ability runs in families, so it probably has a genetic component.

What causes synesthesia? Apparently it can involve communication between different brain areas that process different sensations—often regions that lie close to each other in the cortex. Brain imaging studies implicate a cortical area called the *TPO,* lying at the junction of the *t*emporal, *p*arietal, and *o*ccipital lobes (Ramachandran & Hubbard, 2003). This region simultaneously processes information coming from many pathways. We all have some neural connections among these areas, theorizes Ramachandran, but synesthetes seem to have more than most.

The condition occurs slightly more often in highly creative people, Ramachandran notes. And it may account for the "auras" purportedly seen around people by some mystics (Holden, 2004). But perhaps we all have some cross-sensory abilities in us, which may be why we resonate with Shakespeare's famous metaphor in *Romeo and Juliet,* "It is the east, and Juliet is the sun." We know that he was not speaking literally, of course. Rather we understand that, for Romeo—and so for us—Juliet is linked, across our senses, with light, warmth, and sensory pleasure (Ramachandran & Hirstein, 1999).

Do It Yourself! A SYNESTHESIA TEST

Most people will not have any trouble seeing the 5 while staring at the cross (left), although the 5 becomes indistinct when surrounded by other numbers (right). If you are a synesthete who associates colors with numbers, however, you may be able to identify the 5 in the figure on the right because it appears as a blotch of the color associated with that number. (Adapted from Ramachandran & Hubbard, 2003.)



[PSYCHOLOGY MATTERS]

The Sense and Experience of Pain

If you have severe pain, nothing else matters. A wound or a toothache can dominate all other sensations. And if you are among the one-third of Americans who suffer from persistent or recurring pain, the experience can be debilitating and can sometimes even lead to suicide. Yet, pain is also part of your body's adaptive mechanism that makes you respond to conditions that threaten damage to your body.

Unlike other sensations, pain can arise from intense stimulation of various kinds, such as a very loud sound, heavy pressure, a pinprick, or an extremely bright light. But pain is not merely the result of stimulation. It is also affected by our moods and expectations, as you know if you were ever anxious about going to the dentist (Koyama et al., 2005).

Pain Receptors

In the skin, several types of specialized nerve cells, called *nociceptors,* sense painful stimuli and send their unpleasant messages to the central nervous system. Some nociceptors are most sensitive to heat, while others respond mainly to pressure, chemical trauma, or other tissue injury (Foley & Matlin, 2010). There are even specialized nociceptors for the sensation of itching—itself a type of pain (Gieler & Walter, 2008).

A Pain in the Brain

Even though they may seem emanate from far-flung parts of the body, we actually feel painful sensations in the brain. There two distinct regions have primary roles in processing incoming pain messages (Foley & Matlin, 2010; Porreca & Price, 2009). One, involving a pathway terminating in the parietal lobe, registers the location, intensity, and the sharpness or dullness of pain. The other, a group of structures deep in the frontal cortex and in the limbic system, registers just how unpleasant the painful sensation is. People with damage to this second region may notice a painful stimulus but report that it does not feel unpleasant.

Phantom Limbs

One intriguing puzzle about pain concerns the mysterious sensations often experienced by people who have lost an arm or leg—a condition known as a *phantom limb.* In such cases, the amputee feels sensations—sometimes quite painful ones—that seem to come from the missing body part (Ramachandran & Blakeslee, 1998). Neurological studies show that the phantom limb sensations do not originate in damaged nerves in the sensory pathways. Nor are they purely imaginary. Rather, they arise in the brain itself—perhaps the result of the brain generating sensation when none comes from the missing limb (Dingfelder, 2007). The odd phenomenon of phantom limbs teaches us that understanding pain requires understanding not only painful sensations but also mechanisms in the brain that both process and inhibit pain.

The Gate-Control Theory

No one has yet developed a theory that explains everything about pain, but Melzack and Wall's(1965, 1983) **gate-control theory** explains a lot. In particular, it explains why pain can sometimes be blocked or facilitated "top-down" by our mental state. The "gate" itself involves special interneurons that, when inhibited, "open" the pain pathway running up the spinal cord toward the brain. Closing the gate interferes with the transmission of pain messages in the spinal pathway.

gate-control theory An explanation for pain control that proposes we have a neural "gate" that can, under some circumstances, block incoming pain signals.

What can close the gate? Messages from nonpain nerve fibers, such as those involved in touch, can inhibit pain transmission. This explains why you vigorously shake your hand when you hit your finger with a hammer. Just as important, messages from the brain can also close the gate. This is how opiate drugs, such as morphine, work—by initiating a cascade of inhibitory messages that travel downward to block incoming pain messages.

The gate on the pain pathway can also be opened and closed by top-down psychological processes, such as hypnosis or the distraction of important events. (See Fields, 2009.) We have long known that people's interpretations of events affect whether or not stimuli are perceived as painful (Turk, 1994). For example, soldiers and athletes may suffer severe injuries that cause little pain until the excitement of the battle or contest is over. And as we will see in a moment, this mind–body effect on pain is evident in the action of *placebos* or other sham treatments.

Dealing with Pain

Wouldn't it be nice to banish the experience of pain altogether? In reality, such a condition can be deadly. People with congenital insensitivity to pain do not feel what is hurting them, and their bodies often become scarred and their limbs deformed from injuries they could have avoided if their brains were able to warn them of danger. Because of their failure to notice and respond to tissue-damaging stimuli, these people tend to die young (Manfredi et al., 1981).

In general, pain serves as an essential defense signal: It warns us of potential harm, and it helps us to survive in hostile environments and to get treatment for sickness and injury. Sometimes, however, chronic pain seems to be a disease in itself, with neurons in the pain pathways becoming hypersensitive, amplifying normal sensory stimulation into pain messages (Watkins & Maier, 2003). Research also suggests that chronic pain may, at least sometimes, arise from genes that get "turned on" in nerve-damaged tissue (Marx, 2004).

Analgesics

What can you do if you are in pain? Analgesic drugs, ranging from over-the-counter remedies such as aspirin and ibuprofen to prescription narcotics such as morphine, are widely used and effective. These act in a variety of ways. Morphine, as we have seen, suppresses pain messages in the spinal cord and the brain; aspirin interferes with a chemical signal produced by damaged tissue (Basbaum & Julius, 2006; Carlson, 2007). Those using pain-killing drugs should be aware of unwanted side effects, such as digestive tract or liver damage and even addiction. But studies have shown that if you must use narcotics to control severe pain, the possibility of your becoming addicted is far less than it would be if you were using narcotics recreationally (Melzack, 1990).

Psychological Techniques for Pain Control

Many people can also learn to control pain by psychological techniques, such as hypnosis, relaxation, and thought-distraction procedures (Brown, 1998). For instance, a child receiving a shot at the doctor's office might be asked to take a series of deep breaths and look away. You also may be among those for whom pain can also be modified by **placebos**, mock drugs made to appear as real drugs. For example, a placebo may be an injection of mild saline solution (salt water) or a pill made of sugar. Such fake drugs are routinely given to a control group in tests of new pain drugs. Their effectiveness, of course, involves the people's *belief* that they are getting real medicine (Niemi, 2009; Wager, 2005; Wager et al., 2004). It is important to note, however, that the brain's response to a placebo is much the same as that of pain-relieving drugs: closing the spinal gate. Because this **placebo effect** is common, any drug deemed effective must prove itself stronger than a placebo.

placebo Substance that appears to be a drug but is not. Placebos are often referred to as "sugar pills" because they might contain only sugar rather than a real drug.

placebo effect A response to a placebo (a fake drug) caused by the belief that it is a real drug.

How do placebos produce their effects? Apparently, the expectation of pain relief is enough to cause the brain to release painkilling endorphins. We believe this is so because brain scans show that essentially the same pain-suppression areas "light up" when patients take placebos or analgesic drugs (Petrovic et al., 2002). Further, we find that individuals who respond to placebos report that their pain increases when they take the endorphin-blocking drug *naltrexone* (Fields, 1978; Fields & Levine, 1984).

Surprisingly, the placebo effect doesn't necessarily require a placebo! In a controlled experiment, Dr. Fabrizio Benedetti and his colleagues (2005) showed that the physician's bedside manner, even without a painkilling drug, can suppress pain. For psychologists, this is an important discovery, demonstrating that the psychosocial context itself can have a therapeutic effect (Guterman, 2005).

Controlling *Psychological* Pain with Analgesics

In another surprising development, psychologist C. Nathan DeWall and his colleagues (2010) have found that acetaminophen (the pain reliever in Tylenol) can lessen the psychological pain of social rejection. Volunteers who took acetaminophen, as compared with those taking placebos, reported far fewer feelings of social rejection in everyday life. And in a follow-up experimental study involving a computer game rigged to make players feel social rejection, fMRI scans showed that acetaminophen reduced activity in brain areas associated with social rejection and also with physical pain. What makes this research interesting is the suggestion that both physical and psychological hurts involve some of the same pain mechanisms in the brain.

Pain Tolerance

The threshold of pain varies enormously from person to person. Some people always demand Novocain from their dentist, while others may prefer dental work without the added hassle of an injection. And in the laboratory, one study found that electric shocks had to be eight times more powerful to produce painful sensations in their least-sensitive subjects as compared with their most-sensitive subjects (Rollman & Harris, 1987). Another experiment found that brain scans of people who are highly sensitive to pain show greater activation of the thalamus and the anterior cingulate cortex than in scans of those with greater pain tolerance (Coghill et al., 2003). At least part of this variation has a genetic basis (Couzin, 2006).

We should be clear on this point: There is no evidence of genetic differences in sensitivity to pain among different ethnic or racial groups, although many reports suggest that *culture* does affect how people interpret pain and respond to painful stimulation. For example, Western women often report that childbirth is an excruciatingly painful experience, while women in some cultures routinely give birth with little indication of distress. Severely wounded soldiers, too, typically need less pain medication than do civilians with comparable injuries—perhaps because of the "culture of bravery" instilled in soldiers or because a soldier knows that a wound represents a ticket out of the combat zone.

Readers should be cautioned, however, that much of the literature on cultural differences in response to pain relies far more on anecdotes than on controlled studies. Further, the scientific work that does exist in this area has frequently come to conflicting conclusions (Foster, 2006). Perhaps one of the most important influences to emerge from this work involves poverty and access to health care: Poor people are much less likely to seek medical attention until pain becomes severe.

Check Your Understanding

Study and Review on **mypsychlab.com**

1. **RECALL:** Name the two types of photoreceptors and indicate what sort of stimulation they detect.
2. **RECALL:** The *wavelength* of light causes sensations of ________, while the *intensity* of light causes sensations of ________.
   - **a.** motion/shape
   - **b.** color/brightness
   - **c.** primary colors/secondary colors
   - **d.** depth/color
3. **RECALL:** The *frequency theory* best explains how we hear ________ sounds, while the *place theory* best explains how we hear ________ sounds.
4. **SYNTHESIS:** What do all of the following senses have in common: vision, hearing, taste, smell, hearing, pain, equilibrium, and body position?
5. **RECALL:** Studies of painful phantom limbs show that the phantom pain originates in ________
   - **a.** the brain.
   - **b.** nerve cells damaged from the amputation.
   - **c.** the imagination.
   - **d.** ascending pathways in the spinal cord.
6. **UNDERSTANDING THE CORE CONCEPT:** Explain why different senses give us different sensations.

Answers 1. The rods are better than the cones for detecting objects in dim light. The cones give us high-resolution color vision in relatively bright light. **2.** b (color/brightness) **3.** low-pitched/high-pitched **4.** Each of these senses transduces physical stimulation into neural activity, and each responds more to change than to constant stimulation. **5.** a (the brain) **6.** The different sensations occur because the sensory information is processed by different parts of the brain.

FIGURE 3.13
Who is this?
Perceptual processes help us recognize people and objects by matching the stimulus to images in memory.

percept The meaningful product of perception—often an image that has been associated with concepts, memories of events, emotions, and motives.

3.3 KEY QUESTION
What Is the Relationship between Sensation and Perception?

We have described how sensory signals are transduced and transmitted to specific regions of your brain for further processing as visual images, pain, odors, and other sensations. Then what? You enlist your brain's perceptual machinery to attach *meaning* to the incoming sensory information. Does a bitter taste mean poison? Does a red flag mean danger? Does a smile signify a friendly overture? The Core Concept of this section emphasizes this perceptual elaboration of sensory information:

Core Concept 3.3

Perception brings *meaning* to sensation, so perception produces an interpretation of the world, not a perfect representation of it.

In brief, we might say that the task of perception is to organize sensation into stable, meaningful *percepts*. A **percept,** then, is not just a sensation but the associated meaning as well. As we describe this complex perceptual process, we will first consider how our perceptual apparatus usually manages to give us a reasonably accurate and useful image of the world. Then we will look at some illusions and other instances in which perception apparently fails spectacularly. Finally, we will examine two theories that attempt to capture the most fundamental principles at work behind these perceptual successes and failures.

Perceptual Processing: Finding Meaning in Sensation

How does the sensory image of a person (such as the individual pictured in Figure 3.13) become the percept of someone you recognize? That is, how does mere sensation become an elaborate and meaningful perception? Let's begin with two visual pathways that help us identify objects and locate them in space: the *what* pathway and the *where* pathway.

what pathway A neural pathway, projecting from the primary visual cortex to the temporal lobe, which involves identifying objects.

where pathway A neural pathway that projects visual information to the parietal lobe; responsible for locating objects in space.

blindsight The ability to locate objects despite damage to the visual system making it impossible for a person consciously to see and identify objects. Blindsight is thought to involve unconscious visual processing in the where pathway.

The What and Where Pathways in the Brain The primary visual cortex, at the back of the brain, splits visual information into two interconnected streams (Fariva, 2009; Goodale & Milner, 1992). One stream, which flows mainly to the temporal lobe, extracts information about an object's color and shape. This **what pathway** allows us to determine *what* objects are. The other stream, the **where pathway,** projects to the parietal lobe, which determines an object's location. Evidence suggests that other senses, such as touch and hearing, also have *what* and *where* streams that interact with those in the visual system (Rauschecker & Tian, 2000).

Curiously, we are conscious of information in the *what* pathway but not necessarily in the *where* pathway. This fact explains a curious phenomenon known as **blindsight,** a condition that occurs in some people with damage to the *what* pathway—damage that makes them visually unaware of objects around them. Yet if the *where* pathway is intact, blindsight patients may be able to step over objects in their path or reach out and touch objects that they claim not to see (Ramachandran & Rogers-Ramachandran, 2008). In this way, persons with blindsight are much like a sophisticated robot that can sense and react to objects around it even though it lacks the ability to represent them in consciousness.

feature detectors Cells in the cortex that specialize in extracting certain features of a stimulus.

Feature Detectors The deeper information travels into the brain along the *what* and *where* pathways, the more specialized processing becomes. Ultimately, specialized groups of cells in the visual pathways extract very specific stimulus features, such as an object's length, slant, color, boundary, location, and movement (Kandel & Squire, 2000). Perceptual psychologists call these cells **feature detectors.**

We know about feature detectors from animal experiments and also from cases like Jonathan's, in which brain injury or disease selectively robs an individual of the ability to detect certain features, such as colors or shapes. There is even a part of the temporal lobe—near the occipital cortex—with feature detectors that are especially sensitive to features of the human face (Carpenter, 1999).

Despite our extensive knowledge of feature detectors, we still don't know exactly how the brain manages to combine (or "bind") the multiple features it detects into a single percept of, say, a face. Psychologists call this puzzle the **binding problem**, and it may be the deepest mystery of perceptual psychology (Kandel & Squire, 2000).

We do have one tantalizing piece of this perceptual puzzle: Neuroscientists have discovered that the brain synchronizes the firing patterns in different groups of neurons that have each detected different features of the same object—much as an orchestra conductor determines the tempo at which all members of the ensemble will play a musical piece (Buzsáki, 2006). But just how this synchronization is involved in "binding" these features together remains a mystery.

Many viewers report that the flowers in Claude Monet's floral paintings, such as *Coquelicots*, produce a shimmering or moving sensation. Neuroscientists believe this occurs because the colors of the flowers have the same level of brightness as the colors in the surrounding field—and so are difficult for the colorblind "where" pathway to locate precisely in space (Dingfelder, 2010).

binding problem Refers to the process used by the brain to combine (or "bind") the results of many sensory operations into a single percept. This occurs, for example, when sensations of color, shape, boundary, and texture are combined to produce the percept of a person's face. No one knows exactly how the brain does this. Thus, the binding problem is one of the major unsolved mysteries in psychology.

top-down processing Perceptual analysis that emphasizes the perceiver's expectations, concept memories, and other cognitive factors, rather than being driven by the characteristics of the stimulus. "Top" refers to a mental set in the brain—which stands at the "top" of the perceptual processing system.

bottom-up processing Perceptual analysis that emphasizes characteristics of the stimulus, rather than our concepts and expectations. "Bottom" refers to the stimulus, which occurs at step one of perceptual processing.

Top-Down and Bottom-Up Processing

Forming a percept also seems to involve imposing a pattern on sensation. This involves two complementary processes that psychologists call *top-down processing* and *bottom-up processing*. In **top-down processing**, our goals, past experience, knowledge, expectations, memory, motivations, or cultural background guide our perceptions of objects—or events (see Nelson, 1993). Trying to find your car keys in a cluttered room requires top-down processing. So does searching for Waldo in the popular children's series *Where's Waldo*? And if you skip lunch to go grocery shopping, top-down hunger signals will probably make you notice all the snack foods in the store.

In **bottom-up processing**, the characteristics of the stimulus (rather than a concept in our minds) exert a strong influence on our perceptions. Bottom-up processing relies heavily on the brain's feature detectors to sense these stimulus characteristics: Is it moving? What color is it? Is it loud, sweet, painful, pleasant smelling, wet, hot…? You are doing bottom-up processing when you notice a moving fish in an aquarium, a hot pepper in a stir-fry, or a loud noise in the middle of the night.

Thus, bottom-up processing involves sending sensory data into the system through receptors and sending it "upward" to the cortex, where a basic analysis, involving the feature detectors, is first performed to determine the characteristics of the stimulus. Psychologists also refer to this as *stimulus-driven processing* because the resulting percept is determined, or "driven," by stimulus features. By contrast, top-down processing flows in the opposite direction, with the percept being driven by some concept in the cortex—at the "top" of the brain. Because this sort of thinking relies heavily on concepts in the perceiver's own mind, it is also known as *conceptually driven processing*.

Perceptual Constancies

We can illustrate another aspect of perception with yet another example of top-down processing. Suppose that you are looking at a door, such as the one pictured in Figure 3.14A. You "know" that the door is rectangular, even though your sensory image of it is distorted when you are not looking at it straight-on. Your brain automatically corrects the sensory distortion so that you perceive the door as being rectangular, as in Figure 3.14B.

This ability to see an object as being the same shape from different angles or distances is just one example of a **perceptual constancy.** In fact, there are many kinds of perceptual constancies. These include *color constancy,* which allows us to see a flower as being the same color in the reddish light of sunset as in the white glare of midday. *Size constancy* allows us to perceive a person as the same size at different distances and also serves as a strong cue for depth perception. And it was *shape constancy* that allowed us to see the door as remaining rectangular from different angles. Together, these constancies help us identify and track objects in a changing world.

perceptual constancy The ability to recognize the same object as remaining "constant" under different conditions, such as changes in illumination, distance, or location.

(A)

(B)

FIGURE 3.14

A Door by Any Other Shape Is Still a Door

(A) A door seen from an angle presents the eye with a distorted rectangle image. **(B)** The brain perceives the door as rectangular.

Inattentional Blindness and Change Blindness Sometimes we don't notice things that occur right in front of our noses—particularly if they are unexpected and we haven't focused our attention on them. While driving, you may not notice a car unexpectedly shifting lanes. Psychologists call this **inattentional blindness** (Beck et al., 2004; Greer, 2004a). Magicians rely on it for many of their tricks (Sanders, 2009). They also rely on **change blindness**, a related phenomenon in which we fail to notice that something is different now than it was before, as when a friend changes hair color or shaves a mustache (Martinez-Conde & Macknik, 2008).

We *do* notice changes that we anticipate, such as a red light turning to green. But laboratory studies show that many people don't notice when, in a series of photographs of the same scene, a red light is replaced by a stop sign. One way this may cause trouble in the world outside the laboratory is that people underestimate the extent to which they can be affected by change blindness. This probably occurs because our perceptual systems and our attention have limits on the amount of information they can process, so our expectations coming from the "top down" cause us to overlook the unexpected.

inattentional blindness A failure to notice changes occurring in one's visual field, apparently caused by narrowing the focus of one's attention.

change blindness A perceptual failure to notice that a visual scene has changed from the way it had appeared previously. Unlike inattentional blindness, change blindness requires comparing a current scene to one from the past, stored in memory.

illusion You have experienced an illusion when you have a demonstrably incorrect perception of a stimulus pattern, especially one that also fools others who are observing the same stimulus. (If no one else sees it the way you do, you could be having a *hallucination.* We'll take that term up in a later chapter on mental disorder.)

Perceptual Ambiguity and Distortion

A primary goal of perception is to get an accurate "fix" on the world—to recognize friends, foes, opportunities, and dangers. Survival sometimes depends on accurately perceiving the environment, but the environment is not always easy to "read." We can illustrate this difficulty with the photo of black and white splotches in Figure 3.15. What is it? When you eventually extract the stimulus figure from the background, you will see it as a Dalmatian dog walking toward the upper left with its head down. The dog is hard to find because it blends so easily with the background. The same problem occurs when you try to single out a voice against the background of a noisy party.

But it is not just the inability to find an image that causes perceptual problems. Sometimes our perceptions can be wildly inaccurate because we misinterpret an image—as happens with sensory and perceptual *illusions.*

FIGURE 3.15

An Ambiguous Picture

What is depicted here? The difficulty in seeing the figure lies in its similarity to the background.

What Illusions Tell Us about Sensation and Perception When your mind deceives you by interpreting a stimulus pattern incorrectly, you are experiencing an **illusion**. Such illusions can help us understand some fundamental properties of sensation and perception—particularly the discrepancy between our percepts and external reality (Cohen & Girgus, 1973).

Let's first examine a remarkable bottom-up illusion that works at the level of sensation: the black-and-white Hermann grid (see Figure 3.16). As you stare at the center of the grid, note how dark, fuzzy spots appear at the intersections of the white bars. But when you focus on an intersection, the spot vanishes. Why? The answer lies in the way receptor cells in your visual pathways interact with each other. The firing of certain cells that are sensitive to light–dark boundaries inhibits the activity of adjacent cells that would otherwise detect the white grid lines. This inhibiting process makes you sense darker regions—the

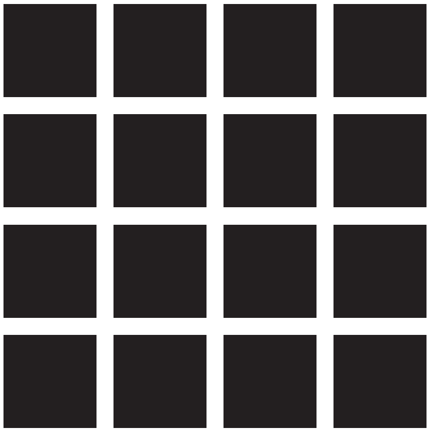


FIGURE 3.16

The Hermann Grid

Why do faint gray dots appear at the intersections of the grid? The illusion, which operates at the sensory level, is explained in the text.

Source: "The Hermann Grid," from *Fundamentals of Sensation & Perception* by M. W. Levine & J. Shefner. Reprinted by permission of Michael W. Levine.

grayish areas—at the white intersections just outside your focus. Even though you know (top-down) that the squares in the Hermann grid are black and the lines are white, this knowledge cannot overcome the illusion, which operates at a more basic, sensory level.

To study illusions at the level of perception, psychologists often employ **ambiguous figures**—stimulus patterns that can be interpreted (top-down) in two or more distinct ways, as in Figures 3.17A and 3.17B. There you see that both the vase/faces figure and the Necker cube are designed to confound your interpretations, not just your sensations. Each suggests two conflicting meanings: Once you have seen both, your perception will cycle back and forth between them as you look at the figure. Studies suggest that these alternating interpretations may involve the shifting of perceptual control between the left and right hemispheres of the brain (Gibbs, 2001).

Another dramatic illusion, recently discovered, appears in Figure 3.18. Although it is hard to believe, the squares marked A and B are the same shade of gray. Proof appears in the right-hand image, where the vertical bars are also the same gray shade. Why are we fooled by this illusion? Perceptual psychologists respond that the effect derives from *color and brightness constancy:* our ability to see an object as essentially unchanged under different lighting conditions, from the bright noon sun to near darkness (Gilchrist, 2006). Under normal conditions, this prevents us from being misled by shadows.

Figure 3.19 shows several other illusions that operate primarily at the level of perceptual interpretation. All are compelling, and all are controversial—particularly the Müller–Lyer illusion, which has intrigued psychologists for more than 100 years. Disregarding the arrowheads, which of the two horizontal lines in this figure appears longer? If you measure them, you will see that the horizontal lines are exactly the same length. What is the explanation? Answers to that question have

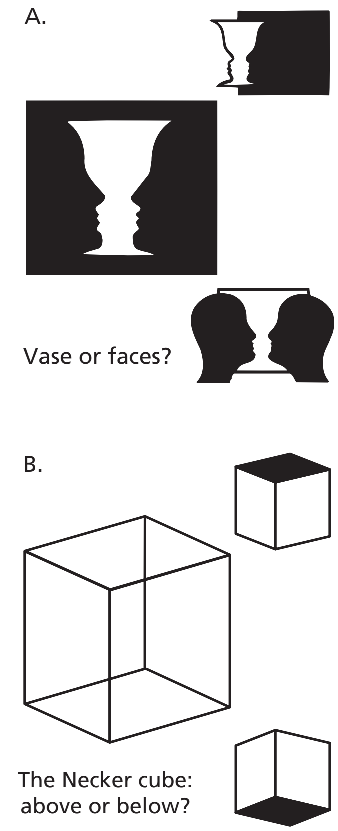


FIGURE 3.17

Perceptual Illusions

These ambiguous figures are illusions of perceptual interpretation.

ambiguous figures Images that can be interpreted in more than one way. There is no "right" way to see an ambiguous figure.

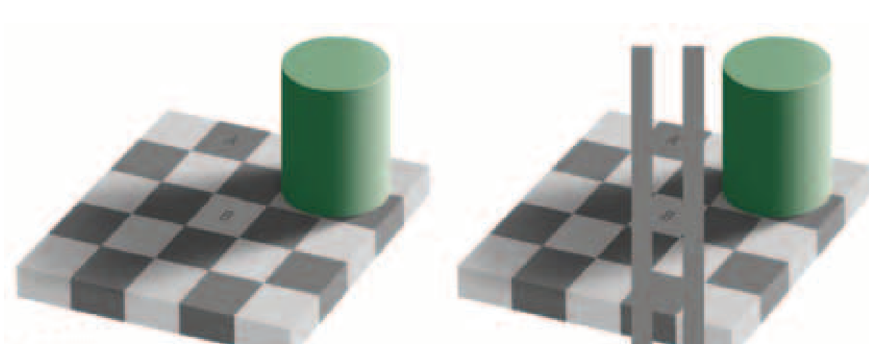


FIGURE 3.18

The Checkerboard Illusion

Appearances are deceiving: Squares A and B are actually the same shade of gray, as you can see on the right by comparing the squares with the vertical bars. The text explains why this occurs.

Source: © 1995, Edward H. Adelson

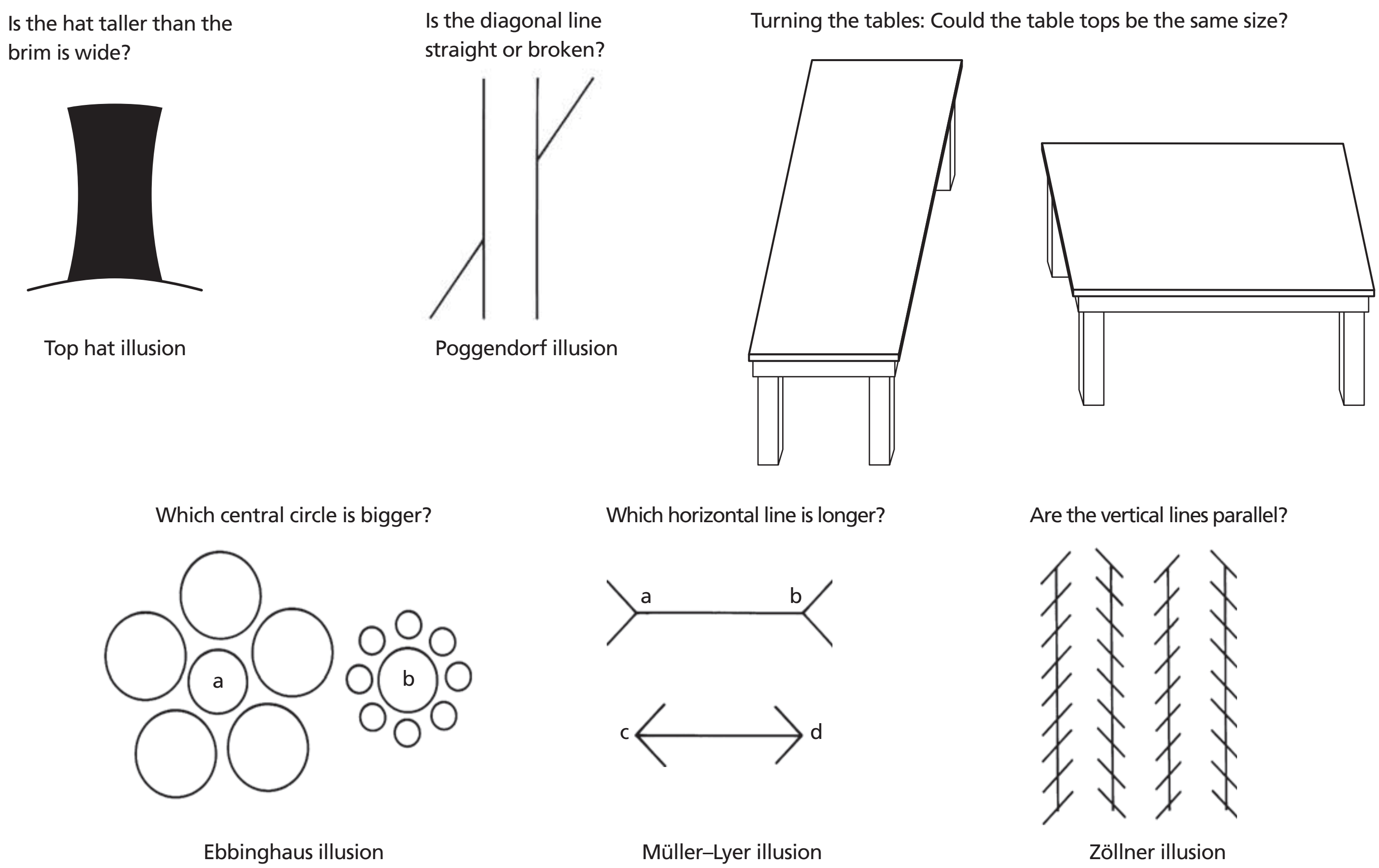


FIGURE 3.19

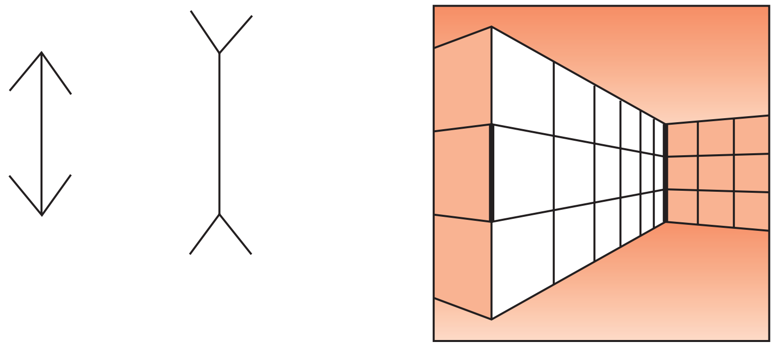
Six Illusions to Tease Your Brain

Each of these illusions involves a bad "bet" made by your brain. What explanations can you give for the distortion of reality that each of these illusions produces? Are they caused by nature or nurture? The table illusion was originally developed by Roger N. Shepard and presented in his 1990 book *Mind Sights* (Freeman).

been offered in well over a thousand published studies, and psychologists still don't know for sure.

One popular theory, combining both top-down and bottom-up factors, has gathered some support. It suggests that we unconsciously interpret the Müller–Lyer figures as three-dimensional objects. So instead of arrowheads, we see the ends as angles that project toward or away from us like the inside and outside corners of a building or a room, as in Figure 3.20 The inside corner seems to recede in the distance, while the outside corner appears to extend toward us. Therefore, we judge the outside corner to be closer—and shorter. Why? When two objects make the same-size image on the retina and we judge one to be farther away than the other, we assume that the more distant one is larger.

Illusions in the Context of Culture But what if you had grown up in a culture with no square-cornered buildings? Would you still see one line as longer than the other in the Müller–Lyer? In other words, do you have to *learn* to see the illusion, or is it "hard wired" into your brain? One way to answer such questions is through cross-cultural research. With this in mind, Richard Gregory (1977) went to South Africa to study a group of people known as the Zulus, who live in what he called a "circular culture." Aesthetically, people in that culture prefer curves to straight lines and square corners: Their round huts have round doors and windows; they till



(a) (b)

FIGURE 3.20

The Müller-Lyer Illusion

One explanation for the Müller-Lyer illusion says that your brain thinks it is seeing the inside and outside corners of a building in perspective.

their fields along sweeping curved lines, using curved plows; the children's toys lack straight lines.

So what happened when Gregory showed them the Müller–Lyer? Most saw the lines as nearly the same length. This suggests that the Müller–Lyer illusion is learned. A number of other studies support Gregory's conclusion that people who live in "carpentered" environments—where buildings are built with straight sides and 90-degree angles—are more susceptible to the illusion than those who (like the Zulus) live in "noncarpentered" worlds (Segall et al., 1999).

Applying the Lessons of Illusions Several prominent modern artists, fascinated with the visual experiences created by ambiguity, have used perceptual illusion as a central artistic feature of their work. Consider the two examples of art shown here. *Gestalt Bleue* by Victor Vasarely (see Figure 3.21) produces depth reversals like those in the Necker cube, with corners that alternately project and recede. In *Sky and Water* by M. C. Escher (see Figure 3.22), you can see birds and fishes only through the process of figure–ground reversal, much like the vase/faces illusion we encountered earlier (see Figure 3.17). The effect of these paintings on us underscores the function of human perception to make sense of the world and to fix on the best interpretation we can make.

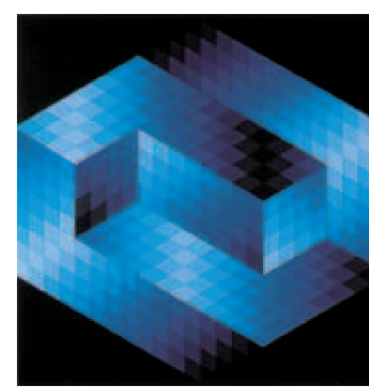


FIGURE 3.21

Victor Vasarely's *Gestalt Bleue*

To interpret such illusions, we draw on our personal experiences, learning, and motivation. Knowing this, those who understand the principles of perception often can control illusions to achieve desired effects far beyond the world of painting. Architects and interior designers, for example, create illusions that make spaces seem larger or smaller than they really are. They may, for example, make a small apartment appear more spacious when it is painted in light colors and sparsely furnished. Similarly, set and lighting designers in movies and theatrical productions purposely create visual illusions on film and on stage. So, too, do many of us make everyday use of illusion in our choices of cosmetics and clothing (Dackman, 1986). Light-colored clothing and horizontal stripes can make our bodies seem larger, while dark-colored clothing and vertical stripes can make our bodies seem slimmer. In such ways, we use illusions to distort "reality" and make our lives more pleasant.

Theoretical Explanations for Perception

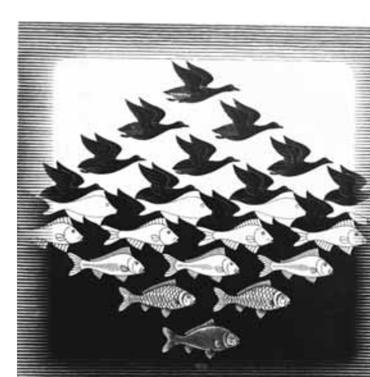


FIGURE 3.22

M. C. Escher's *Sky and Water*

The fact that most people perceive most illusions and ambiguous figures in essentially the same way suggests that fundamental perceptual principles are at work. But what are these principles? To find some answers, we will examine two influential theories that explain how we form our perceptions: *Gestalt theory* and *learning-based inference*.

Although these two approaches may seem contradictory at first, they really emphasize complementary influences on perception. The Gestalt theory emphasizes how we organize incoming stimulation into meaningful perceptual patterns—because of the

CONNECTION CHAPTER 2

The *nature–nurture* issue centers on the relative importance of heredity and environment (p. XXX).

way our brains are innately "wired." On the other hand, learning-based inference emphasizes learned influences on perception, including the power of expectations, context, and culture. In other words, Gestalt theory emphasizes *nature,* and learning-based inference emphasizes *nurture.*

Perceptual Organization: The Gestalt Theory You may have noticed that a series of blinking lights, perhaps on a theater marquee, can create the illusion of motion where there really is no motion. Similarly, there appears to be a white triangle in the nearby *Do It Yourself!* box—but there really is no white triangle. And, as we have seen, the Necker cube seems to flip back and forth between two alternative perspectives—but, of course, the flipping is all in your mind.

About 100 years ago, such perceptual tricks captured the interest of a group of German psychologists, who argued that the brain is innately wired to perceive not just stimuli but also *patterns* in stimulation (Sharps & Wertheimer, 2000). They called such a pattern a *Gestalt,* the German word for "perceptual pattern" or "configuration." Thus, from the raw material of stimulation, the brain forms a perceptual whole that is more than the mere sum of its sensory parts (Prinzmetal, 1995; Rock & Palmer, 1990). This perspective became known as **Gestalt psychology.**

Gestalt psychology From a German word (pronounced *gush-TAWLT*) that means "whole" or "form" or "configuration." (A Gestalt is also a *percept.*) The Gestalt psychologists believed that much of perception is shaped by innate factors built into the brain.

The Gestaltists liked to point out that we perceive a square as a single figure rather than merely as four individual lines. Similarly, when you hear a familiar song, you do not focus on the individual notes. Rather, your brain extracts the melody, which is your perception of the overall *pattern* of notes. Such examples, the Gestalt psychologists argued, show that we always attempt to organize sensory information into meaningful patterns, the most basic elements of which are already present in our brains at birth. Because this approach has been so influential, we will examine some of the Gestalt discoveries in more detail.

Listen
Gestalt Principles at Work
on **mypsychlab.com**

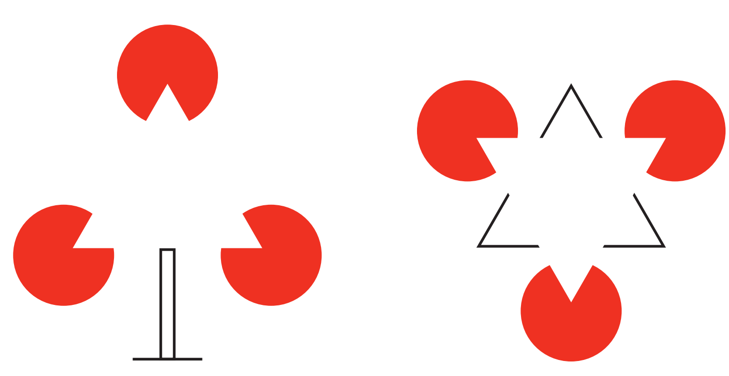
Figure and Ground One of the most basic of perceptual processes identified by Gestalt psychology divides our perceptual experience into *figure* and *ground.* A **figure** is simply a pattern or image that grabs our attention. As we noted, psychologists sometimes call this a *Gestalt.* Everything else becomes **ground,** the backdrop against which we perceive

figure The part of a pattern that commands attention. The figure stands out against the ground.

ground The part of a pattern that does not command attention; the background.

Do It Yourself! FIGURE OBSCURES GROUND

The tendency to perceive a figure as being in front of a ground is strong. It is so strong, in fact, that you can even get this effect when the perceived figure doesn't actually exist! You can demonstrate this with an examination of the accompanying figure. (See also Ramachandran & Rogers-Ramachandran, 2010.) You probably perceive a fir-tree shape against a ground of red circles on a white surface. But, of course, there is no fir-tree figure printed on the page; the figure consists only of three solid red shapes and a black-line base. You perceive the illusory white triangle in front because the wedge-shaped cuts in the red circles seem to be the corners of a solid white triangle. To see an illusory six-pointed star, look at part B. Here, the nonexistent "top" triangle appears to blot out parts of red circles and a black-lined triangle, when in fact none of these is depicted as complete figures. Again, this demonstrates that we prefer to see the figure as an object that obscures the ground behind it. (That's why we often call the ground a "*back*ground.")



Subjective Contours
(A) A subjective fir tree; **(B)** a subjective six-pointed star.

the figure. A melody becomes a figure heard against a background of complex harmonies, and a spicy chunk of pepperoni becomes the figure against the ground of cheese, sauce, and bread that makes up a pizza. Visually, a figure could be a bright flashing sign or a word on the background of a page. And in the ambiguous faces/vase seen in Figure 3.17A, figure and ground reverse when the faces and vase alternately "pop out" as figure.

Closure: Filling in the Blanks Our minds seem built to abhor a gap, as you saw in the *Do It Yourself!* above. Note especially the illusory white triangle—superimposed on red circles and black lines. Moreover, you will note that you have mentally divided the white area into two regions, the triangle and the background. Where this division occurs, you perceive *subjective contours:* boundaries that exist not in the stimulus but only in the subjective experience of your mind.

Your perception of these illusory triangles demonstrates a second powerful organizing process identified by the Gestalt psychologists. **Closure** makes you see incomplete figures as wholes by supplying the missing segments, filling in gaps, and making inferences about potentially hidden objects. So when you see a face peeking around a corner, your mind automatically fills in the hidden parts of the face and body. In general, humans have a natural tendency to perceive stimuli as complete and balanced even when pieces are missing. (Does this ring a _______ with you?) Closure is also responsible for filling in your "blind spot," as you saw on page 13.

closure The Gestalt principle that identifies the tendency to fill in gaps in figures and to see incomplete figures as complete.

In the foregoing demonstrations, we have seen how the perception of subjective contours and closure derives from the brain's ability to create percepts out of incomplete stimulation. Now let us turn to the perceptual laws that explain how we group the stimulus elements that are actually present in Gestalts.

The Gestalt Laws of Perceptual Grouping It's easy to see a school of fish as a single unit—as a Gestalt. But why? And how do we mentally combine hundreds of notes together and perceive them as a single melody? How do we combine the elements of color, shadow, form, texture, and boundary into the percept of a friend's face? And why have thousands of people reported seeing "flying saucers" or the face of Jesus in the scorch marks on a tortilla? That is, how do we pull together in our minds the separate stimulus elements that seem to "belong" together? This is the *binding problem* again: one of the most fundamental problems in psychology. As we will see, the Gestalt psychologists made great strides in this area, even though the processes by which perceptual organization works are still debated today (Palmer, 2002).

In the heyday of Gestalt psychology, of course, there were no MRIs or PET scans. Modern neuroscience didn't exist. Hence, Gestalt psychologists like Max Wertheimer (1923) had to focus on the problem of perceptual organization in a different way—with

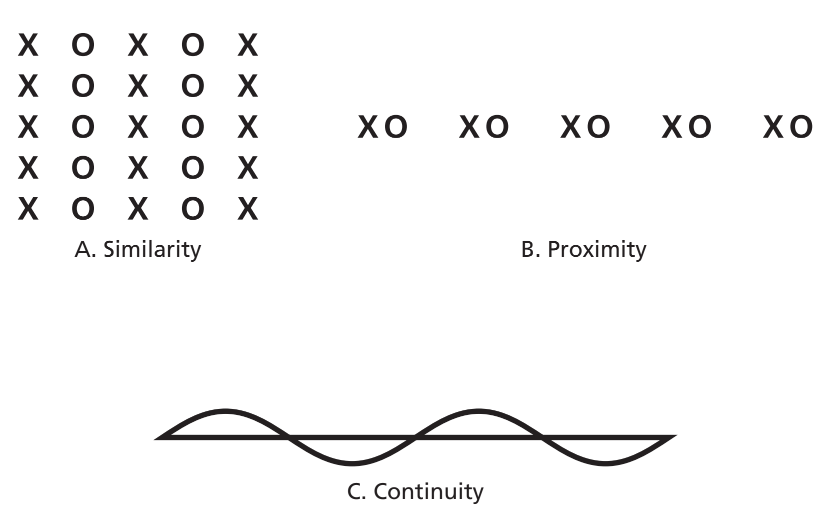


FIGURE 3.23

Gestalt Laws of Perceptual Grouping

(A) Similarity, **(B)** proximity (nearness), and **(C)** continuity. In **(A),** you most easily see the *X*s grouped together, while *O*s form a separate Gestalt. So columns group together more easily than rows. The rows, made up of dissimilar elements, do not form patterns so easily. In **(B),** dissimilar elements easily group together when they are near each other. In **(C),** even though the lines cut each other into many discontinuous segments, it is easier to see just two lines—each of which appears to be continuous as a single line cutting through the figure.

laws of perceptual grouping The Gestalt principles of similarity, proximity, continuity, and common fate. These "laws" suggest how our brains prefer to group stimulus elements together to form a percept (Gestalt).

law of similarity The Gestalt principle that we tend to group similar objects together in our perceptions.

law of proximity The Gestalt principle that we tend to group objects together when they are near each other. *Proximity* means "nearness."

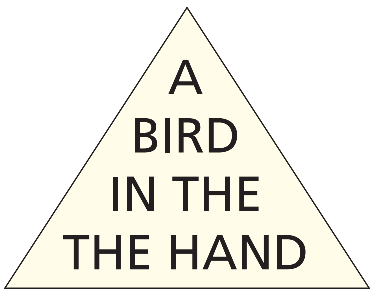


FIGURE 3.24

A Bird in the . . .

We usually see what we expect to see—not what is really there. Look again.

arrays of simple figures, such as you see in Figure 3.23. By varying a single factor and observing how it affected the way people perceived the structure of the array, Wertheimer was able to formulate a set of **laws of perceptual grouping,** which he inferred were built into the neural fabric of the brain.

According to Wertheimer's **law of similarity,** we group things together that have a similar look (or sound, or feel, and so on). So in Figure 3.23A, you see that the *X*s and *O*s form distinct columns, rather than rows, because of similarity. Likewise, when you watch a football game, you use the colors of the uniforms to group the players into two teams because of similarity, even when they are mixed together during a play. You can also hear the law of similarity echoed in the old proverb "Birds of a feather flock together," which is a commentary not only on avian behavior but also on the assumptions we make about perceptual grouping. Any such tendency to perceive things as belonging together because they share common features reflects the law of similarity.

Now, suppose that, on one drowsy morning, you mistakenly put on two different-colored socks because they were together in the drawer and you assumed that they were a pair. Your mistake was merely Wertheimer's **law of proximity** (nearness) at work. The proximity principle says that we tend to group things together that are near each other, as you can see in the pairings of the *X*s with the *O*s in Figure 3.23B. On the level of social perception, your parents were invoking the law of proximity when they cautioned you, "You're known by the company you keep."

We can see the Gestalt **law of continuity** in Figure 3.23C, where the straight line appears as a single, continuous line, even though the curved line repeatedly cuts through it. In general, the law of continuity says that we prefer smoothly connected and continuous figures to disjointed ones. Continuity also operates in the realm of social perception, where we commonly make the assumption of continuity in the personality of an individual whom we haven't seen for some time. So, despite interruptions in our contact with that person, we will expect to find continuity—to find him or her to be essentially the same person we knew earlier.

There is yet another form of perceptual grouping—one that we cannot illustrate in the pages of a book because it involves motion. But you can easily conjure up your own image that exemplifies the **law of common fate:** Imagine a school of fish, a gaggle of geese, or a uniformed marching band. When visual elements (the individual fish, geese, or band members) are moving together, you perceive them as a single Gestalt.

According to the Gestalt perspective, then, each of these examples of perceptual grouping illustrates the profound idea that our perceptions reflect innate patterns in the brain. These inborn mental processes, in a top-down fashion, determine the organization of the individual parts of the percept, just as mountains and valleys determine the course of a river. Moreover, the Gestalt psychologists suggested, the laws of perceptual grouping exemplify a more general principle known as the **law of Prägnanz** ("meaningfulness"). This principle states that we perceive the simplest pattern possible—the percept requiring the least mental effort. The most general of all the Gestalt principles, Prägnanz (pronounced *PRAYG-nonce*) has also been called the *minimum principle of perception*. The law of Prägnanz is what makes proofreading so hard to do, as you will find when you examine Figure 3.24.

Quickly scan this photo. Then look away and describe as much as you recall. Next, turn to page 40 to learn what you may or may not have seen.

Learning-Based Inference: The *Nurture* of Perception In 1866, Hermann von Helmholtz pointed out the important role of *learning* (or *nurture*) in perception. His theory of **learning-based inference** emphasized how people use prior learning to interpret new sensory information. Based on experience, then, the observer makes *inferences*—guesses or predictions—about what the sensations mean. This theory explains, for example, why you assume a birthday party is in progress when you see lighted candles on a cake: You have *learned* to associate cakes, candles, and birthdays.

Ordinarily, such perceptual inferences are fairly accurate. On the other hand, we have seen that confusing sensations and ambiguous arrangements can create perceptual illusions and erroneous conclusions. Our perceptual interpretations are, in effect, hypotheses about our sensations. For example, babies learn to expect that faces will have certain features in fixed arrangements (pair of eyes above nose, mouth below nose, etc.). In fact, we so thoroughly learn about faces in their usual configuration that we fail to "see" facial patterns that violate our expectations, particularly when they appear in an unfamiliar orientation. When you look at the two inverted portraits of Beyoncé (Figure 3.25), do you detect any important differences between them? Turn the book upside down for a surprise.

What, according to the theory of learning-based inference, determines how successful we will be in forming an accurate percept? The most important factors include the *context,* our *expectations,* and our *perceptual set.* We will see that each of these involves a way of narrowing our search of the vast store of concepts in long-term memory.

Context and Expectations Once you identify a context, you form expectations about what persons, objects, and events you are likely to experience (Biederman, 1989). To see what we mean, take a look at the following:

It says THE CAT, right? Now look again at the middle letter of each word. Physically, these two letters are exactly the same, yet you perceived the first as an *H* and the second as an *A*. Why? Clearly, your perception was affected by what you know about words in English. The context provided by *T__E* makes an *H* highly likely and an *A* unlikely, whereas the reverse is true of the context of *C__T* (Selfridge, 1955).

Here's a more real-world example: You have probably had difficulty recognizing people you know in situations where you didn't expect to see them, such as in a different city or a new social group. The problem, of course, is not that they looked different but that the context was unusual: You didn't *expect* them to be there. Thus, perceptual identification depends on context and expectations as well as on an object's physical properties.

Perceptual Set Another way learning serves as a platform from which context and expectation exert an influence on perception involves **perceptual set**—which is closely related to expectation. Under the influence of perceptual set, we have a readiness to notice and respond to certain stimulus cues—like a sprinter anticipating the starter's pistol. In general, perceptual set involves a focused alertness for a particular stimulus in a given context. For example, a new mother is set to hear the cries of her child. Likewise, if you drive a sporty red car, you probably know how the highway patrol has a perceptual set to notice speeding sporty red cars.

Often, a perceptual set leads you to transform an ambiguous stimulus into the one you were expecting. To experience this yourself, read quickly through the series of words that follow in both rows:

FOX; OWL; SNAKE; TURKEY; SWAN; D?CK

BOB; RAY; DAVE; BILL; TOM; D?CK

Notice how the words in the two rows lead you to read D?CK differently in each row. The meanings of the words read prior to the ambiguous stimulus create a perceptual

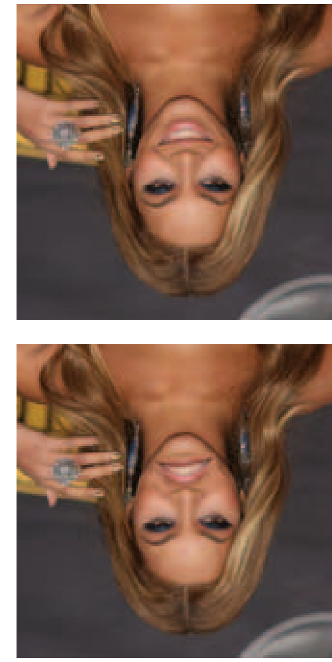


FIGURE 3.25

Two Perspectives on Beyoncé

Although one of these photos clearly has been altered, they look similar when viewed this way. However, turn the book upside down and look again.

law of continuity The Gestalt principle that we prefer perceptions of connected and continuous figures to disconnected and disjointed ones.

law of common fate The Gestalt principle that we tend to group similar objects together that share a common motion or destination.

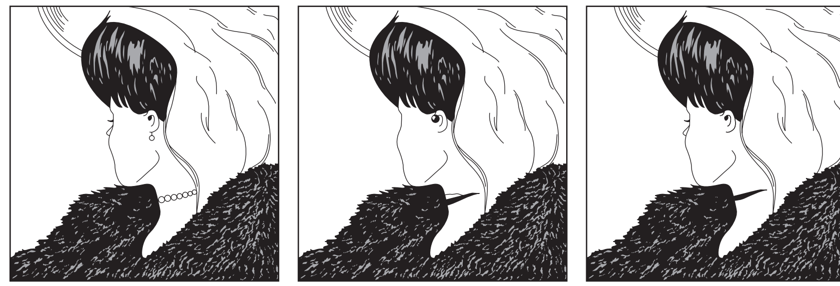
law of Prägnanz The most general Gestalt principle, which states that the simplest organization, requiring the least cognitive effort, will emerge as the figure. *Prägnanz* shares a common root with *pregnant,* and so it carries the idea of a "fully developed figure." That is, our perceptual system prefers to see a fully developed Gestalt, such as a complete circle—as opposed to a broken circle.

learning-based inference The view that perception is primarily shaped by learning (or experience), rather than by innate factors.

perceptual set Readiness to detect a particular stimulus in a given context—as when a person who is afraid interprets an unfamiliar sound as a threat.

Do It Yourself! YOU SEE WHAT YOU'RE SET TO SEE

Labels create a context that can impose a perceptual set for an ambiguous figure. Have a friend look carefully at the picture of the "young woman" in part A of the accompanying figure, and have another friend examine the "old woman" in part B. (Cover the other pictures while they do this.) Then have them look together at part C. What do they see? Each will probably see something different, even though it's the same stimulus pattern. Prior exposure to the picture with a specific label will usually affect a person's perception of the ambiguous figure.



A. A Young Woman B. An Old Woman C. Now what do you see?

set. Words that refer to animals create a perceptual set that influences you to read D?CK as "DUCK." Names create a perceptual set leading you to see D?CK as DICK. Yet another illustration of perceptual set appears in the *Do It Yourself!* box "You See What You're Set to See."

Cultural Influences on Perception Which of the following three items go together: chicken, cow, grass? If you are American, you are likely to group chicken and cow, because they are both animals. But if you are Chinese, you are more likely to put the latter two together, because cows eat grass. In general, says cross-cultural psychologist Richard Nisbett, Americans tend to put items in categories by abstract type rather than by relationship or function (Winerman, 2006d).

Nisbett and his colleagues have also found that East Asians typically perceive in a more holistic fashion than do Americans (Nisbett, 2003; Nisbett & Norenzayan, 2002). That is, the Asians pay more attention to, and can later recall more detail about, the context than do Americans. (This is true, incidentally, even if the American is of Chinese ancestry.) Specifically, when looking at a scene, people raised in America tend to spend more time scanning the "figure," while those raised in China usually focus more on details of the "ground" (Chua et al., 2005). "The Americans are more zoom and the East Asians are more panoramic," says neuroscientist Denise Park (Goldberg, 2008). Such distinctions are now even showing up as subtle differences on scans comparing brain activity of Asians and Americans on simple perceptual judgment tasks (Hedden et al., 2008).

Cross-cultural psychologists have pointed to still other cultural differences in perception (Segall et al., 1999). Consider, for example, the famous Ponzo illusion, based on linear perspective depth cues (see Figure 3.26). In your opinion, which bar is longer: the one on top (marked A) or the one on the bottom (marked B)? In actuality, both bars are the same length. (If you've developed a skeptical scientific attitude, you'll measure them!) Research shows, however, that responses to these figures depend strongly on culture-related experiences. Most readers of this book will report that the top bar appears longer than the bottom bar, yet people from some cultural backgrounds are not so easily fooled.

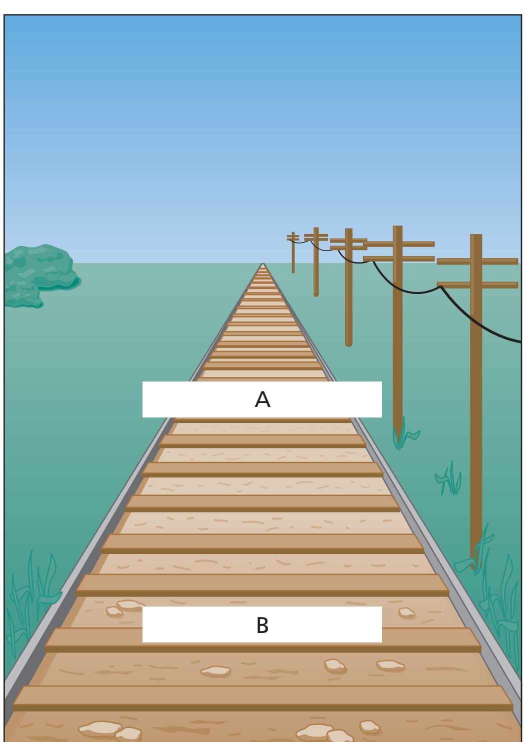


FIGURE 3.26

The Ponzo Illusion

The two white bars superimposed on the railroad track are actually identical in length. Because A appears farther away than B, we perceive it as longer.

Why the difference? The world you have grown up in probably included many structures featuring parallel lines that seemed to converge in the distance: railroad tracks, long buildings, highways, and tunnels. Such experiences leave you vulnerable to images, such as the Ponzo illusion, in which cues for size and distance are unreliable.

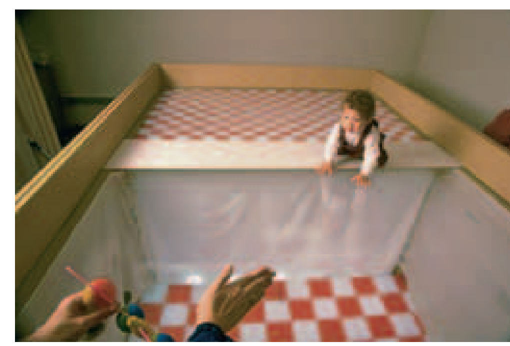
But what about people from cultures where individuals have had far less experience with this cue for distance? Research on this issue has been carried out on the Pacific island of Guam, where there are no Ponzolike railroad tracks (Brislin, 1974, 1993). There, too, the roads are so winding that people have few opportunities to see roadsides "converge" in the distance. People who have spent their entire lives on Guam, then, presumably have fewer opportunities to learn the strong perceptual cue that converging lines indicate distance.

And, sure enough—just as researchers had predicted—people who had lived all their lives on Guam were less influenced by the Ponzo illusion than were respondents from the mainland United States. That is, they were less likely to report that the top line in the figure was longer. These results strongly support the argument that people's experiences affect their perceptions—as Helmholz had theorized.

Read Cultural Differences in Interpretation of Symbols on **mypsychlab.com**

Depth Perception: Nature or Nurture? Now that we have looked at two contrasting approaches to perception—Gestalt theory, which emphasizes nature, and learning-based inference, which emphasizes nurture—let's see how each explains a classic problem in psychology: depth perception. Are we born with the ability to perceive depth, or must we learn it? Let's look at the evidence.

We know that depth perception appears early in human development, although the idea of being cautious when there is danger of falling seems to develop later in infancy. In a famous demonstration, psychologists Eleanor Gibson and Richard Walk placed infants on a Plexiglas-topped table that appeared to drop off sharply on one end. (See the accompanying photo.) Reactions to the *visual cliff* occurred mainly in infants older than 6 months—old enough to crawl. Most readily crawled across the "shallow" side of the table, but they were reluctant to go over the "edge" of the visual cliff—indicating not only that they could perceive depth but also that they associated the drop-off with danger (Gibson & Walk, 1960). Developmental psychologists believe that crawling and depth perception are linked in that crawling helps infants develop their understanding of the three-dimensional world.



Apprehension about the "visual cliff" shows that infants make use of distance clues. This ability develops at about the same time an infant is learning to crawl.

Using another technique, Bower (1971) found evidence of depth perception in infants only 2 weeks old. By fitting his subjects with 3-D goggles, Bower produced powerful virtual reality images of a ball moving about in space. When the ball image suddenly appeared to move directly toward the infant's face, the reaction was increased heart rate and obvious anxiety. This suggests that some ability for depth perception is probably inborn or heavily influenced by genetic programming that unfolds in the course of early development.

Digging deeper into the problem of depth perception, we find that our sense of depth or distance relies on multiple cues. We can group these depth cues in two categories, either *binocular cues* or *monocular cues*.

Binocular Cues Certain depth cues, the **binocular cues,** depend on the use of two eyes. You can demonstrate this to yourself: Hold one finger about 6 inches from your eyes and look at it. Now move it about a foot farther away. Do you feel the change in your eye muscles as you focus at different distances? This feeling serves as one of the main cues for depth perception when looking at objects that are relatively close. The term for this, *binocular convergence,* suggests how the lines of vision from each eye converge at different angles on objects at different distances.

binocular cues Information taken in by both eyes that aids in depth perception, including binocular convergence and retinal disparity.

A related binocular depth cue, *retinal disparity,* arises from the difference in perspectives of the two eyes. To see how this works, again hold a finger about 12 inches from your face and look at it alternately with one eye and then with the other. Notice how you see a different view of your finger with each eye. Because we see greater disparity when looking at nearby objects than we do when viewing distant objects, these image differences coming from each eye provide us with depth information.

We can't say for sure whether the binocular cues are innate or learned. What we can say is that they rely heavily on our biology: a sense of eye muscle movement and the physically different images on the two retinas. The monocular cues, however, present a very different picture.

Did you see a woman committing suicide in the photo on page 36? Most people have difficulty identifying the falling woman in the center of the photo because of the confusing background and because they have no perceptual schema that makes them expect to see a person positioned horizontally in midair.

monocular cues Information about depth that relies on the input of just one eye—includes relative size, light and shadow, interposition, relative motion, and atmospheric perspective.

Monocular Cues for Depth Perception Not all cues for depth perception require both eyes. A one-eyed pilot we know, who manages to perceive depth well enough to maneuver the airplane safely during takeoffs and landings, is proof that one-eye cues convey a great deal of depth information. Here are some of the **monocular cues** that a one-eyed pilot (or a two-eyed pilot, for that matter) could learn to use while flying:

- If two objects that are assumed to be the same size cast different-sized images on the retina, observers usually judge them to lie at different distances. So a pilot flying low can learn to use the *relative size* of familiar objects on the ground as a cue for depth and distance. Because of this cue, automakers who install wide-angle rear-view mirrors always inscribe the warning on them, "Objects in the mirror are closer than they appear."
- If you have ever looked down a long, straight railroad track, you know that the parallel rails seem to come together in the distance—as we saw in the Ponzo illusion. Likewise, a pilot approaching a runway for landing sees the runway as being much wider at the near end than at the far end. Both examples illustrate how *linear perspective,* the apparent convergence of parallel lines, can serve as a depth cue.
- Lighter-colored objects seem closer to us, and darker objects seem farther away. Thus, *light and shadow* work together as a distance cue. You will notice this the next time you drive your car at night with the headlights on: Objects that reflect the most light appear to be nearer than more dimly lit objects in the distance.
- We assume that closer objects will cut off our vision of more distant objects behind them, a distance cue known as *interposition.* So we know that partially hidden objects are more distant than the objects that hide them. You can see this effect right in front of you now, as your book partially obscures the background, which you judge to be farther away.
- As you move, objects at different distances appear to move through your field of vision at a different rate or with a different *relative motion.* Look for this one from your car window. Notice how the power poles or fence posts along the roadside appear to move by at great speed, while more distant objects stay in your field of view longer, appearing to move by more slowly. With this cue, student pilots learn to set up a glide path to landing by adjusting their descent so that the end of the runway appears to stay at a fixed spot on the windshield while more distant points appear to move upward and nearer objects seem to move downward.
- Haze or fog makes objects in the distance look fuzzy, less distinct, or invisible, creating another learned distance cue called *atmospheric perspective.* In the accompanying photo, you can see that more distant buildings lack clarity through the Los Angeles smog. At familiar airports, most pilots have identified a landmark three miles away. If they cannot see the landmark, they know that they must fly by relying on instruments.

Haze, fog, or air pollution makes distant objects less distinct, creating atmospheric perspective, which acts as a distance cue. Even the air itself provides a cue for distance by giving far-away objects a bluish cast.

So which of the two theories about perception that we have been discussing—Helmholtz's learning theory or the Gestaltists' innate theory—best accounts for depth perception? Both of them! That is, depth and distance perception—indeed, all our perceptual processes—show the influence of both nature and nurture.

Seeing and Believing

If you assume, as most people do, that your senses give you an accurate and undistorted picture of the outside world, you are mistaken (Segall et al., 1990). We hope that the illusions presented in this chapter will help make the point. We also hope that the chapter has helped you realize that people see the world through the filter of their own perceptions—and that marketing and politics depend on manipulating our perceptions (think iPhones, Droids, and Blackberries).

Magicians are also experts in manipulating perceptions—and so perceptual scientists are making them partners in perceptual research (Hyman, 1989; Martinez-Conde & Macknik, 2008; Sanders, 2009). The results include discoveries about change blindness, inattentional blindness, and brain modules involved in both attention and perception.

Unlike magicians, however, perceptual scientists are happy to reveal how sensation and perception play tricks on us all. (Incidentally, a magician friend of ours warns that smart people are the easiest ones to fool. So watch out!)

We hope that this chapter has shaken your faith in your senses and perceptions . . . just a bit. To drive the point home, consider this statement (which, unfortunately, was printed backward):

.rat eht saw tac ehT

Please turn it around in your mind: What does it say? At first most people see a sensible sentence that says, "The cat saw the rat." But take another look. The difficulty lies in the power of expectations to shape your interpretation of stimulation.

This demonstration illustrates once again that we don't merely sense the world as it is; we perceive it. The goal of the process by which stimulation becomes sensation and, finally, perception is to find meaning in our experience. But it is well to remember that we impose our own meanings on sensory experience.

Differences in the ways we interpret our experiences explain why two people can look at the same sunset, the same presidential candidates, or the same religions and perceive them so differently. Perceptual differences make us unique individuals. An old Spanish proverb makes the point elegantly:

En este mundo traidor	In this treacherous world
No hay verdad ni mentira;	There is neither truth nor lie;
Todo es según el color	All is according to the color
Del cristál con que se mira.	Of the lens through which we spy.

With this proverb in mind, let's return one more time to the problem with which we began the chapter—and in particular to the question of whether the world looks (feels, tastes, smells . . .) the same to different people. We have every reason to suspect that we all (with some variation) *sense* the world in roughly the same way. But because we attach different *meanings* to our sensations, it is clear that people *perceive* the world in many different ways—with, perhaps, as many differences as there are people.

Most of us assume that our senses give us an accurate picture of the world. This helps magicians like Lance Burton fool us with perceptual illusions.

Read Extrasensory Perception on **mypsychlab.com**

PSYCHOLOGY MATTERS

Using Psychology to Learn Psychology

One of the most mistaken notions about studying and learning is that students should set aside a certain amount of time for study every day. This is not to suggest that you shouldn't study regularly. Rather, it is to say that you shouldn't focus on merely putting in your time. So where should you place your emphasis? (And what does this have to do with perceptual psychology?)

Recall the concept of *Gestalt*, the idea of the meaningful pattern, discussed earlier in this chapter. The Gestalt psychologists taught that we have an innate tendency to understand our world in terms of meaningful patterns. Applied to your studying, this means that your emphasis should be on finding meaningful patterns—Gestalts—in your course work.

In this chapter, for example, you will find that your authors have helped you by dividing the material into three major sections. You can think of each section as a conceptual Gestalt built around a Core Concept that ties it together and gives it meaning. We suggest that you organize your study of psychology around one of these meaningful units of material. That is, identify a major section of your book and study that until it makes sense.

To be more specific, you might spend an hour or two working on the first section of this chapter, where you would not only read the material but also connect each boldfaced term to the Core Concept. For example, what does the *difference threshold* have to do with the idea that the brain senses the world through neural messages? (Sample brief answer: The brain is geared to detect *changes* or *differences* that are conveyed to it in the form of neural impulses.) We suggest that you do the same thing with each

subliminal perception The process by which a stimulus that is below the awareness threshold can be sensed and interpreted outside of consciousness.

of the other boldfaced terms in the chapter. The result will be a deeper understanding of the material. In perceptual terms, you will be constructing a meaningful pattern—a Gestalt—around the Core Concept.

You can do that only by focusing on meaningful units of material rather than on the clock.

Check Your Understanding

Study and Review on **mypsychlab.com**

1. **APPLICATION:** Give an example, from your own experience, of top-down processing.
2. **RECALL:** Our brains have specialized cells, known as ________ ________, dedicated to identifying stimulus properties such as length, slant, color, and boundary.
3. **RECALL:** What do perceptual constancies do for us?
4. **RECALL:** What two basic perceptual properties seem to reverse or alternate in the faces/vase image (in Figure 3.17A)?
5. **APPLICATION:** When two close friends are talking, other people may not be able to follow their conversation because it has many gaps that the friends can mentally fill in from their shared experience. Which Gestalt principle is illustrated by the friends' ability to fill in these conversational gaps?
6. **UNDERSTANDING THE CORE CONCEPT:** Which of the following best illustrates the idea that perception is not an exact internal copy of the world?
   - **a.** the sound of a familiar tune
   - **b.** the Ponzo illusion
   - **c.** a bright light
   - **d.** jumping in response to a pinprick

Answers 1. Your example should involve perception based on expectations, motives, emotions, or mental images—such as seeing a friend's face in a crowd or making sense of an unexpected sound in the house at night. **2.** feature detectors **3.** Perceptual constancies allow us to identify and track objects under a variety of conditions, such as changes in illumination or perspective. **4.** Figure and ground **5.** Closure **6.** b—because, of all the choices listed, the Ponzo illusion involves the most extensive perceptual interpretation.

CRITICAL THINKING APPLIED

Subliminal Perception and Subliminal Persuasion

Could extremely weak stimulation—stimulation that you don't even notice—affect your attitudes, opinions, or behavior? We know that the brain does a lot of information processing outside of awareness. So the notion that your sensory system can operate below the level of awareness is the basis for the industry that sells "subliminal" recordings touted as remedies for obesity, shoplifting, smoking, and low self-esteem. The same notion also feeds the fear that certain musical groups imbed hidden messages in their recordings or that advertisers may be using subliminal messages to influence our buying habits and, perhaps, our votes (Vokey, 2002).

What Is the Issue?

People are always hoping for a bit of magic. But before you put your money in the mail for that subliminal weight-loss CD, let's identify what exactly we're talking about—and what we're *not* talking about. If subliminal persuasion works as claimed, then it must work on *groups* of people—a mass audience—rather than just on individuals. It also means that a persuasive message can change the behavior of large numbers of people, even though no one is aware of the message. The issue is *not* whether sensory and perceptual processing can occur outside of awareness. The issue is whether subliminal messages can effect a substantial change in people's attitudes, opinions, and behaviors.

Fame, Fortune, Fraud, and Subliminal Perception There is always a possibility of fraud when fortune or fame is involved, which is certainly the case with claims of amazing powers—such as persuasion through **subliminal perception**. This should cue us to ask: What is the source of claims that subliminal persuasion techniques work? That question leads us to an advertising executive, one James Vicary, who dramatically announced to the press some years ago that he had discovered an irresistible sales technique, now known as "subliminal advertising." Vicary said that his method consisted of projecting very brief messages on the screen of a movie theater, urging the audience to "Drink Coke" and "Buy popcorn." He claimed that the ads presented ideas so fleetingly that the conscious mind could not perceive them—yet, he said, the messages would still lodge in the unconscious mind, where they would work on the viewers' desires unnoticed. Vicary also boasted that sales of Coca-Cola and popcorn had soared at a New Jersey theater where he tested the technique.

The public was both fascinated and outraged. Subliminal advertising became the subject of intense debate. People worried that they were being manipulated by powerful psychological forces without their consent. As a result, laws were proposed to quash the practice. But aside from the hysteria, was there any real cause for concern? To answer that question, we must ask: What is the evidence?

Examining the Evidence Let's first see what the psychological science of perceptual thresholds can tell us. As you will recall, a *threshold* refers to the minimum amount of stimulation necessary to trigger a response. The word *subliminal* means "below the threshold" (*limen* = threshold). In the language of perceptual psychology, *subliminal* more specifically refers to stimuli lying near the absolute threshold. Such stimuli may, in fact, be strong enough to affect the sense organs and to enter the sensory system without causing conscious awareness of the stimulus. But the real question is this: Can subliminal stimuli in this range influence our thoughts and behavior?

Several studies have found that subliminal words flashed briefly on a screen (for less than 1/100 second) can "prime" a person's later responses (Merikle & Reingold, 1990). For example, can you fill in the following blanks to make a word?

S N _ _ _ E L

If you had been subliminally primed by a brief presentation of the appropriate word or picture, it would be more likely that you would have found the right answer, even though you were not aware of the priming stimulus. So does the fact that subliminal stimulation can affect our responses on such tasks mean that subliminal persuasion really works?

Of course, priming doesn't *always* work: It merely increases the chances of getting the "right" answer. The answer to the problem, by the way, is "snorkel." And were you aware that we were priming you with the photo, in the margin, of a snorkeler? If you were, it just goes to show that sometimes people *do* realize when they are being primed.

What Conclusions Can We Draw?

Apparently people do perceive stimuli below the absolute threshold, under circumstances such as the demonstration above (Greenwald et al., 1996; Reber, 1993). Under very carefully controlled conditions, subliminal perception is a fact. But here is the problem for would-be subliminal advertisers who would attempt to influence us in the uncontrolled world outside the laboratory: Different people have thresholds at different levels. So what might be *sub*liminal for me could well be *supra*liminal (above the threshold) for you. Consequently, the would-be subliminal advertiser runs the risk that some in the audience will notice—and perhaps be angry about—a stimulus aimed slightly below the average person's threshold. In fact, *no controlled research has ever shown that subliminal messages delivered to a mass audience can influence people's buying habits or voting patterns.*

And what about those subliminal recordings that some stores play to prevent shoplifting? Again, no reputable study has ever demonstrated their effectiveness. A more likely explanation for any decrease in shoplifting attributed to these messages lies in increased vigilance from employees who know that management is worried about shoplifting. The same goes for the tapes that claim to help you quit smoking, lose weight, become wildly creative, or achieve other dozens of elusive dreams. In a comprehensive study of subliminal self-help techniques, the U.S. Army found all to be without foundation (Druckman & Bjork, 1991). The simplest explanation for reports of success lies in the purchasers' expectations and in the need to prove that they did not spend their money foolishly. And finally, to take the rest of the worry out of subliminal persuasion, you should know one more bit of evidence. James Vicary eventually admitted that his claims for subliminal advertising were a hoax (Druckman & Bjork, 1991).

So, using our previous SNORKEL example, could you use what you know about the Gestalt principle of closure to get theatergoers to think about popcorn?

This photo carries a subliminal message, explained in the text.

CHAPTER SUMMARY

Listen to an audio file of your chapter on **mypsychlab.com**

CHAPTER PROBLEM: **Is there any way to tell whether the world we "see" in our minds is the same as the external world—and whether we see things as most others do?**

- Different people probably have similar *sensations* in response to a stimulus because their sense organs and parts of the brain they use in sensation are similar.
- People differ, however, in their *perceptions,* because they draw on different experiences to interpret their sensations.
- The brain does not sense the external world directly. The sense organs *transduce* stimulation and deliver stimulus information to the brain in the form of neural impulses. Our sensory experiences are, therefore, what the brain creates from the information delivered in these neural impulses.

3.1 How Does Stimulation Become Sensation?

Core Concept 3.1 **The brain senses the world indirectly because the sense organs convert stimulation into the language of the nervous system: neural messages.**

The most fundamental step in sensation involves the **transduction** by the sense organs of physical stimuli into neural messages, which are sent onward in the sensory pathways to the appropriate part of the brain for further processing. Not all stimuli become sensations, because some fall below the **absolute threshold.** Further, changes in stimulation are noticed only if they exceed the **difference threshold.** Classical psychophysics focused on identifying thresholds for sensations and for just-noticeable differences, but a newer approach, called **signal detection theory,** explains sensation as a process involving context, physical sensitivity, and judgment. We should consider our senses to be *change detectors*. But because they accommodate to unchanging stimulation, we become less and less aware of constant stimulation.

absolute threshold **(p. XXX)**
difference threshold **(p. XXX)**
perception **(p. XXX)**
sensation **(p. XXX)**
sensory adaptation **(p. XXX)**
signal detection theory **(p. XXX)**
transduction **(p. XXX)**
Weber's law **(p. XXX)**

3.2 How Are the Senses Alike? How Are They Different?

Core Concept 3.2 **The senses all operate in much the same way, but each extracts different information and sends it to its own specialized sensory processing region in the brain.**

All the senses involve transduction of physical stimuli into nerve impulses. In vision, **photoreceptors** in the retina transduce light waves into neural codes, which retain **frequency** and **amplitude** information. This visual information is then transmitted by the optic nerve to the brain's occipital lobe, which converts the neural signals into sensations of **color** and **brightness.** Both the **trichromatic theory** and the **opponent process theory** are required to explain how visual sensations are extracted. Vision makes use of only a tiny "window" in the electromagnetic spectrum.

In the ear, sound waves in the air are transduced into neural energy in the **cochlea** and then sent on to the brain's temporal lobes, where frequency and amplitude information are converted to sensations of **pitch, loudness,** and **timbre.** Our sensations of light and sound are not properties of the original stimulus but rather are creations of the brain. Other senses include position and movement (the **vestibular** and **kinesthetic senses**), smell, taste, the **skin senses** (touch, pressure, and temperature), and pain. Like vision and hearing, these other senses are especially attuned to detect changes in stimulation. Further, all sensations are carried to the brain by neural impulses, but we experience different sensations because the impulses are processed by different sensory regions of the brain. In some people, sensations cross sensory domains. Studies suggest that **synesthesia** involves communication between sensory areas of the brain that lie close together. This seems to occur more often in highly creative people.

The experience of pain can be the result of intense stimulation in any of several sensory pathways. While we don't completely understand pain, the **gate-control theory** explains how pain can be suppressed by competing sensations or other mental processes. Similarly, the ideal *analgesic*—one without unwanted side effects—has not been discovered, although the **placebo effect** works exceptionally well for some people.

afterimages **(p. XXX)**
amplitude **(p. XXX)**
basilar membrane **(p. XXX)**

blind spot **(p. XXX)**
brightness **(p. XXX)**
cochlea **(p. XXX)**
color **(p. XXX)**
color blindness **(p. XXX)**
cones **(p. XXX)**
electromagnetic spectrum **(p. XXX)**
fovea **(p. XXX)**
frequency **(p. XXX)**
gate-control theory **(p. XXX)**
gustation **(p. XXX)**
kinesthetic sense **(p. XXX)**
loudness **(p. XXX)**
olfaction **(p. XXX)**
opponent-process theory **(p. XXX)**
optic nerve **(p. XXX)**
percept **(p. XXX)**
pheromones **(p. XXX)**
photoreceptors **(p. XXX)**
pitch **(p. XXX)**
placebo **(p. XXX)**
placebo effect **(p. XXX)**
retina **(p. XXX)**
rods **(p. XXX)**
skin senses **(p. XXX)**
synesthesia **(p. XXX)**
timbre **(p. XXX)**
trichromatic theory **(p. XXX)**
tympanic membrane **(p. XXX)**
vestibular sense **(p. XXX)**
visible spectrum **(p. XXX)**

3.3 What Is the Relationship between Sensation and Perception?

Core Concept 3.3 Perception brings meaning to sensation, so perception produces an interpretation of the world, not a perfect representation of it.

Psychologists define perception as the stage at which meaning is attached to sensation. Visual identification of objects involves **feature detectors** in the **what pathway** that projects to the temporal lobe. The **where pathway,** projecting to the parietal lobe, involves the location of objects in space. The disorder known as **blindsight** occurs because the where pathway operates outside of consciousness. We also derive meaning from **bottom-up** stimulus cues picked up by feature detectors and from **top-down** processes, especially those involving expectations. What remains unclear is how the brain manages to combine the output of many sensory circuits into a single percept: This is called the **binding problem.** By studying such perceptual phenomena as **illusions,** *constancies,* **change blindness,** and **inattentional blindness,** researchers can learn about the factors that influence and distort the construction of perceptions. Illusions demonstrate that perception does not necessarily form an accurate representation of the outside world.

Perception has been explained by theories that differ in their emphasis on the role of innate brain processes versus learning—nature versus nurture. **Gestalt psychology** emphasizes innate factors that help us organize stimulation into meaningful patterns. In particular, the Gestaltists have described the processes that help us distinguish **figure** from **ground,** to identify contours and apply **closure,** and to group stimuli according to **similarity, proximity, continuity,** and **common fate.** Some aspects of *depth perception,* such as *retinal disparity* and *convergence,* may be innate as well. The theory of **learning-based inference** also correctly points out that perception is influenced by experience, such as *context,* **perceptual set,** and *culture.* Many aspects of depth perception, such as *relative motion, linear perspective,* and *atmospheric perspective,* seem to be learned.

Despite all we know about sensation and perception, many people uncritically accept the evidence of their senses (and perceptions) at face value. This allows magicians, politicians, and marketers an opening through which they can manipulate our perceptions and, ultimately, our behavior.

ambiguous figures **(p. XXX)**
binding problem **(p. XXX)**
binocular cues **(p. XXX)**
blindsight **(p. XXX)**
bottom-up processing **(p. XXX)**
change blindness **(p. XXX)**
closure **(p. XXX)**
feature detectors **(p. XXX)**
figure **(p. XXX)**
Gestalt psychology **(p. XXX)**
ground **(p. XXX)**
illusion **(p. XXX)**
inattentional blindness **(p. XXX)**
law of common fate **(p. XXX)**
law of continuity **(p. XXX)**
law of Prägnanz **(p. XXX)**
law of proximity **(p. XXX)**
law of similarity **(p. XXX)**
laws of perceptual grouping **(p. XXX)**
learning-based inference **(p. XXX)**
monocular cues **(p. XXX)**
percept **(p. XXX)**
perceptual constancy **(p. XXX)**
perceptual set **(p. XXX)**
top-down processing **(p. XXX)**
what pathway **(p. XXX)**
where pathway **(p. XXX)**

CRITICAL THINKING APPLIED

Subliminal Perception and Subliminal Persuasion

Subliminal messages, in the form of *priming,* have been shown to affect an individual's responses on simple tasks under carefully controlled conditions. Yet, despite advertising claims to the contrary, there is no evidence that techniques of **subliminal persuasion** are effective in persuading a mass audience to change their attitudes or behaviors.

DISCOVERING PSYCHOLOGY **VIEWING GUIDE**

Watch the following video by logging into MyPsychLab (www.mypsychlab.com).
After you have watched the video, complete the activities that follow.

PROGRAM 7: **SENSATION AND PERCEPTION**

Program Review

1. Imagine that a teaspoon of sugar is dissolved in 2 gallons of water. Rita can detect this level of sweetness at least half the time. This level is called the
   a. distal stimulus.
   b. perceptual constant.
   c. response bias.
   d. absolute threshold.

2. What is the job of a receptor?
   a. to transmit a neural impulse
   b. to connect new information with old information
   c. to detect a type of physical energy
   d. to receive an impulse from the brain

3. In what area of the brain is the visual cortex located?
   a. in the front
   b. in the middle
   c. in the back
   d. under the brain stem

4. What is the function of the thalamus in visual processing?
   a. It relays information to the cortex.
   b. It rotates the retinal image.
   c. It converts light energy to a neural impulse.
   d. It makes sense of the proximal stimulus.

5. David Hubel discusses the visual pathway and the response to a line. The program shows an experiment in which the response to a moving line changed dramatically with changes in the line's
   a. thickness.
   b. color.
   c. speed.
   d. orientation.

6. Misha Pavel used computer graphics to study how
   a. we process visual information.
   b. rods differ from cones in function.
   c. we combine information from different senses.
   d. physical energy is transduced in the visual system.

7. Imagine that a baseball player puts on special glasses that shift his visual field up 10 degrees. When he wears these glasses, the player sees everything higher than it actually is. After some practice, the player can hit with the glasses on. What will happen when the player first tries to hit with the glasses off?
   a. He will think that the ball is lower than it is.
   b. He will think that the ball is higher than it is.
   c. He will accurately perceive the ball's position.
   d. It is impossible to predict an individual's reaction in this situation.

8. Imagine that a small dog is walking toward you. As the dog gets closer, the image it casts on your retina
   a. gets larger.
   b. gets darker.
   c. gets smaller.
   d. stays exactly the same size.

9. Imagine the same small dog walking toward you. You know that the dog's size is unchanged as it draws nearer. A psychologist would attribute this to
   a. perceptual constancy.
   b. visual paradoxes.
   c. contrast effects.
   d. threshold differences.

10. Which of the following best illustrates that perception is an active process?
    a. bottom-up processing
    b. motion parallax
    c. top-down processing
    d. parietal senses

11. The program shows a drawing that can be seen as a rat or as a man. People were more likely to identify the drawing as a man if they
    a. were men themselves.
    b. had just seen pictures of people.
    c. were afraid of rats.
    d. looked at the picture holistically rather than analytically.

12. Where is the proximal stimulus found?
    a. in the outside world
    b. on the retina
    c. in the occipital lobe
    d. in the thalamus

13. How is visual information processed by the brain?
    a. It's processed by the parietal lobe, which relays the information to the temporal lobe.
    b. It's processed entirely within the frontal lobe.
    c. It's processed by the occipital lobe, which projects to the thalamus, which projects to a succession of areas in the cortex.
    d. If the information is abstract, it's processed by the cortex; if it's concrete, it's processed by the thalamus.

14. Which of the following is true about the proximal stimulus in visual perception?

- **a.** It's identical to the distal stimulus because the retina produces a faithful reproduction of the perceptual world.
- **b.** It's upside-down, flat, distorted, and obscured by blood vessels.
- **c.** It's black and white and consists of very sparse information about horizontal and vertical edges.
- **d.** It contains information about the degree of convergence of the two eyes.

15. Which of the following is an example of pure top-down processing (i.e., requires no bottom-up processing)?

- **a.** hallucinating
- **b.** understanding someone else's speech when honking horns are obscuring individual sounds
- **c.** perceiving a circular color patch that has been painted onto a canvas
- **d.** enjoying a melody

16. Which sensory information is *not* paired with the cortical lobe that is primarily responsible for processing it?

- **a.** visual information, occipital lobe
- **b.** speech, frontal lobe
- **c.** body senses, parietal lobe
- **d.** hearing, central sulcus lobe

17. When your eyes are shut, you cannot

- **a.** hallucinate.
- **b.** use contextual information from other senses to make inferences about what's there.
- **c.** transform a distal visual stimulus into a proximal stimulus.
- **d.** experience perceptual constancy.

18. The researcher David Hubel is best known for

- **a.** mapping visual receptor cells.
- **b.** discovering subjective contours.
- **c.** identifying the neural pathways by which body sensations occur.
- **d.** realizing that hearing and smell originate from the same brain area.

19. The primary reason why psychologists study illusions is because

- **a.** they help in identifying areas of the cortex that have been damaged.
- **b.** they serve as good "public relations" material for curious novices.
- **c.** they help in categorizing people into good and bad perceivers.
- **d.** they help in understanding how perception normally works.

20. The shrinking-square illusion demonstrated by Misha Pavel relies on processing of which kinds of feature?

- **a.** edges and corners
- **b.** color and texture
- **c.** torque and angular momentum
- **d.** density gradients and motion

Questions to Consider

1. Why do psychologists identify sensation and perception as two different fields of study? Does this reflect the relative youth of psychology as a science, or does it represent a scientific distinction that will still be favored in 50 years?

2. As the population ages, adapting the environment for people with a range of sensory abilities and deficits will become increasingly important. Architects will need to improve access to and safety of buildings, taking into account that older people need about three times as much light as young people in order to distinguish objects. They also need higher visual contrasts to detect potential hazards, such as curbs or steps. How might you identify some changes you could make in and around your home to create a safer, more comfortable environment for a person with disabilities or a person with visual or hearing impairments?

3. Choose a familiar context, such as a grocery store, and describe how the Gestalt principles of perceptual organization are used to help people perceive objects and group them.

4. Describe how film and television directors use sight and sound techniques to create meaning and feeling. As you watch a television commercial, program, or film, notice the way the camera frames the image and how angle and motion create a mood or point of view. Notice the use of sound. Consider how these elements shape viewers' desires, expectations, and feelings.

5. Absolute thresholds seem to differ across species. For example, you are much better at detecting degraded visual stimuli than animals of some other species would be, but at the same time you may be much worse than them at smelling faint odors. Why do you think that humans evolved to favor the visual sense?

Activities

1. Blindfold yourself. (Have someone standing by to prevent injury or damage.) Contrast the experience of moving about in a familiar room, such as your bedroom or kitchen, with the experience of moving about a room in which you spend little time. Note the expectations and significant sensory cues you depend on to avoid tripping and bumping into things. How relaxed or tense were you in each room?

2. Listen to a conversation, trying hard to (a) notice all of the other noise going on around you and (b) notice all the instances of imperfect transmission of speech sounds. For example, the speaker might mispronounce something or speak unclearly, or an outside noise may obscure the sound coming from the speaker. Is it hard for you to snap out of top-down mode to do this exercise?

3. If you have access to a virtual reality game, try playing it while also monitoring what is going on in the room around you. While interacting with the virtual objects in the game, think about how you must look to passersby, and think about the layout of the objects in the space that physically surrounds you. How good are you at immersing yourself in two worlds at once? Do you find that you have to switch back and forth, or are you able to consider yourself as being in two very different realities simultaneously?