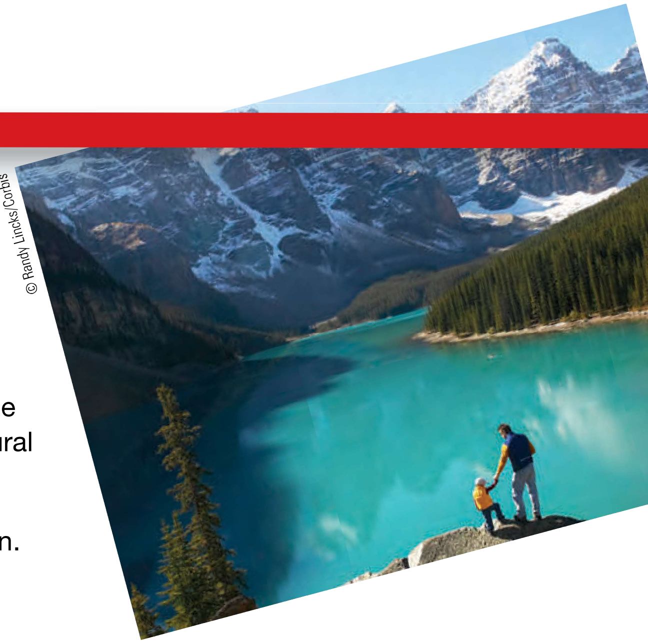
Module 18

Vision



Module Learning Objectives

18-1 Describe the characteristics of visible light, and explain the process by which the eye transforms light energy into neural messages.

18-2 Describe how the eye and brain process visual information.

18-3 Discuss the theories that help us understand color vision.

wavelength the distance from the peak of one light or sound wave to the peak of the next. Electromagnetic wavelengths vary from the short blips of cosmic rays to the long pulses of radio transmission.

18-1 What is the energy that we see as visible light, and how does the eye transform light energy into neural messages?

Our eyes receive light energy and transduce (transform) it into neural messages that our brain then processes into what we consciously see. How does such a taken-for-granted yet remarkable thing happen?

The Stimulus Input: Light Energy

When you look at a bright red tulip, what strikes your eyes is not particles of the color red but pulses of electromagnetic energy that your visual system perceives as red. What we see as visible light is but a thin slice of the whole spectrum of electromagnetic energy, ranging from imperceptibly short gamma waves to the long waves of radio transmission (**FIGURE 18.1**). Other organisms are sensitive to differing portions of the spectrum. Bees, for instance, cannot see what we perceive as red but can see ultraviolet light.

Two physical characteristics of light help determine our sensory experience of them. Light's **wavelength**—the distance from one wave peak to the next

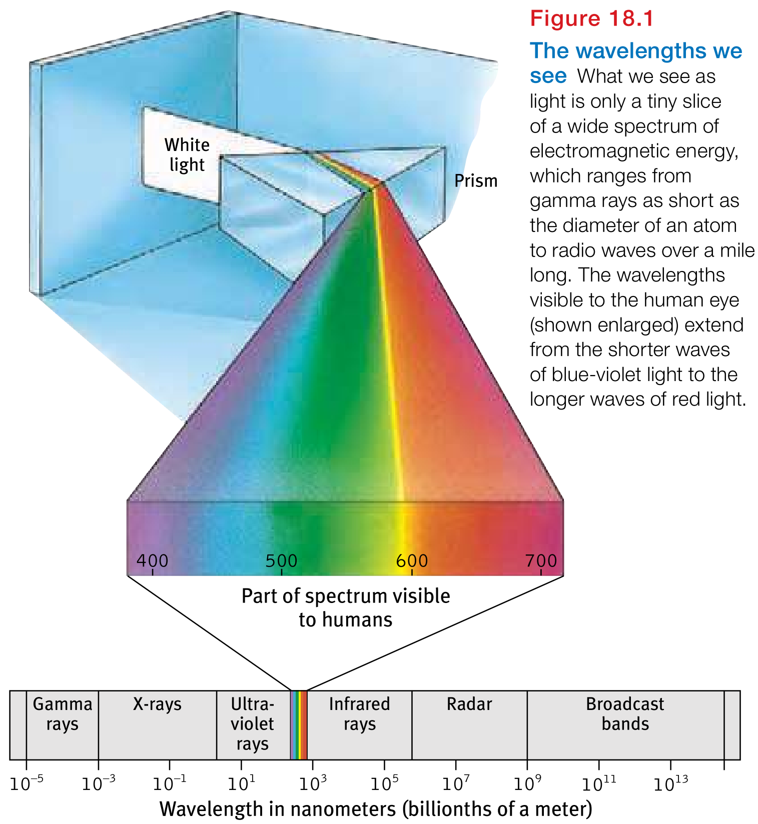


Figure 18.1
The wavelengths we see What we see as light is only a tiny slice of a wide spectrum of electromagnetic energy, which ranges from gamma rays as short as the diameter of an atom to radio waves over a mile long. The wavelengths visible to the human eye (shown enlarged) extend from the shorter waves of blue-violet light to the longer waves of red light.

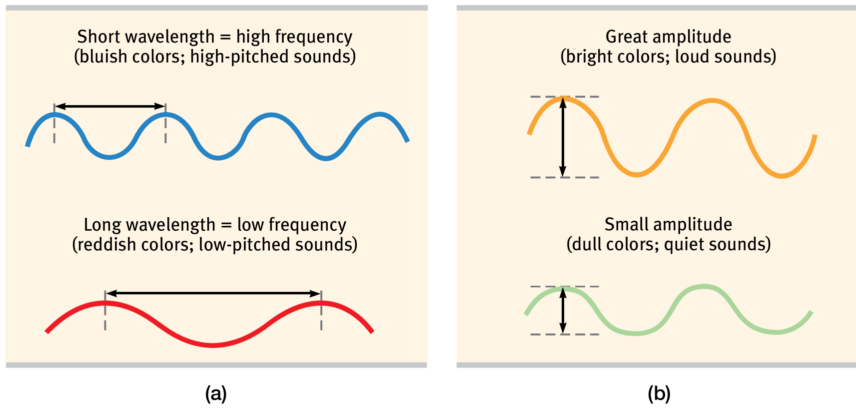


Figure 18.2
The physical properties of waves (a) Waves vary in *wavelength* (the distance between successive peaks). *Frequency*, the number of complete wavelengths that can pass a point in a given time, depends on the wavelength. The shorter the wavelength, the higher the frequency. Wavelength determines the perceived color of light (and also the *pitch* of sound). (b) Waves also vary in *amplitude* (the height from peak to trough). Wave amplitude determines the *brightness* of colors (and also the loudness of sounds).

(**FIGURE 18.2a**)—determines its **hue** (the color we experience, such as the tulip's red petals or green leaves). **Intensity,** the amount of energy in light waves (determined by a wave's *amplitude,* or height), influences brightness (Figure 18.2b). To understand *how* we transform physical energy into color and meaning, we first need to understand vision's window, the eye.

The Eye

Light enters the eye through the *cornea,* which protects the eye and bends light to provide focus (**FIGURE 18.3**). The light then passes through the **pupil,** a small adjustable opening. Surrounding the pupil and controlling its size is the **iris,** a colored muscle that dilates or constricts in response to light intensity and even to inner emotions. (When we're feeling amorous, our telltale dilated pupils and dark eyes subtly signal our interest.) Each iris is so distinctive that an iris-scanning machine can confirm your identity.

Behind the pupil is a **lens** that focuses incoming light rays into an image on the **retina,** a multilayered tissue on the eyeball's sensitive inner surface. The lens focuses the rays by changing its curvature in a process called **accommodation.**

For centuries, scientists knew that when an image of a candle passes through a small opening, it casts an inverted mirror image on a dark wall behind. If the retina receives this sort of upside-down image, as in Figure 18.3, how can we see the world right side up? The ever-curious Leonardo da Vinci had an idea: Perhaps the eye's watery fluids bend the light rays, reinverting the image to the upright position as it reaches the retina. But then in 1604, the astronomer and optics expert Johannes Kepler showed that the retina does receive upside-down images of the world (Crombie, 1964). And how could we understand such a world? "I leave it," said the befuddled Kepler, "to natural philosophers."

hue the dimension of color that is determined by the wavelength of light; what we know as the color names *blue, green*, and so forth.

intensity the amount of energy in a light or sound wave, which we perceive as brightness or loudness, as determined by the wave's amplitude.

pupil the adjustable opening in the center of the eye through which light enters.

iris a ring of muscle tissue that forms the colored portion of the eye around the pupil and controls the size of the pupil opening.

lens the transparent structure behind the pupil that changes shape to help focus images on the retina.

retina the light-sensitive inner surface of the eye, containing the receptor rods and cones plus layers of neurons that begin the processing of visual information.

accommodation the process by which the eye's lens changes shape to focus near or far objects on the retina.

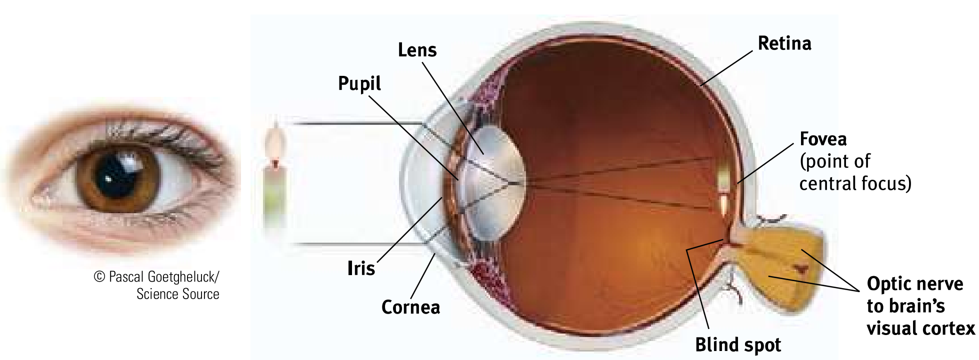


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Figure 18.3
The eye Light rays reflected from a candle pass through the cornea, pupil, and lens. The curvature and thickness of the lens change to bring nearby or distant objects into focus on the retina. Rays from the top of the candle strike the bottom of the retina, and those from the left side of the candle strike the right side of the retina. The candle's image on the retina thus appears upside down and reversed.

Eventually, the answer became clear: The retina doesn't "see" a whole image. Rather, its millions of receptor cells convert particles of light energy into neural impulses and forward those to the brain. *There,* the impulses are reassembled into a perceived, upright-seeming image.

The Retina

If you could follow a single light-energy particle into your eye, you would first make your way through the retina's outer layer of cells to its buried receptor cells, the **rods** and **cones** (**FIGURE 18.4**). There, you would see the light energy trigger chemical changes that would spark neural signals, activating nearby *bipolar cells.* The bipolar cells in turn would activate the neighboring *ganglion cells,* whose axons twine together like the strands of a rope to form the **optic nerve.** That nerve will carry the information to your brain, where your thalamus stands ready to distribute the information. The optic nerve can send nearly 1 million messages at once through its nearly 1 million ganglion fibers. (The auditory nerve, which enables hearing, carries much less information through its mere 30,000 fibers.) We pay a small price for this eye-to-brain highway. Where the optic nerve leaves the eye, there are no receptor cells—creating a **blind spot** (**FIGURE 18.5** on the next page). Close one eye and you won't see a black hole, however. Without seeking your approval, your brain fills in the hole.

Rods and cones differ in where they're found and in what they do (**TABLE 18.1** on the next page). *Cones* cluster in and around the **fovea,** the retina's area of central focus (see Figure 18.3). Many have their own hotline to the brain: Each one transmits to a single bipolar cell that helps relay the cone's individual message to the visual cortex, which devotes a large area to input from the fovea. These direct connections preserve the cones' precise information, making them better able to detect fine detail.

Rods have no such hotline; they share bipolar cells with other rods, sending combined messages. To experience this rod-cone difference in sensitivity to details, pick a word in this sentence and stare directly at it, focusing its image on the cones in your fovea. Notice that

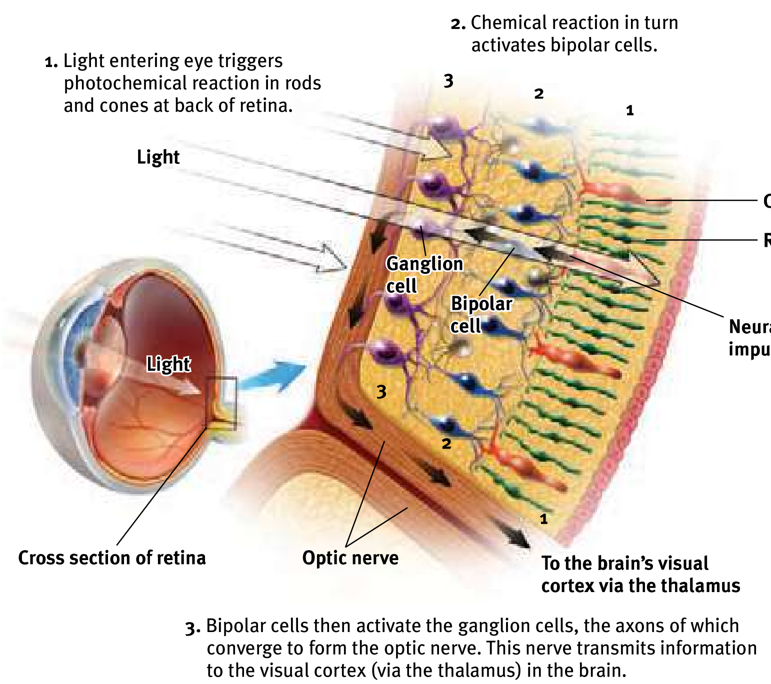


Figure 18.4 The retina's reaction to light

AP® Exam Tip

There's a lot of vocabulary here. Make sure you understand the name and the function of each of the parts of the eye. To learn how all the parts fit together, it may help to make rough sketches (you don't need to be an artist to try this!) and then compare your sketches with Figures 18.3 and 18.4. You'll be better off making several quick, rough sketches than one time-consuming, nicely drawn one.

rods retinal receptors that detect black, white, and gray; necessary for peripheral and twilight vision, when cones don't respond.

cones retinal receptor cells that are concentrated near the center of the retina and that function in daylight or in well-lit conditions. The cones detect fine detail and give rise to color sensations.

optic nerve the nerve that carries neural impulses from the eye to the brain.

blind spot the point at which the optic nerve leaves the eye, creating a "blind" spot because no receptor cells are located there.

fovea the central focal point in the retina, around which the eye's cones cluster.

Figure 18.5
The blind spot There are no receptor cells where the optic nerve leaves the eye. This creates a blind spot in your vision. To demonstrate, first close your left eye, look at the spot, and move the page to a distance from your face at which one of the cars disappears (which one do you predict it will be?). Repeat with the other eye closed—and note that now the other car disappears. Can you explain why?

words a few inches off to the side appear blurred? Their image strikes the outer regions of your retina, where rods predominate. Thus, when driving or biking, you can detect a car in your peripheral vision well before perceiving its details.

Cones also enable you to perceive color. In dim light they become ineffectual, so you see no colors. Rods, which enable black-and-white vision, remain sensitive in dim light. Several rods will funnel their faint energy output onto a single bipolar cell. Thus, cones and rods each provide a special sensitivity—cones to detail and color, and rods to faint light.

Table 18.1 Receptors in the Human Eye: Rod-Shaped Rods and Cone-Shaped Cones

	Cones	Rods
Number	6 million	120 million
Location in retina	Center	Periphery
Sensitivity in dim light	Low	High
Color sensitivity	High	Low
Detail sensitivity	High	Low

Omikron/Science Source

When you enter a darkened theater or turn off the light at night, your eyes adapt. Your pupils dilate to allow more light to reach your retina, but it typically takes 20 minutes or more before your eyes fully adapt. You can demonstrate dark adaptation by closing or covering one eye for up to 20 minutes. Then make the light in the room not quite bright enough to read this book with your open eye. Now open the dark-adapted eye and read (easily). This period of dark adaptation matches the average natural twilight transition between the Sun's setting and darkness. How wonderfully made we are.

Andrey Armyagov /Shutterstock

Visual Information Processing

18-2 How do the eye and the brain process visual information?

Visual information percolates through progressively more abstract levels on its path through the thalamus and on to the visual cortex. At the entry level, information processing begins in the retina's neural layers, which are actually brain tissue that has migrated to the eye during early fetal development. These layers don't just pass along electrical impulses; they also help to encode and analyze sensory information. The third neural layer in a frog's eye, for example, contains the "bug detector" cells that fire only in response to moving fly-like stimuli.

After processing by your retina's nearly 130 million receptor rods and cones, information travels to your bipolar cells, then to your million or so ganglion cells, and through their axons making up the optic nerve to your brain. Any given retinal area relays its information to a corresponding location in the visual cortex, in the occipital lobe at the back of your brain (**FIGURE 18.6**).

The same sensitivity that enables retinal cells to fire messages can lead them to misfire, as you can demonstrate for yourself. Turn your eyes to the left, close them, and then gently rub the right side of your right eyelid with your fingertip. Note the patch of light to the left, moving as your finger moves. Why do you see light? Why at the left?

Your retinal cells are so responsive that even pressure triggers them. But your brain interprets their firing as light. Moreover, it interprets the light as coming from the left—the normal direction of light that activates the right side of the retina.

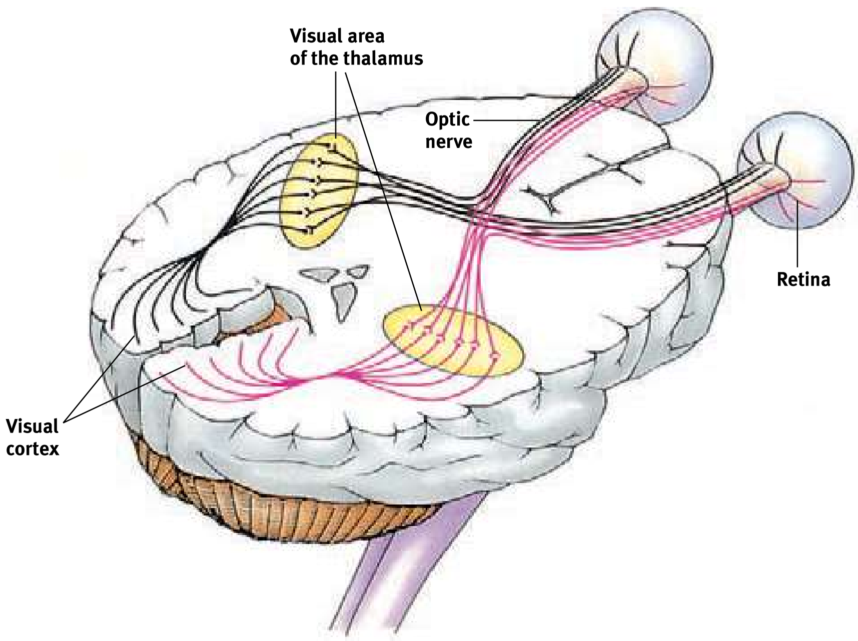


Figure 18.6
Pathway from the eyes to the visual cortex Ganglion axons forming the optic nerve run to the thalamus, where they synapse with neurons that run to the visual cortex.

Feature Detection

David Hubel and Torsten Wiesel (1979) received a Nobel Prize for their work on **feature detectors.** These specialized neurons in the occipital lobe's visual cortex receive information from individual ganglion cells in the retina. Feature detector cells derive their name from their ability to respond to a scene's specific features—to particular edges, lines, angles, and movements. These cells pass this information to other cortical areas, where teams of cells *(supercell clusters)* respond to more complex patterns. As we noted in Module 12, one temporal lobe area by your right ear (**FIGURE 18.7** on the next page) enables you to perceive faces and, thanks to a specialized neural network, to recognize them from varied viewpoints (Connor, 2010). If this region were damaged, you might recognize other forms and objects, but, like Heather Sellers, not familiar faces. When researchers temporarily disrupt the brain's face-processing areas with magnetic pulses, people are unable to recognize faces.

feature detectors nerve cells in the brain that respond to specific features of the stimulus, such as shape, angle, or movement.

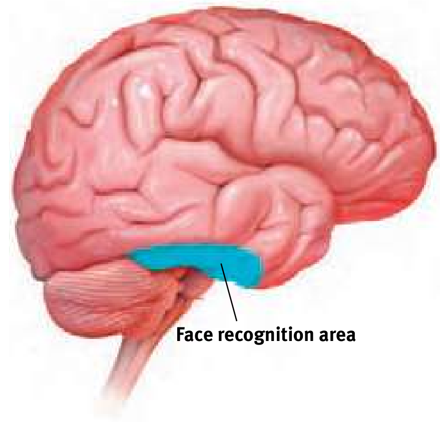
They will, however, be able to recognize houses, because the brain's face-perception occurs separately from its object-perception (McKone et al., 2007; Pitcher et al., 2007). Thus, functional MRI (fMRI) scans show different brain areas activating when people

AP® Exam Tip

Warning! Sometimes students spend so much time mastering the parts of the eye that they skim over the part you're about to read. Do not forget that you see with your brain as much as you see with your eyes.

Figure 18.7

Face recognition processing In social animals such as humans, a dedicated brain system (shown here in a right-facing brain) assigns considerable neural bandwidth to the crucial task of face recognition.



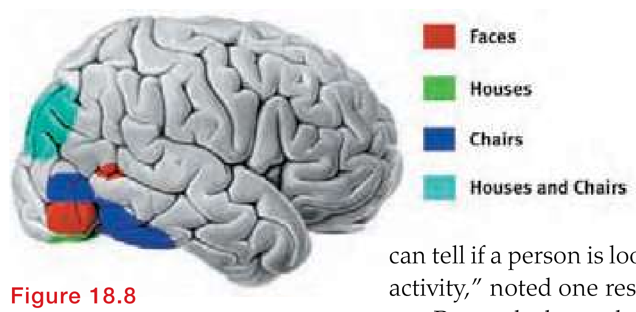


Figure 18.8

The telltale brain Looking at faces, houses, and chairs activates different brain areas in this right-facing brain.

view varied objects (Downing et al., 2001). Brain activity is so specific (**FIGURE 18.8**) that, with the help of brain scans, "we can tell if a person is looking at a shoe, a chair, or a face, based on the pattern of their brain activity," noted one researcher (Haxby, 2001).

Research shows that for biologically important objects and events, monkey brains (and surely ours as well) have a "vast visual encyclopedia" distributed as specialized cells (Perrett et al., 1988, 1992, 1994). These cells respond to one type of stimulus, such as a specific gaze, head angle, posture, or body movement. Other supercell clusters integrate this information and fire only when the cues collectively indicate the direction of someone's attention and approach. This instant analysis, which aided our ancestors' survival, also helps a soccer goalkeeper anticipate the direction of an impending kick, and a driver anticipate a pedestrian's next movement.

FIFA via Getty Images

Well-developed supercells In this 2011 World Cup match, USA's Abby Wambach instantly processed visual information about the positions and movements of Brazil's defenders and goalkeeper and somehow managed to get the ball around them all and into the net.

parallel processing the processing of many aspects of a problem simultaneously; the brain's natural mode of information processing for many functions, including vision. Contrasts with the step-by-step (serial) processing of most computers and of conscious problem solving.

Parallel Processing

Our brain achieves these and other remarkable feats by means of **parallel processing:** doing many things at once. To analyze a visual scene, the brain divides it into subdimensions—motion, form, depth, color—and works on each aspect simultaneously (Livingstone & Hubel, 1988). We then construct our perceptions by integrating the separate but parallel work of these different visual teams (**FIGURE 18.9**).

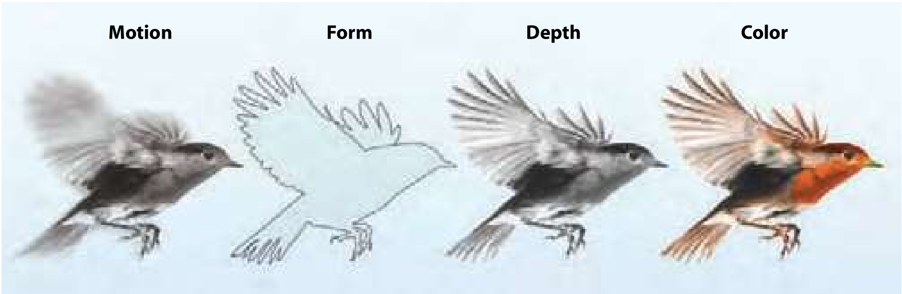


Figure 18.9
Parallel processing Studies of patients with brain damage suggest that the brain delegates the work of processing motion, form, depth, and color to different areas. After taking a scene apart, the brain integrates these subdimensions into the perceived image. How does the brain do this? The answer to this question is the Holy Grail of vision research.

To recognize a face, your brain integrates information projected by your retinas to several visual cortex areas, compares it with stored information, and enables you to recognize the face: *Grandmother!* Scientists are debating whether this stored information is contained in a single cell or distributed over a network. Some supercells—"grandmother cells"—do appear to respond very selectively to 1 or 2 faces in 100 (Bowers, 2009). The whole facial recognition process requires tremendous brain power—30 percent of the cortex (10 times the brain area devoted to hearing).

Destroy or disable a neural workstation for a visual subtask, and something peculiar results, as happened to "Mrs. M." (Hoffman, 1998). Since a stroke damaged areas near the rear of both sides of her brain, she has been unable to perceive movement. People in a room seem "suddenly here or there but I have not seen them moving." Pouring tea into a cup is a challenge because the fluid appears frozen—she cannot perceive it rising in the cup.

After stroke or surgery damage to the brain's visual cortex, others have experienced *blindsight* (a phenomenon we met in Module 13). Shown a series of sticks, they report seeing nothing. Yet when asked to guess whether the sticks are vertical or horizontal, their visual intuition typically offers the correct response. When told, "You got them all right," they are astounded. There is, it seems, a second "mind"—a parallel processing system—operating unseen. These separate visual systems for perception and action illustrate dual processing—the two-track mind.

* * *

Think about the wonders of visual processing. As you look at that tiger in the zoo, information enters your eyes, is transduced, and is sent to your brain as millions of neural impulses. As your brain buzzes with activity, various areas focus on different aspects of the tiger's image. Finally, in some as yet mysterious way, these separate teams pool their work to produce a meaningful image, which you compare with previously stored images and recognize: a crouching tiger (**FIGURE 18.10**).

"I am . . . wonderfully made."
-King David, Psalm 139:14

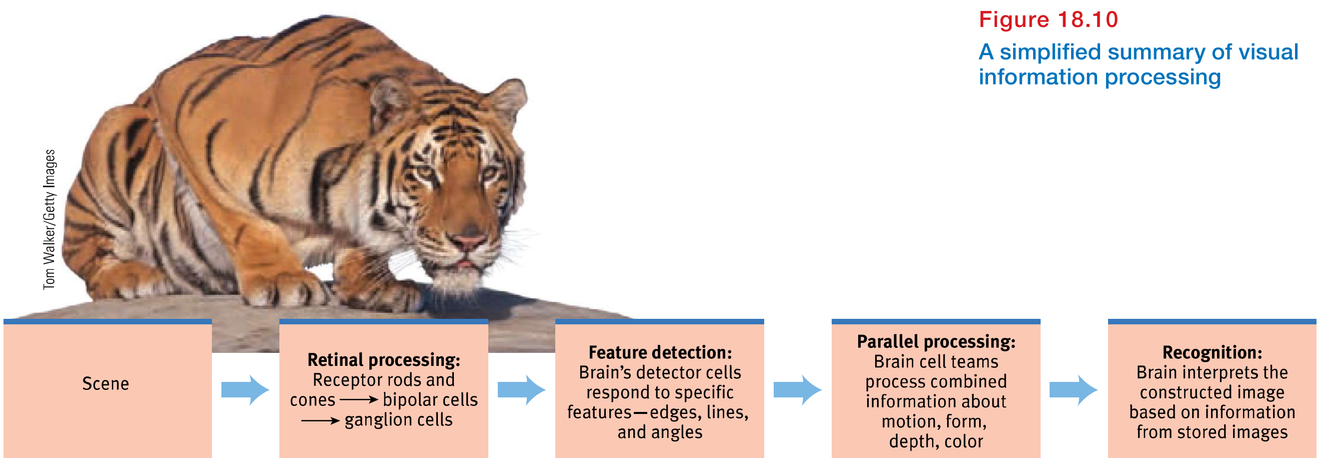


Figure 18.10
A simplified summary of visual information processing

Think, too, about what is happening as you read this page. The printed squiggles are transmitted by reflected light rays onto your retina, which triggers a process that sends formless nerve impulses to several areas of your brain, which integrates the information and decodes meaning, thus completing the transfer of information across time and space from my mind to your mind. That all of this happens instantly, effortlessly, and continuously is indeed awesome. As Roger Sperry (1985) observed, the "insights of science give added, not lessened, reasons for awe, respect, and reverence."

Color Vision

18-3 What theories help us understand color vision?

We talk as though objects possess color: "A tomato is red." Perhaps you have pondered the old question, "If a tree falls in the forest and no one hears it, does it make a sound?" We can ask the same of color: If no one sees the tomato, is it red?

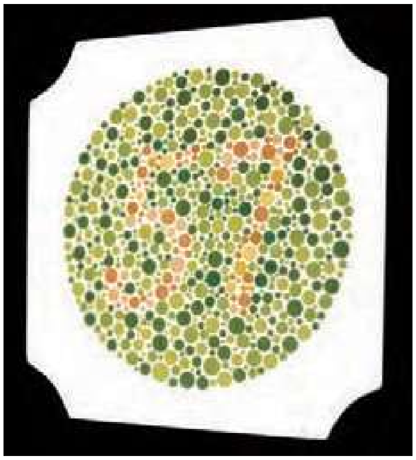
The answer is *No.* First, the tomato is everything *but* red, because it *rejects* (reflects) the long wavelengths of red. Second, the tomato's color is our mental construction. As Isaac Newton (1704) noted, "The [light] rays are not colored." Color, like all aspects of vision, resides not in the object but in the theater of our brain, as evidenced by our dreaming in color.

"Only mind has sight and hearing; all things else are deaf and blind." -Epicharmus, *Fragments*, 550 b.c.e.

One of vision's most basic and intriguing mysteries is how we see the world in color. How, from the light energy striking the retina, does the brain manufacture our experience of color—and of such a multitude of colors? Our difference threshold for colors is so low that we can discriminate more than 1 million different color variations (Neitz et al., 2001). At least most of us can. For about 1 person in 50, vision is color deficient—and that person is usually male, because the defect is genetically sex-linked.

Why is some people's vision deficient? To answer that question, we need to understand how normal color vision works. Modern detective work on this mystery began in the nineteenth century, when Hermann von Helmholtz built on the insights of an English physicist, Thomas Young. Knowing that any color can be created by combining the light waves of three primary colors—red, green, and blue—Young and von Helmholtz inferred that the eye must have three corresponding types of color receptors. Years later, researchers measured the response of various cones to different color stimuli and confirmed the **Young-Helmholtz trichromatic (three-color) theory,** which implies that the receptors do their color magic in teams of three. Indeed, the retina has three types of color receptors, each especially sensitive to one of three colors. And those colors are, in fact, red, green, and blue. When we stimulate combinations of these cones, we see other colors. For example, there are no receptors especially sensitive to yellow. We see yellow when mixing red and green light, which stimulates both red-sensitive and green-sensitive cones.

Young-Helmholtz trichromatic (three-color) theory the theory that the retina contains three different color receptors—one most sensitive to red, one to green, one to blue—which, when stimulated in combination, can produce the perception of any color.



Annabella Bluesky/Science Source

Figure 18.11 Color-deficient vision People who suffer red-green deficiency have trouble perceiving the number within the design.

Most people with color-deficient vision are not actually "colorblind." They simply lack functioning red- or green-sensitive cones, or sometimes both. Their vision—perhaps unknown to them, because their lifelong vision *seems* normal—is monochromatic (one-color) or dichromatic (two-color) instead of trichromatic, making it impossible to distinguish the red and green in **FIGURE 18.11** (Boynton, 1979). Dogs, too, lack receptors for the wavelengths of red, giving them only limited, dichromatic color vision (Neitz et al., 1989).

Figure 18.12
Afterimage effect Stare at the center of the flag for a minute and then shift your eyes to the dot in the white space beside it. What do you see? (After tiring your neural response to black, green, and yellow, you should see their opponent colors.) Stare at a white wall and note how the size of the flag grows with the projection distance.

But how is it that people blind to red and green can often still see yellow? And why does yellow appear to be a pure color and not a mixture of red and green, the way purple is of red and blue? As Ewald Hering soon noted, trichromatic theory leaves some parts of the color vision mystery unsolved.

Hering, a physiologist, found a clue in *afterimages.* Stare at a green square for a while and then look at a white sheet of paper, and you will see red, green's *opponent color.* Stare at a yellow square and its opponent color, blue, will appear on the white paper. (To experience this, try the flag demonstration in **FIGURE 18.12**.) Hering surmised that there must be two additional color processes, one responsible for red-versus-green perception, and one for blue-versus-yellow.

Indeed, a century later, researchers also confirmed Hering's **opponent-process theory.** Three sets of opponent retinal processes—*red-green, yellow-blue,* and *white-black*—enable color vision. In the retina and in the thalamus (where impulses from the retina are relayed en route to the visual cortex), some neurons are turned "on" by red but turned "off" by green. Others are turned on by green but off by red (DeValois & DeValois, 1975). Like red and green marbles sent down a narrow tube, "red" and "green" messages cannot both travel at once. So we do not experience a reddish green. (Red and green are thus opponents.) But red and blue travel in separate channels, so we *can* see a reddish-blue magenta.

opponent-process theory the theory that opposing retinal processes (red-green, yellow-blue, white-black) enable color vision. For example, some cells are stimulated by green and inhibited by red; others are stimulated by red and inhibited by green.

So how do we explain afterimages, such as in the flag demonstration? By staring at green, we tire our green response. When we then stare at white (which contains all colors, including red), only the red part of the green-red pairing will fire normally.

The present solution to the mystery of color vision is therefore roughly this: Color processing occurs in two stages. The retina's red, green, and blue cones respond in varying degrees to different color stimuli, as the Young-Helmholtz trichromatic theory suggested. Their signals are then processed by the nervous system's opponent-process cells, as Hering's theory proposed.

Before You Move On

▶ ASK YOURSELF

If you were forced to give up one sense, which would it be? Why?

▶ TEST YOURSELF

What is the rapid sequence of events that occurs when you see and recognize a friend?

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

Module 18 Review

18-1 What is the energy that we see as visible light, and how does the eye transform light energy into neural messages?

- The *hue* we perceive in light depends on its *wavelength,* and its brightness depends on its *intensity.*
- After entering the eye and being focused by the *lens,* light energy particles (from a thin slice of the broad spectrum of electromagnetic energy) strike the eye's inner surface, the *retina.* The retina's light-sensitive *rods* and color-sensitive *cones* convert the light energy into neural impulses.

18-2 How do the eye and the brain process visual information?

- After processing by bipolar and ganglion cells in the eyes' retina, neural impulses travel through the *optic nerve,* to the thalamus, and on to the visual cortex. In the visual cortex, *feature detectors* respond to specific features of the visual stimulus. Supercell clusters in other critical brain areas respond to more complex patterns.
- Through *parallel processing,* the brain handles many aspects of vision (color, movement, form, and depth) simultaneously. Other neural teams integrate the results, comparing them with stored information and enabling perceptions.

18-3 What theories help us understand color vision?

- *The Young-Helmholtz trichromatic (three-color) theory* proposed that the retina contains three types of color receptors. Contemporary research has found three types of cones, each most sensitive to the wavelengths of one of the three primary colors of light (red, green, or blue).
- Hering's *opponent-process theory* proposed three additional color processes (red-versus-green, blue-versus-yellow, black-versus-white). Contemporary research has confirmed that, en route to the brain, neurons in the retina and the thalamus code the color-related information from the cones into pairs of opponent colors.
- These two theories, and the research supporting them, show that color processing occurs in two stages.

Multiple-Choice Questions

1. Light's __________ is the distance from one wave peak to the next. This dimension determines the __________ we experience.

a. hue; wavelength
b. wavelength; hue
c. hue; intensity
d. wavelength; intensity
e. intensity; wavelength

2. What do we call the specialized neurons in the occipital lobe's visual cortex that respond to particular edges, lines, angles, and movements?

a. Rods
b. Cones
c. Foveas
d. Feature detectors
e. Ganglion cells

3. Which of the following explains reversed-color afterimages?

a. Young-Helmholtz trichromatic theory
b. The blind spot
c. Hering's opponent-process theory
d. Feature detectors
e. Parallel processing

4. Your best friend decides to paint her room an extremely bright electric blue. Which of the following best fits the physical properties of the color's light waves?

a. No wavelength; large amplitude
b. Short wavelength; large amplitude
c. Short wavelength; small amplitude
d. Long wavelength; large amplitude
e. No wavelength; small amplitude

5. What do we call the transparent, protective layer that light passes through as it enters the eye?

a. Pupil
b. Iris
c. Cornea
d. Lens
e. Fovea

Practice FRQs

1. As light reflected off an object reaches your eye, it passes through several structures before it reaches the retina. Describe three of these structures, including the function of each.

Answer

1 point: The cornea is at the front of the eye. It bends and focuses the light waves.

1 point: The pupil is the opening through which light enters the eyeball. It is surrounded by the iris, which can expand or contract to allow more or less light to pass through the pupil.

1 point: The lens is the transparent structure behind the pupil that changes shape to help focus images on the retina.

2. Explain two theories of color vision in humans. How does one of them explain color deficiency?

(3 points)

Module 19

Visual Organization and Interpretation

Rob Kavanagh/Alamy

Module Learning Objectives

19-1 Describe Gestalt psychologists' understanding of perceptual organization, and explain how figure-ground and grouping principles contribute to our perceptions.

19-2 Explain how we use binocular and monocular cues to perceive the world in three dimensions and perceive motion.

19-3 Explain how perceptual constancies help us organize our sensations into meaningful perceptions.

19-4 Describe what research on restored vision, sensory restriction, and perceptual adaptation reveals about the effects of experience on perception.

Visual Organization

19-1 How did the Gestalt psychologists understand perceptual organization, and how do figure-ground and grouping principles contribute to our perceptions?

It's one thing to understand how we see shapes and colors. But how do we organize and interpret those sights (or sounds or tastes or smells) so that they become meaningful perceptions—a rose in bloom, a familiar face, a sunset?

Early in the twentieth century, a group of German psychologists noticed that when given a cluster of sensations, people tend to organize them into a **gestalt,** a German word meaning a "form" or a "whole." For example, look at **FIGURE 19.1**. Note that the individual elements of this figure, called a *Necker cube,* are really nothing but eight blue circles, each containing three converging white lines. When we view these elements all together, however, we see a cube that sometimes reverses direction. This phenomenon nicely illustrates a favorite saying of Gestalt psychologists: In perception, the whole may exceed the sum of its parts. If we combine sodium (a corrosive metal) with chlorine (a poisonous gas), something very different emerges—table salt. Likewise, a unique perceived form emerges from a stimulus' components (Rock & Palmer, 1990).

Over the years, the Gestalt psychologists demonstrated many principles we use to organize our sensations into perceptions. Underlying all of them is a fundamental truth: *Our brain does more than register information about the world.* Perception is not just opening a shutter and letting a picture print itself on the brain. We filter incoming information and construct perceptions. Mind matters.

gestalt an organized whole. Gestalt psychologists emphasized our tendency to integrate pieces of information into meaningful wholes.

AP® Exam Tip

The Necker cube is an excellent vehicle for understanding the distinction between sensation and perception. The only visual stimuli are the blue wedges. The circles, lines, and cube are all the products of perception—they are in your mind and not on the page.

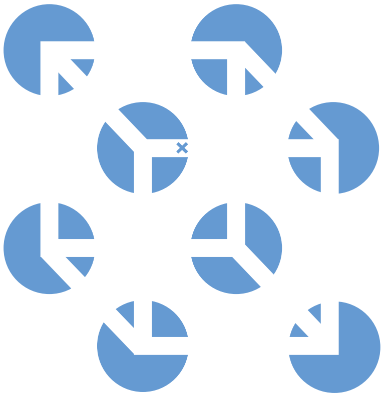


Figure 19.1
A Necker cube What do you see: circles with white lines, or a cube? If you stare at the cube, you may notice that it reverses location, moving the tiny X in the center from the front edge to the back. At times, the cube may seem to float in front of the page, with circles behind it. At other times, the circles may become holes in the page through which the cube appears, as though it were floating behind the page. There is far more to perception than meets the eye. (From Bradley et al., 1976.)

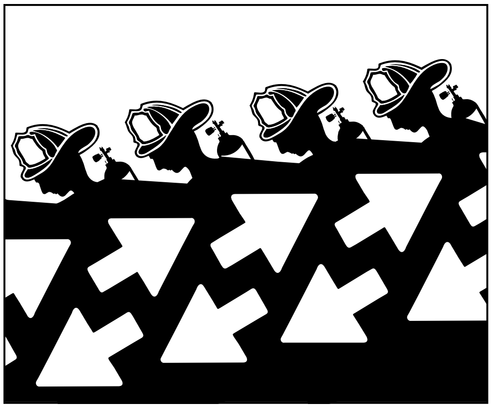


Figure 19.2
Reversible figure and ground

Form Perception

Imagine designing a video-computer system that, like your eye-brain system, can recognize faces at a glance. What abilities would it need?

FIGURE AND GROUND

To start with, the video-computer system would need to separate faces from their backgrounds. Likewise, in our eye-brain system, our first perceptual task is to perceive any object (the *figure*) as distinct from its surroundings (the *ground*). Among the voices you hear at a party, the one you attend to becomes the figure; all others are part of the ground. As you read, the words are the figure; the white paper is the ground. Sometimes the same stimulus can trigger more than one perception. In **FIGURE 19.2,** the **figure-ground** relationship continually reverses—but always we organize the stimulus into a figure seen against a ground.

figure-ground the organization of the visual field into objects (the *figures*) that stand out from their surroundings (the *ground*).

grouping the perceptual tendency to organize stimuli into coherent groups.

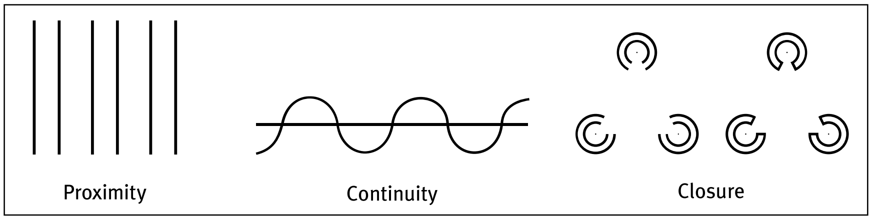
GROUPING

Having discriminated figure from ground, we (and our video-computer system) must also organize the figure into a *meaningful* form. Some basic features of a scene—such as color, movement, and light-dark contrast—we process instantly and automatically (Treisman, 1987). Our minds bring order and form to stimuli by following certain rules for **grouping**. These rules, identified by the Gestalt psychologists and applied even by infants, illustrate how the perceived whole differs from the sum of its parts (Quinn et al., 2002; Rock & Palmer, 1990). Three examples:

PROXIMITY We group nearby figures together. We see not six separate lines, but three sets of two lines.

CONTINUITY We perceive smooth, continuous patterns rather than discontinuous ones. This pattern could be a series of alternating semicircles, but we perceive it as two continuous lines—one wavy, one straight.

CLOSURE We fill in gaps to create a complete, whole object. Thus we assume that the circles on the right are complete but partially blocked by the (illusory) triangle. Add nothing more than little line segments to close off the circles and your brain stops constructing a triangle. Such principles usually help us construct reality.



Depth Perception

19-2 How do we use binocular and monocular cues to perceive the world in three dimensions and perceive motion?

From the two-dimensional images falling on our retinas, we somehow organize three-dimensional perceptions. **Depth perception** enables us to estimate an object's distance from us. At a glance, we can estimate the distance of an oncoming car or the height of a house. Depth perception is partly innate, as Eleanor Gibson and Richard Walk (1960) discovered using a model of a cliff with a drop-off area (which was covered by sturdy glass). Gibson's inspiration for these **visual cliff** experiments occurred while she was picnicking on the rim of the Grand Canyon. She wondered: Would a toddler peering over the rim perceive the dangerous drop-off and draw back?

Figure 19.3
Visual cliff Eleanor Gibson and Richard Walk devised a miniature cliff with a glass-covered drop-off to determine whether crawling infants can perceive depth. Even when coaxed, infants are reluctant to venture onto the glass over the cliff (Gibson & Walk, 1960).

Back in their Cornell University laboratory, Gibson and Walk placed 6- to 14-month-old infants on the edge of a safe canyon and had the infants' mothers coax them to crawl out onto the glass (**FIGURE 19.3**). Most infants refused to do so, indicating that they could perceive depth.

Had they *learned* to perceive depth? Learning seems to be part of the answer because crawling, no matter when it begins, seems to increase infants' wariness of heights (Campos et al., 1992). Yet, the researchers observed, mobile newborn animals come prepared to perceive depth. Even those with virtually no visual experience—including young kittens, a day-old goat, and newly hatched chicks—will not venture across the visual cliff. Thus, it seems that biology predisposes us to be wary of heights and experience amplifies that fear.

How do we perceive depth? *How* do we transform two differing two-dimensional (2-D) retinal images into a single three-dimensional (3-D) perception? Our brain constructs these perceptions using information supplied by one or both eyes.

depth perception the ability to see objects in three dimensions although the images that strike the retina are two-dimensional; allows us to judge distance.

visual cliff a laboratory device for testing depth perception in infants and young animals.

binocular cues depth cues, such as retinal disparity, that depend on the use of two eyes.

retinal disparity a binocular cue for perceiving depth: By comparing images from the retinas in the two eyes, the brain computes distance—the greater the disparity (difference) between the two images, the closer the object.

BINOCULAR CUES

Try this: With both eyes open, hold two pens or pencils in front of you and touch their tips together. Now do so with one eye closed. With one eye, the task becomes noticeably more difficult, demonstrating the importance of **binocular cues** in judging the distance of nearby objects. Two eyes are better than one.

Because your eyes are about 2½ inches apart, your retinas receive slightly different images of the world. By comparing these two images, your brain can judge how close an object is to you. The greater the **retinal disparity,** or difference between the two images, the closer the object. Try it. Hold your two index fingers, with the tips about half an inch apart, directly in front of your nose, and your retinas will receive quite different views. If you close one eye and then the other, you can see the difference. (You may also create a finger sausage, as in **FIGURE 19.4.**) At a greater distance—say, when you hold your fingers at arm's length—the disparity is smaller.

We could easily build this feature into our video-computer system. Moviemakers can simulate or exaggerate retinal disparity by filming a scene with two cameras placed a few inches apart. Viewers then wear glasses that allow the left eye to see only the image from the left camera, and the right eye to see only the image from the right camera.

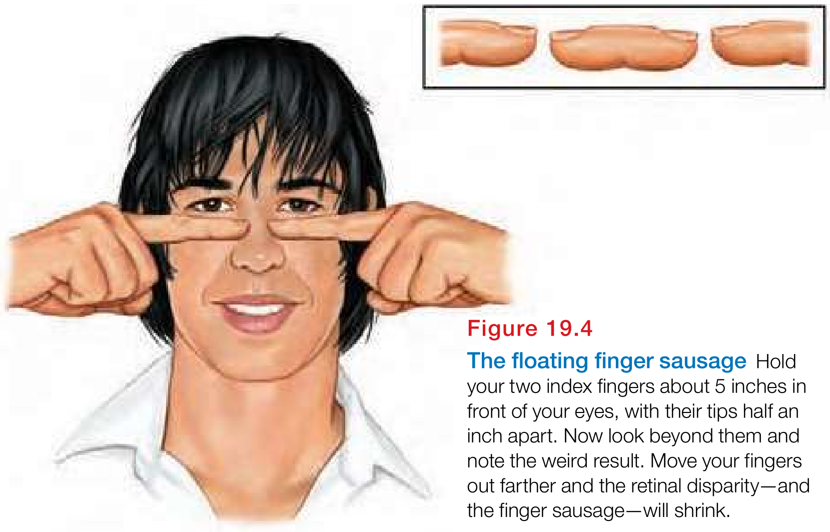


Figure 19.4

The floating finger sausage Hold your two index fingers about 5 inches in front of your eyes, with their tips half an inch apart. Now look beyond them and note the weird result. Move your fingers out farther and the retinal disparity—and the finger sausage—will shrink.

FYI

Carnivorous animals, including humans, have eyes that enable forward focus on a prey and offer binocular vision-enhanced depth perception. Grazing herbivores, such as horses and sheep, typically have eyes on the sides of their skull. Although lacking binocular depth perception, they have sweeping peripheral vision.

The resulting 3-D effect, as 3-D movie fans know, mimics or exaggerates normal retinal disparity. Similarly, twin cameras in airplanes can take photos of terrain for integration into 3-D maps.

MONOCULAR CUES

How do we judge whether a person is 10 or 100 meters away? Retinal disparity won't help us here, because there won't be much difference between the images cast on our right and left retinas. At such distances, we depend on **monocular cues** (depth cues available to each eye separately). See **FIGURE 19.5** on the next page for some examples.

monocular cues depth cues, such as interposition and linear perspective, available to either eye alone.

phi phenomenon an illusion of movement created when two or more adjacent lights blink on and off in quick succession.

Motion Perception

Imagine that you could perceive the world as having color, form, and depth but that you could not see motion. Not only would you be unable to bike or drive, you would have trouble writing, eating, and walking.

Normally your brain computes motion based partly on its assumption that shrinking objects are retreating (not getting smaller) and enlarging objects are approaching. But you are imperfect at motion perception. Large objects, such as trains, appear to move more slowly than smaller objects, such as cars, moving at the same speed. (Perhaps at an airport you've noticed that jumbo jets seem to land more slowly than little jets.)

To catch a fly ball, softball or cricket players (unlike drivers) want to achieve a collision—with the ball that's flying their way. To accomplish that, they follow an unconscious rule—one they can't explain but know intuitively: Run to keep the ball at a constantly increasing angle of gaze (McBeath et al., 1995). A dog catching a Frisbee does the same (Shaffer et al., 2004).

"Sometimes I wonder: Why is that Frisbee getting bigger? And then it hits me." -Anonymous

The brain also perceives continuous movement in a rapid series of slightly varying images (a phenomenon called *stroboscopic movement*). As film animation artists know well, you can create this illusion by flashing 24 still pictures a second. The motion we then see in popular action adventures is not in the film, which merely presents a superfast slide show. We construct that motion in our heads, just as we construct movement in blinking marquees and holiday lights. When two adjacent stationary lights blink on and off in quick succession, we perceive a single light moving back and forth between them. Lighted signs exploit this **phi phenomenon** with a succession of lights that creates the impression of, say, a moving arrow.

"From there to here, from here to there, funny things are everywhere." -Dr. Seuss, *One Fish, Two Fish, Red Fish, Blue Fish,* 1960

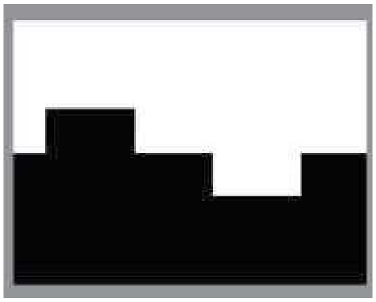


Image courtesy Shaun P. Vecera, Ph.D., adapted from stimuli that appeared in Vecera et al., 2002

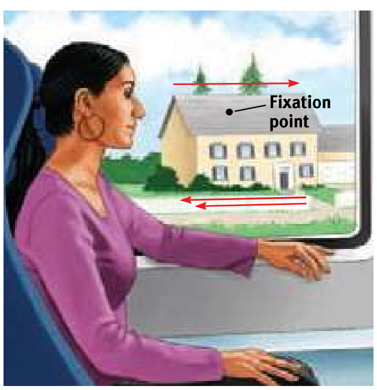
Relative height We perceive objects higher in our field of vision as farther away. Because we assume the lower part of a figure-ground illustration is closer, we perceive it as figure (Vecera et al., 2002). Invert this illustration and the black will become ground, like a night sky.

Relative size If we assume two objects are similar in size, *most* people perceive the one that casts the smaller retinal image as farther away.

© Philip Mugridge/Alamy

Interposition *Interpose* means "to come between." If one object partially blocks our view of another, we perceive it as closer.

Relative motion As we move, objects that are actually stable may appear to move. If while riding on a bus you fix your gaze on some point—say, a house—the objects beyond the fixation point will appear to move with you. Objects in front of the point will appear to move backward. The farther an object is from the fixation point, the faster it will seem to move.



Direction of passenger's motion →

Linear perspective Parallel lines appear to meet in the distance. The sharper the angle of convergence, the greater the perceived distance.

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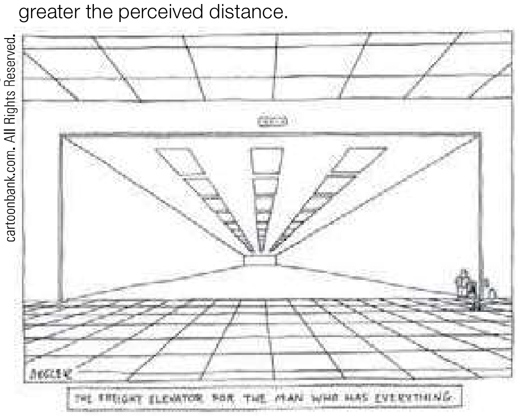


Light and shadow Shading produces a sense of depth consistent with our assumption that light comes from above. If you invert this illustration, the hollow will become a hill.

From "Perceiving Shape From Shading" by Vilayanur S. Ramachandran. Copyright © 1988 by Scientific American, Inc. All Rights Reserved.

Figure 19.5
Monocular depth cues

AP® Exam Tip

The illustrations in Figure 19.5 provide you with excellent opportunities to practice identifying monocular depth cues. To really demonstrate your understanding, look for these cues in other drawings and photographs. There are almost always cues to identify.

Perceptual Constancy

19-3 How do perceptual constancies help us organize our sensations into meaningful perceptions?

So far, we have noted that our video-computer system must perceive objects as we do—as having a distinct form, location, and perhaps motion. Its next task is to recognize objects without being deceived by changes in their color, brightness, shape, or size—a top-down process called **perceptual constancy.** Regardless of the viewing angle, distance, and illumination, we can identify people and things in less time than it takes to draw a breath, a feat that would be a monumental challenge for even advanced computers and that has intrigued researchers for decades.

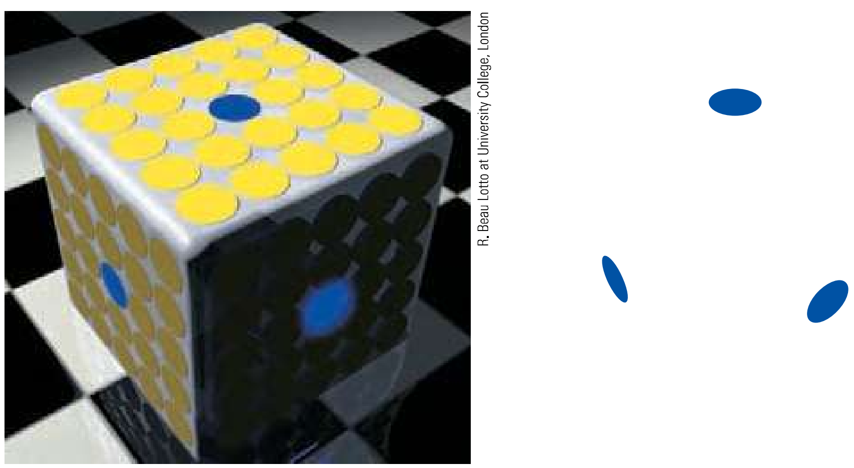
COLOR AND BRIGHTNESS CONSTANCIES

Color does not reside in an object. Our experience of color depends on the object's *context.* If you view an isolated tomato through a paper tube, its color would seem to change as the light—and thus the wavelengths reflected from its surface—changed. But if you viewed that tomato as one item in a bowl of fresh fruit and vegetables, its color would remain roughly constant as the lighting shifts. This perception of consistent color is known as **color constancy.**

perceptual constancy perceiving objects as unchanging (having consistent shapes, size, brightness, and color) even as illumination and retinal images change.

color constancy perceiving familiar objects as having consistent color, even if changing illumination alters the wavelengths reflected by the object.

Though we take color constancy for granted, this ability is truly remarkable. A blue poker chip under indoor lighting reflects wavelengths that match those reflected by a sunlit gold chip (Jameson, 1985). Yet bring a bluebird indoors and it won't look like a goldfinch. The color is not in the bird's feathers. You and I see color thanks to our brain's computations of the light reflected by an object *relative to the objects surrounding it*. (But only if we grew up with normal light, it seems. Monkeys raised under a restricted range of wavelengths later have great difficulty recognizing the same color when illumination varies [Sugita, 2004].) **FIGURE 19.6** dramatically illustrates the ability of a blue object to appear very different in three different contexts. Yet we have no trouble seeing these disks as blue.



(a) (b)

R. Beau Lotto at University College, London

Figure 19.6
Color depends on context
(a) Believe it or not, these three blue disks are identical in color.
(b) Remove the surrounding context and see what results.

Similarly, *brightness constancy* (also called *lightness constancy*) depends on context. We perceive an object as having a constant brightness even while its illumination varies. This perception of constancy depends on *relative luminance*—the amount of light an object reflects *relative to its surroundings* (**FIGURE 19.7** on the next page). White paper reflects 90 percent of the light falling on it; black paper, only 10 percent. Although a black paper viewed in sunlight may reflect 100 times more light than does a white paper viewed indoors, it will still look black (McBurney & Collings, 1984). But if you view sunlit black paper through a narrow tube so nothing else is visible, it may look gray, because in bright sunshine it reflects a fair amount of light. View it without the tube and it is again black, because it reflects much less light than the objects around it.

This principle—that we perceive objects not in isolation but in their environmental context—matters to artists, interior decorators, and clothing designers. Our perception of the color and brightness of a wall or of a streak of paint on a canvas is determined not just by the paint in the can but by the surrounding colors. The take-home lesson: *Comparisons govern our perceptions.*

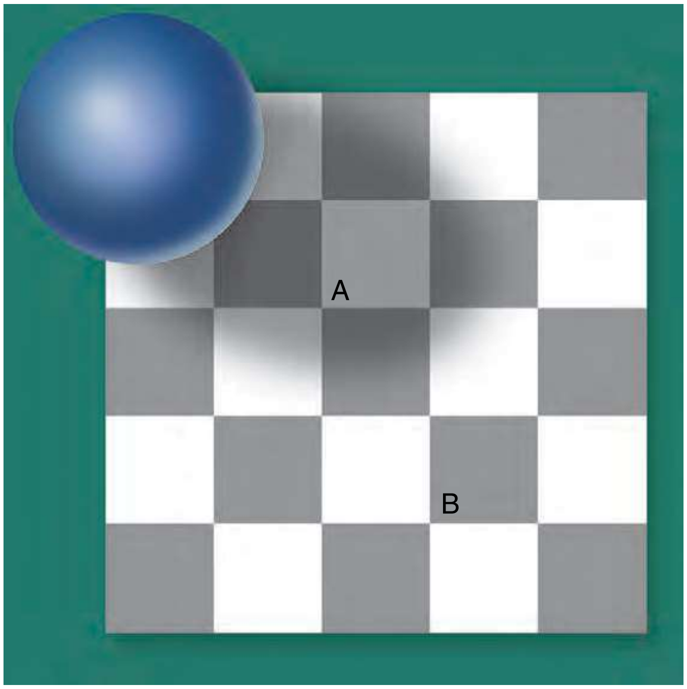


Figure 19.7
Relative luminance Squares A and B are identical in color, believe it or not. (If you don't believe me, photocopy the illustration, cut out the squares, and compare.) But we perceive A as lighter, thanks to its surrounding context.

SHAPE AND SIZE CONSTANCIES

Sometimes an object whose actual shape cannot change *seems* to change shape with the angle of our view (**FIGURE 19.8**). More often, thanks to *shape constancy,* we perceive the form of familiar objects, such as the door in **FIGURE 19.9**, as constant even while our retinas receive changing images of them. Our brain manages this feat thanks to visual cortex neurons that rapidly learn to associate different views of an object (Li & DiCarlo, 2008).

Thanks to *size constancy,* we perceive objects as having a constant size, even while our distance from them varies. We assume a car is large enough to carry people, even when we see its tiny image from two blocks away. This assumption also illustrates the close connection between perceived *distance* and perceived *size*. Perceiving an object's distance gives us cues to its size. Likewise, knowing its general size—that the object is a car—provides us with cues to its distance.

Figure 19.8
Perceiving shape Do the tops of these tables have different dimensions? They appear to. But—believe it or not—they are identical. (Measure and see.) With both tables, we adjust our perceptions relative to our viewing angle.

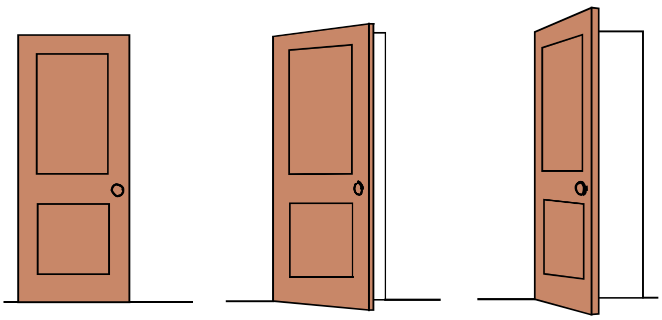


Figure 19.9
Shape constancy A door casts an increasingly trapezoidal image on our retinas as it opens, yet we still perceive it as rectangular.

Even in size-distance judgments, however, we consider an object's context. The dogs in Module 17's Figure 17.3 cast identical images on our retinas. Using linear perspective as a cue (see Figure 19.5), our brain assumes that the pursuing dog is farther away. We therefore perceive it as larger. It isn't.

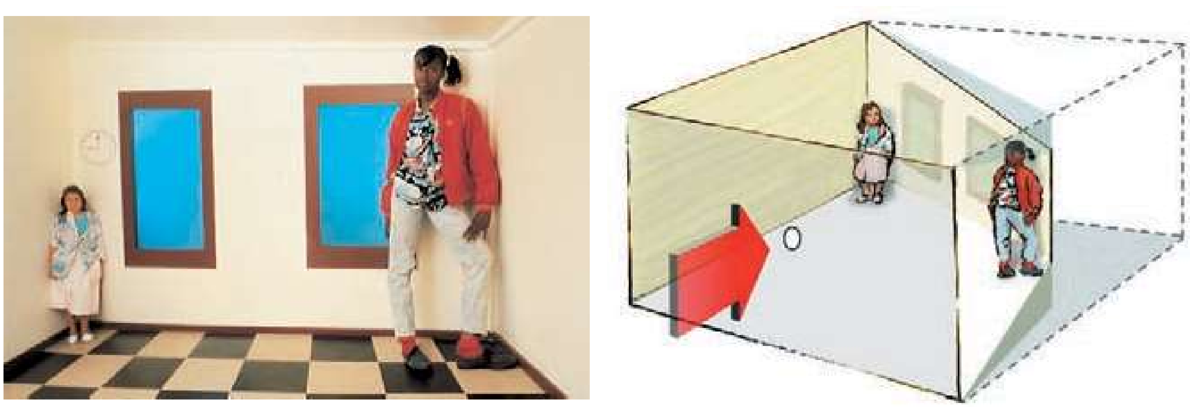
This interplay between perceived size and perceived distance helps explain several well-known illusions, including the *Moon illusion:* The Moon looks up to 50 percent larger when near the horizon than when high in the sky. Can you imagine why? For at least 22 centuries, scholars have debated this question (Hershenson, 1989). One reason is that cues to objects' distances make the horizon Moon—like the distant dog in Figure 17.3—appear farther away. If it's farther away, our brain assumes, it must be larger than the Moon high in the night sky (Kaufman & Kaufman, 2000). Take away the distance cue, by looking at the horizon Moon (or each dog) through a paper tube, and the object will immediately shrink.

Size-distance relationships also explain why in **FIGURE 19.10** the two same-age girls seem so different in size. As the diagram reveals, the girls are actually about the same size, but the room is distorted. Viewed with one eye through a peephole, the room's trapezoidal walls produce the same images you would see in a normal rectangular room viewed with both eyes. Presented with the camera's one-eyed view, your brain makes the reasonable assumption that the room *is* normal and each girl is therefore the same distance from you. Given the different sizes of the girls' images on your retinas, your brain ends up calculating that the girls must be very different in size.

Perceptual illusions reinforce a fundamental lesson: Perception is not merely a projection of the world onto our brain. Rather, our sensations are disassembled into information bits that our brain, using both bottom-up and top-down processing, then reassembles into its own functional model of the external world. During this reassembly process, our assumptions—such as the usual relationship between distance and size—can lead us astray. *Our brain constructs our perceptions.*

* * *

Form perception, depth perception, motion perception, and perceptual constancies illuminate how we organize our visual experiences. Perceptual organization applies to our other senses, too. It explains why we perceive a clock's steady tick not as a *tick-tick-tick-tick* but as grouped sounds, say, *TICK-tick, TICK-tick.* Listening to an unfamiliar language, we have trouble hearing where one word stops and the next one begins. Listening to our own language, we automatically hear distinct words. This, too, reflects perceptual organization. But it is more, for we even organize a string of letters—THEDOGATEMEAT—into words that make an intelligible phrase, more likely "The dog ate meat" than "The do gate me at" (McBurney & Collings, 1984). This process involves not only the organization we've been discussing, but also interpretation—discerning meaning in what we perceive.



S. Schwartzenberg/The Exploratorium

Figure 19.10

The illusion of the shrinking and growing girls This distorted room, designed by Adelbert Ames, appears to have a normal rectangular shape when viewed through a peephole with one eye. The girl in the right corner appears disproportionately large because we judge her size based on the false assumption that she is the same distance away as the girl in the left corner.

Visual Interpretation

Philosophers have debated whether our perceptual abilities should be credited to our nature or our nurture. To what extent do we *learn* to perceive? German philosopher Immanuel Kant (1724–1804) maintained that knowledge comes from our *inborn* ways of organizing sensory experiences. Indeed, we come equipped to process sensory information. But British philosopher John Locke (1632–1704) argued that through our experiences we also *learn* to perceive the world. Indeed, we learn to link an object's distance with its size. So, just how important is experience? How radically does it shape our perceptual interpretations?

"Let us then suppose the mind to be, as we say, white paper void of all characters, without any ideas: How comes it to be furnished? . . . To this I answer, in one word, from EXPERIENCE." -John Locke, *An Essay Concerning Human Understanding*, 1690

Experience and Visual Perception

19-4 What does research on restored vision, sensory restriction, and perceptual adaptation reveal about the effects of experience on perception?

RESTORED VISION AND SENSORY RESTRICTION

Writing to John Locke, William Molyneux wondered whether "a man *born* blind, and now adult, taught by his *touch* to distinguish between a cube and a sphere" could, if made to see, visually distinguish the two. Locke's answer was *No,* because the man would never have *learned* to see the difference.

Molyneux's hypothetical case has since been put to the test with a few dozen adults who, though blind from birth, have gained sight (Gregory, 1978; von Senden, 1932). Most had been born with cataracts—clouded lenses that allowed them to see only diffused light, rather as someone might see a foggy image through a Ping-Pong ball sliced in half. After cataract surgery, the patients could distinguish figure from ground and could sense colors—suggesting that these aspects of perception are innate. But much as Locke supposed, they often could not visually recognize objects that were familiar by touch.

Seeking to gain more control than is provided by clinical cases, researchers have outfitted infant kittens and monkeys with goggles through which they could see only diffuse, unpatterned light (Wiesel, 1982). After infancy, when the goggles were removed, these animals exhibited perceptual limitations much like those of humans born with cataracts. They could distinguish color and brightness, but not the form of a circle from that of a square. Their eyes had not degenerated; their retinas still relayed signals to their visual cortex. But lacking stimulation, the cortical cells had not developed normal connections. Thus, the animals remained functionally blind to shape. Experience guides, sustains, and maintains the brain's neural organization as it forms the pathways that affect our perceptions.

Learning to see: At age 3, Mike May lost his vision in an explosion. Decades later, after a new cornea restored vision to his right eye, he got his first look at his wife and children. Alas, although signals were now reaching his visual cortex, it lacked the experience to interpret them. May could not recognize expressions, or faces, apart from features such as hair. Yet he can see an object in motion and has learned to navigate his world and to marvel at such things as dust floating in sunlight (Abrams, 2002).

AP Photo/Marcio Jose Sanchez

In both humans and animals, similar sensory restrictions later in life do no permanent harm. When researchers cover the eye of an adult animal for several months, its vision will be unaffected after the eye patch is removed. When surgeons remove cataracts that develop during late adulthood, most people are thrilled at the return to normal vision.

The effect of sensory restriction on infant cats, monkeys, and humans suggests there is a *critical period* for normal sensory and perceptual development. Nurture sculpts what nature has endowed. In less dramatic ways, it continues to do so throughout our lives. Despite concerns about their social costs (more on this in Module 78), action video games sharpen spatial skills such as visual attention, eye-hand coordination and speed, and tracking multiple objects (Spence & Feng, 2010).

Experiments on early sensory deprivation provide a partial answer to the enduring question about experience: Does the effect of early experience last a lifetime? For some aspects of perception, the answer is clearly *Yes:* "Use it *soon* or lose it." We retain the imprint of some early sensory experiences far into the future.

PERCEPTUAL ADAPTATION

Given a new pair of glasses, we may feel slightly disoriented, even dizzy. Within a day or two, we adjust. Our **perceptual adaptation** to changed visual input makes the world seem normal again. But imagine a far more dramatic new pair of glasses—one that shifts the apparent location of objects 40 degrees to the left. When you first put them on and toss a ball to a friend, it sails off to the left. Walking forward to shake hands with the person, you veer to the left.

Could you adapt to this distorted world? Baby chicks cannot. When fitted with such lenses, they continue to peck where food grains *seem* to be (Hess, 1956; Rossi, 1968). But we humans adapt to distorting lenses quickly. Within a few minutes your throws would again be accurate, your stride on target. Remove the lenses and you would experience an aftereffect: At first your throws would err in the *opposite* direction, sailing off to the right; but again, within minutes you would readapt.

Indeed, given an even more radical pair of glasses—one that literally turns the world upside down—you could still adapt. Psychologist George Stratton (1896) experienced this when he invented, and for eight days wore, optical headgear that flipped left to right *and* up to down, making him the first person to experience a right-side-up retinal image while standing upright. The ground was up, the sky was down.

At first, when Stratton wanted to walk, he found himself searching for his feet, which were now "up." Eating was nearly impossible. He became nauseated and depressed. But he persisted, and by the eighth day he could comfortably reach for an object in the right direction and walk without bumping into things. When Stratton finally removed the headgear, he readapted quickly.

In later experiments, people wearing the optical gear have even been able to ride a motorcycle, ski the Alps, and fly an airplane (Dolezal, 1982; Kohler, 1962). The world around them still seemed above their heads or on the wrong side. But by actively moving about in these topsy-turvy worlds, they adapted to the context and learned to coordinate their movements.

perceptual adaptation in vision, the ability to adjust to an artificially displaced or even inverted visual field.

Courtesy of Hubert Dolezal

Perceptual adaptation "Oops, missed," thought researcher Hubert Dolezal as he viewed the world through inverting goggles. Yet, believe it or not, kittens, monkeys, and humans can adapt to an inverted world.

Before You Move On

▶ ASK YOURSELF

Try drawing a realistic depiction of the scene from your window. Which monocular cues will you use in your drawing?

▶ TEST YOURSELF

What do we mean when we say that, in perception, "the whole is greater than the sum of its parts"?

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

Module 19 Review

19-1 How did the Gestalt psychologists understand perceptual organization, and how do figure-ground and grouping principles contribute to our perceptions?

- Gestalt psychologists searched for rules by which the brain organizes fragments of sensory data into *gestalts* (from the German word for "whole"), or meaningful forms. In pointing out that the whole may exceed the sum of its parts, they noted that we filter sensory information and construct our perceptions.
- To recognize an object, we must first perceive it (see it as a *figure*) as distinct from its surroundings (the *ground*). We bring order and form to stimuli by organizing them into meaningful *groups,* following such rules as proximity, continuity, and closure.

19-2 How do we use binocular and monocular cues to perceive the world in three dimensions and perceive motion?

- *Depth perception* is our ability to see objects in three dimensions and judge distance. The *visual cliff* and other research demonstrate that many species perceive the world in three dimensions at, or very soon after, birth.
- *Binocular cues,* such as *retinal disparity,* are depth cues that rely on information from both eyes.
- *Monocular cues* (such as relative size, interposition, relative height, relative motion, linear perspective, and light and shadow) let us judge depth using information transmitted by only one eye.
- As objects move, we assume that shrinking objects are retreating and enlarging objects are approaching.
- A quick succession of images on the retina can create an illusion of movement, as in stroboscopic movement or the *phi phenomenon.*

19-3 How do perceptual constancies help us organize our sensations into meaningful perceptions?

- *Perceptual constancy* enables us to perceive objects as stable despite the changing image they cast on our retinas.
  - *Color constancy* is our ability to perceive consistent color in objects, even though the lighting and wavelengths shift.
  - Brightness (or lightness) constancy is our ability to perceive an object as having a constant lightness even when its illumination—the light cast upon it—changes.
  - Our brain constructs our experience of an object's color or brightness through comparisons with other surrounding objects.
  - Shape constancy is our ability to perceive familiar objects (such as an opening door) as unchanging in shape.
  - Size constancy is perceiving objects as unchanging in size despite their changing retinal images.
- Knowing an object's size gives us clues to its distance; knowing its distance gives clues about its size, but we sometimes misread monocular distance cues and reach the wrong conclusions, as in the Moon illusion.

19-4 What does research on restored vision, sensory restriction, and perceptual adaptation reveal about the effects of experience on perception?

- Experience guides our perceptual interpretations. People blind from birth who gained sight after surgery lack the experience to visually recognize shapes, forms, and complete faces.
- Sensory restriction research indicates that there is a critical period for some aspects of sensory and perceptual development. Without early stimulation, the brain's neural organization does not develop normally.
- People given glasses that shift the world slightly to the left or right, or even upside down, experience *perceptual adaptation.* They are initially disoriented, but they manage to adapt to their new context.

Multiple-Choice Questions

1. A teacher used distortion goggles, which shifted the wearer's gaze 20 degrees, to demonstrate an altered perception. A student wearing the goggles initially bumped into numerous desks and chairs while walking around, but chose to wear the goggles for a half hour. After 30 minutes, the student was able to smoothly avoid obstacles, illustrating the concept of

a. perceptual adaptation.
b. visual interpretation.
c. sensory restriction.
d. perceptual constancy.
e. binocular cues.

2. What do we call the illusion of movement that results from two or more stationary, adjacent lights blinking on and off in quick succession?

a. Phi phenomenon
b. Perceptual constancy
c. Binocular cues
d. Retinal disparity
e. Depth perception

3. Bryanna and Charles are in a dancing competition. It is easy for spectators to see them against the dance floor because of

a. the visual cliff.
b. the phi phenomenon.
c. color constancy.
d. sensory restriction.
e. figure-ground relationships.

4. The view from Narmeen's left eye is slightly different from the view from her right eye. This is due to which depth cue?

a. Retinal disparity
b. Relative size
c. Linear perspective
d. Relative motion
e. Convergence

5. Bringing order and form to stimuli, which illustrates how the whole differs from the sum of its parts, is called

a. grouping.
b. monocular cue.
c. binocular cue.
d. disparity.
e. motion.

Practice FRQs

1. Look at the **relative size** cartoon in Figure 19.5. Describe how the artist who drew this cartoon incorporated relative size, linear perspective, and interposition to create depth.

Answer

Specific explanations may utilize different aspects of the cartoon.

1 point: Relative size: We know the woman is closer to us than the police officer, because she is drawn larger.

1 point: Linear perspective: We can tell that the sidewalk is receding into the distance, because its sides pinch closer together in the distance.

1 point: Interposition: We know the woman is closer to us than the police officer, because our view of her partially blocks our view of him.

2. Explain the meaning of the word *gestalt* as it applies to perception. Then, apply any two gestalt principles to the perception of food on a plate.

(3 points)