CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 89

Why study sensation and perception?

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

learning objectives

3.1 How does sensation travel through the central nervous system, and why are some sensations ignored?

3.2 What is light, and how does it travel through the various parts of the eye?

3.3 How do the eyes see, and how do the eyes see different colors?

3.4 What is sound, and how does it travel through the various parts of the ear?

3.5 Why are some people unable to hear, and how can their hearing be improved?

3.6 How do the senses of taste and smell work, and how are they alike?

3.7 What allows people to experience the sense of touch, pain, motion, and balance?

3.8 What are perception and perceptual constancies?

3.9 What are the Gestalt principles of perception?

3.10 What is depth perception and what kind of cues are important for it to occur?

3.11 What are visual illusions and how can they and other factors influence and alter perception?

study tip

As you are reading this chapter, remember to use the SQ3R method discussed on pages I-7–I-8 in *Psychology in Action*. Breaking your reading into small sections will help you get more out of every chapter.

How do we get information from the outside world into our brains?

The ABCs of Sensation

How do we get information from the outside world into our brains?

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

WHAT IS SENSATION?

3.1 How does sensation travel through the central nervous system, and why are some sensations ignored?

Sensation occurs when special receptors in the sense organs—the eyes, ears, nose, skin, and taste buds—are activated, allowing various forms of outside stimuli to become neural signals in the brain. (This process of converting outside stimuli, such as light, into neural activity is called **transduction**.) Let's take a closer look at these special receptors.

SENSORY RECEPTORS The *sensory receptors* are specialized forms of neurons, the cells that make up the nervous system. Instead of receiving neurotransmitters from other cells, these receptor cells are stimulated by different kinds of energy—for example, the receptors in the eyes are stimulated by light, whereas the receptors in the ears are activated by vibrations. Touch receptors are stimulated by pressure or temperature, and the receptors for taste and smell are triggered by chemical substances.

SENSORY THRESHOLDS

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

sensation the process that occurs when special receptors in the sense organs are activated, allowing various forms of outside stimuli to become neural signals in the brain.

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

just noticeable difference (jnd or the **difference threshold)** the smallest difference between two stimuli that is detectable 50 percent of the time.

typically drink a cup of coffee with 10 teaspoons of sugar in it, let alone 12 teaspoons, but you get the point.

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

absolute threshold the lowest level of stimulation that a person can consciously detect 50 percent of the time the stimulation is present.

I've heard about people being influenced by stuff in movies and on television, things that are just below the level of conscious awareness. Is that true?

I've heard about people being influenced by stuff in movies and on television, things that are just below the level of conscious awareness. Is that true?

Stimuli that are below the level of conscious awareness are called *subliminal stimuli*. (The word *limin* means "threshold," so *sublimin* means "below the threshold.") These stimuli are just strong enough to activate the sensory receptors but not strong enough for people to be consciously aware of them. Many people believe that these stimuli act upon the unconscious mind, influencing behavior in a process called *subliminal perception*.

At one time, many people believed that a market researcher named James Vicary had demonstrated the power of subliminal perception in advertising. It was five years before Vicary finally admitted that he had never conducted a real study (Merikle, 2000; Pratkanis, 1992). Furthermore, many researchers have gathered scientific evidence that subliminal perception does not work in advertising (Bargh et al., 1996; Broyles, 2006; Moore, 1988; Pratkanis & Greenwald, 1988; Trappey, 1996; Vokey & Read, 1985).

This is not to say that subliminal perception does not exist—there is a growing body of evidence that we process some stimuli without conscious awareness, especially stimuli that are fearful or threatening (LeDoux & Phelps, 2008; Öhman, 2008). In this effort, researchers have used *event-related potentials* (ERPs) and functional magnetic resonance imaging (fMRI) to verify the existence of subliminal perception and associated learning in the laboratory (Babiloni et al., 2010; Bernat et al., 2001; Fazel-Rezai & Peters, 2005; Sabatini et al., 2009). However, as in about every other case where subliminal perception has reportedly occurred, these studies use stimuli that are *supraliminal*—"above the threshold"—and detectable by our sensory systems. However, they are below the level of conscious perception and participants are not aware or conscious that they have been exposed to the stimuli due to masking or manipulation of attention. Furthermore,

In some parts of the USA, "coffee regular" refers to coffee with two creams and two sugars. How much more sugar would you need to add to taste a difference?

This young woman does not feel the piercings on her ear and nose because sensory adaptation allows her to ignore a constant, unchanging stimulation from the metal rings. What else is she wearing that would cause sensory adaptation?

Table 3.1
Examples of Absolute Thresholds

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

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 92

the stimuli typically influence automatic reactions (such as an increase in facial tension) rather than direct voluntary behaviors (such as going to buy something suggested by advertising).

The real world is full of complex motives that are not as easily influenced as one might think (Pratkanis, 1992). Even the so-called hidden pictures that some artists airbrush into the art in advertisements aren't truly subliminal—if someone points one out, it can be seen easily enough.

HABITUATION AND SENSORY ADAPTATION

In Chapter Two it was stated that the lower centers of the brain filter sensory stimulation and "ignore" or prevent conscious attention to stimuli that do not change. The brain is only interested in changes in information. That's why people don't really "hear" the noise of the air conditioner unless it suddenly cuts off or the noise made in some classrooms unless it gets very quiet. Although they actually are *hearing* it, they aren't paying attention to it. This is called **habituation**, and it is the way the brain deals with unchanging information from the environment. LINK to Chapter Two: The Biological Perspective, p. 70.

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

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

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

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

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

habituation tendency of the brain to stop attending to constant, unchanging information.

sensory adaptation tendency of sensory receptor cells to become less responsive to a stimulus that is unchanging.

CONCEPT MAP

3.1

The ABCs of Sensation

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

- related to the activation of receptors in the various sense organs
- related to changes in physical stimuli
  - detected by sensory receptors
  - sometimes "ignored" through sensory adaptation or cognitive habituation

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 93

PRACTICE quiz How much do you remember? ANSWERS ON PAGE AK-1.

Pick the best answer.

1. The smallest difference between two stimuli that can be detected 50 percent of the time it is present is called __________.
   a. absolute threshold. **c.** sensation.
   b. just noticeable difference. **d.** sensory adaptation.
2. When receptor cells for the senses are activated, the process called __________ has begun.
   a. perception **c.** adaptation
   b. sublimination **d.** sensation
3. You have a piece of candy that you are holding in your mouth. After a while, the candy doesn't taste as strong as it did when you first tasted it. What has happened?
   a. sensory adaptation **c.** habituation
   b. subliminal perception **d.** perceptual defense
4. While driving down the road looking for the new restaurant you want to try out, not hearing the clicking of the turn signal you forgot to turn off until one of your friends point it out is likely due to __________:
   a. accommodation **c.** sublimation
   b. adaptation **d.** habituation

The Science of Seeing

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

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

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

PERCEPTUAL PROPERTIES OF LIGHT: CATCHING THE WAVES

3.2 What is light, and how does it travel through the various parts of the eye?

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

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

Brightness is determined by the amplitude of the wave—how high or how low the wave actually is. The higher the wave, the brighter the light appears to be. Low waves are dimmer. *Color*, or hue, is largely determined by the length of the wave. Long wavelengths (measured in nanometers) are found at the red end of the *visible spectrum* (the portion of the whole spectrum of light that is visible to the human eye; see Figure 3.1), whereas shorter wavelengths are found at the blue end. (Note that when combining different colors, light behaves differently than pigments or paint. We will look at this distinction when we examine perception of color).

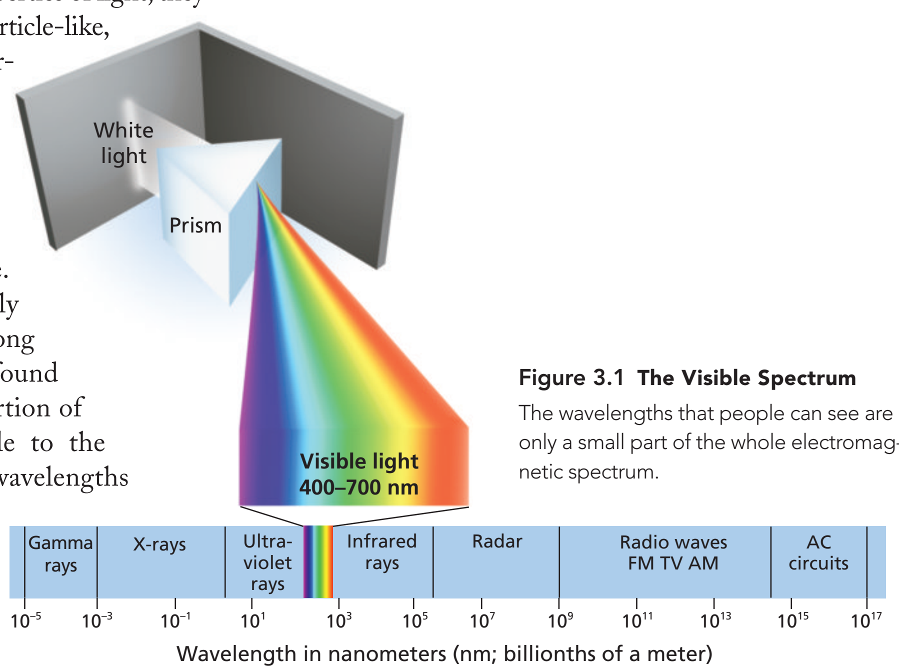


Figure 3.1 The Visible Spectrum
The wavelengths that people can see are only a small part of the whole electromagnetic spectrum.

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 94

Saturation refers to the purity of the color people perceive: A highly saturated red, for example, would contain only red wavelengths, whereas a less-saturated red might contain a mixture of wavelengths. For example, when a child is using the red paint from a set of poster paints, the paint on the paper will look like a pure red, but if the child mixes in some white paint, the paint will look pink. The hue is still red but it will be less of a saturated red because of the presence of white wavelengths. Mixing in black or gray would also lessen the saturation.

THE STRUCTURE OF THE EYE

The best way to talk about how the eye processes light is to talk about what happens to an image being viewed as the photons of light from that image travel through the eye. Refer to Figure 3.2 to follow the path of the image. **Simulate** on **mypsychlab.com**

Simulate the structures of the eye on **mypsychlab.com**

FROM FRONT TO BACK: THE PARTS OF THE EYE Light enters the eye directly from a source (such as the sun) or indirectly by reflecting off of an object. To see clearly, a single point of light from a source or reflected from an object must travel through the structures of the eye and end up on the retina as a single point. Light bends as it passes through substances of different densities, through a process known as refraction. For example, have you ever looked at a drinking straw in a glass of water through the side of the glass? It appears that the straw bends, or is broken, at the surface of the water. That optical illusion is due to the refraction of light. The structures of the eye play a vital role in both collecting and focusing of light so we can see clearly.

The surface of the eye is covered in a clear membrane called the *cornea*. The cornea not only protects the eye but also is the structure that focuses most of the light coming into the eye. The cornea has a fixed curvature, like a camera that has no option to adjust the focus. However, this curvature can be changed somewhat through vision-improving techniques that change the shape of the cornea. For example, ophthalmologists can use both *photoreactive keratectomy (PRK)* and *laser-assisted in situ keratomileusis (LASIK)* procedures to remove small portions of the cornea, changing its curvature, and thus the focus in the eye.

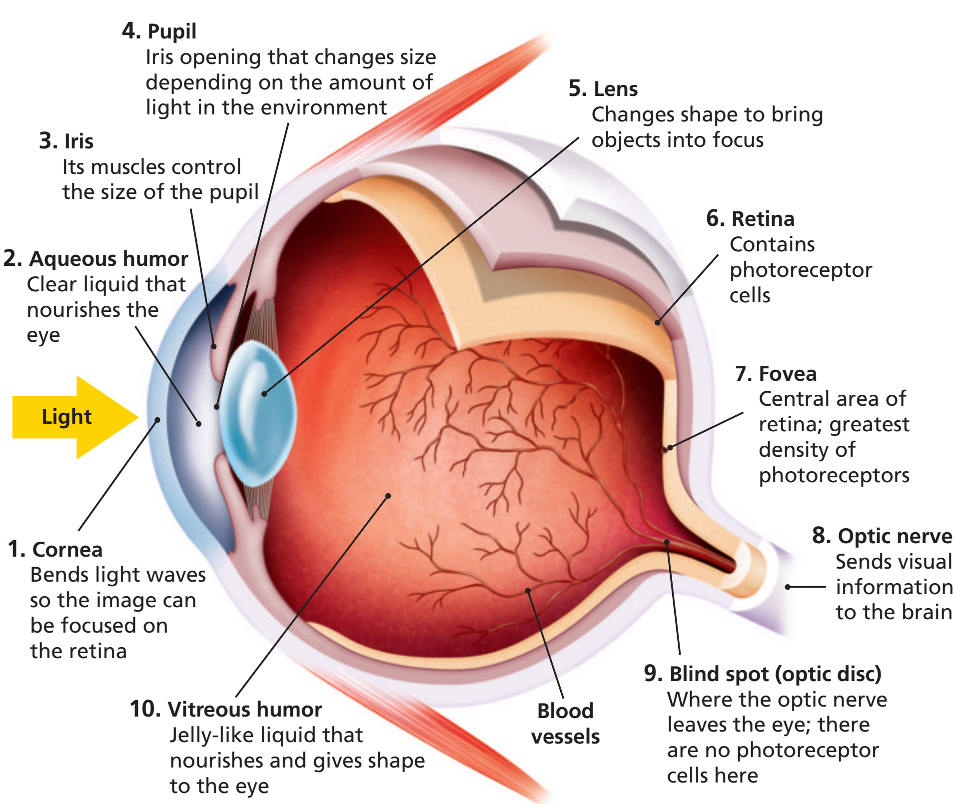


Figure 3.2 Structure of the Eye
Light enters the eye through the cornea and pupil. The iris controls the size of the pupil. From the pupil, light passes through the lens to the retina, where it is transformed into nerve impulses. The nerve impulses travel to the brain along the optic nerve.

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 95

The next visual layer is a clear, watery fluid called the *aqueous humor*. This fluid is continually replenished and supplies nourishment to the eye. The light from the visual image then enters the interior of the eye through a hole, called the *pupil*, in a round muscle called the *iris* (the colored part of the eye). The iris can change the size of the pupil, letting more or less light into the eye. That also helps focus the image; people try to do the same thing by squinting.

Behind the iris, suspended by muscles, is another clear structure called the *lens*. The flexible lens finishes the focusing process begun by the cornea. In a process called **visual accommodation**, the lens changes its shape from thick to thin, enabling it to focus on objects that are close or far away. The variation in thickness allows the lens to project a sharp image on the retina. People lose this ability as the lens hardens through aging (a disorder called *presbyopia*). Although people try to compensate* for their inability to focus on things that are close to them, eventually they usually need bifocals because their arms just aren't long enough anymore.

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

RETINA, RODS, AND CONES The final stop for light within the eye is the *retina*, a light-sensitive area at the back of the eye containing three layers: ganglion cells, bipolar cells, and the **rods** and **cones**, special cells (*photoreceptors*) that respond to the various light waves. (See Figures 3.3a and b.) The rods and the cones are the business end of the retina—the part that actually receives the photons of light and turns them into neural signals to the brain, sending them first to the *bipolar cells* (a type of interneuron; called bipolar or "two-ended" because they have a single dendrite at one end and a single axon on the other; LINK to Chapter Two: The Biological Perspective, p. 57) and then to the retinal *ganglion cells* whose axons form the optic nerve. (See Figure 3.3a.)

visual accommodation the change in the thickness of the lens as the eye focuses on objects that are far away or close.

rods visual sensory receptors found at the back of the retina, responsible for non-color sensitivity to low levels of light.

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

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

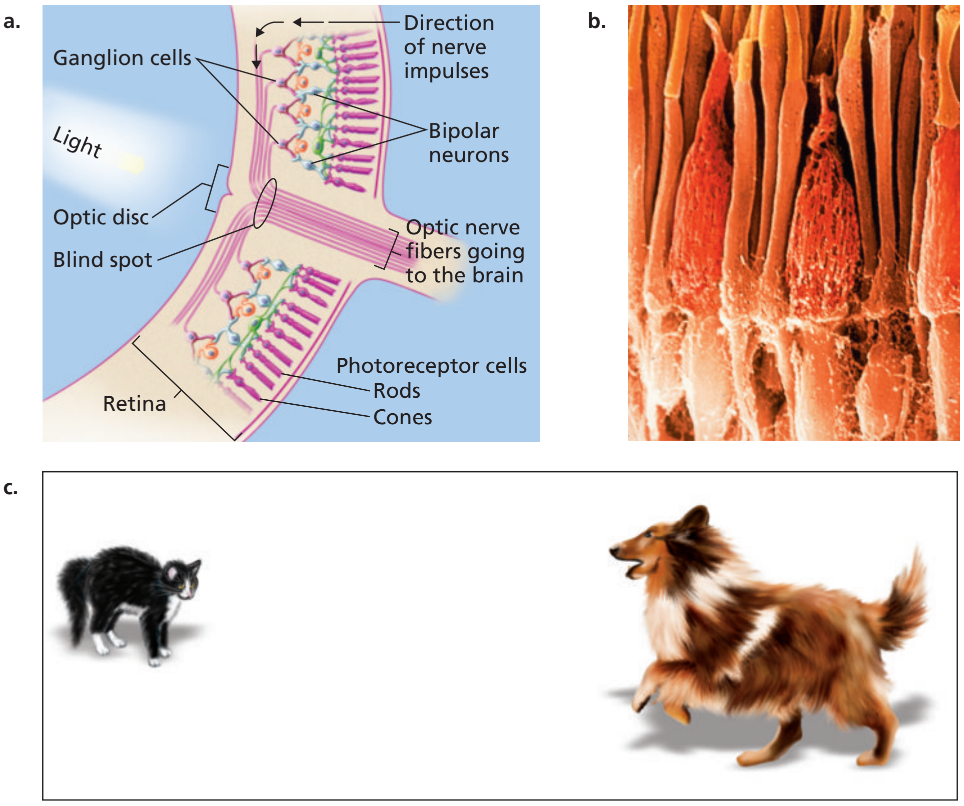


Figure 3.3 The Parts of the Retina

(a) Light passes through ganglion and bipolar cells until it reaches and stimulates the rods and cones. Nerve impulses from the rods and cones travel along a nerve pathway to the brain. (b) On the right of the figure is a photomicrograph of the long, thin rods and the shorter, thicker cones; the rods outnumber the cones by a ratio of about 20 to 1. (c) The blind spot demonstration. Hold the book in front of you. Close your right eye and stare at the picture of the dog with your left eye. Slowly bring the book closer to your face. The picture of the cat will disappear at some point because the light from the picture of the cat is falling on your blind spot.

*compensate: to correct for an error or defect.

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 96

blind spot area in the retina where the axons of the three layers of retinal cells exit the eye to form the optic nerve, insensitive to light.

dark adaptation the recovery of the eye's sensitivity to visual stimuli in darkness after exposure to bright lights.

THE BLIND SPOT The eyes don't adapt to constant stimuli under normal circumstances because of saccadic movements. But if people stare with one eye at one spot long enough, objects that slowly cross their visual field may at one point disappear briefly because there is a "hole" in the retina—the place where all the axons of those ganglion cells leave the retina to become the optic nerve. There are no rods or cones here, so this is referred to as the **blind spot**. You can demonstrate the blind spot for yourself by following the directions in Figure 3.3c.

HOW THE EYE WORKS

3.3 How do the eyes see, and how do the eyes see different colors?

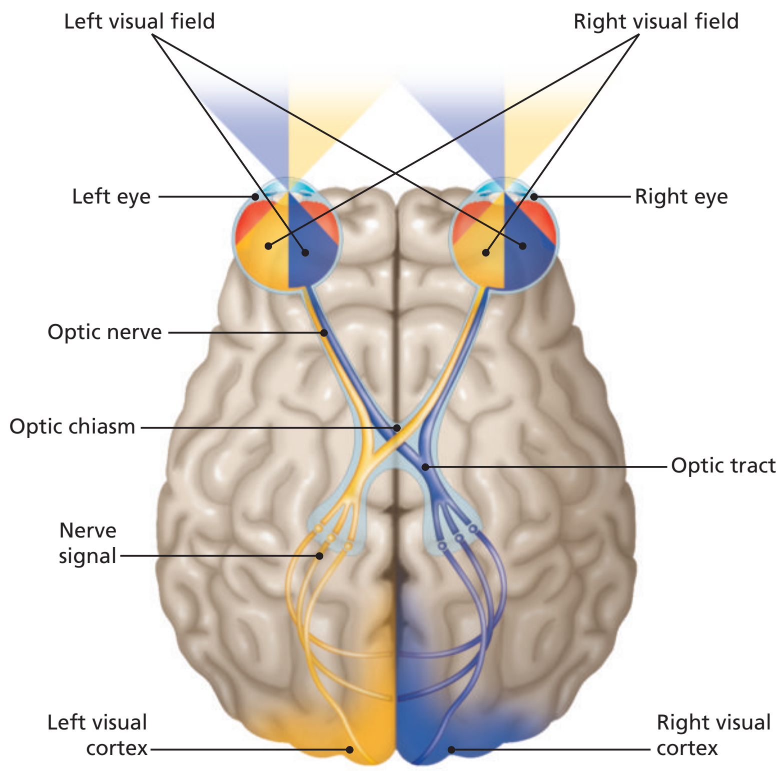


Figure 3.4 Crossing of the Optic Nerve

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

THROUGH THE EYES TO THE BRAIN You may want to first look at Figure 3.4 for a moment before reading this section. Light entering the eyes can be separated into the left and right visual fields. Light from the right visual field falls on the left side of each eye's retina; light from the left visual field falls on the right side of each retina. Light travels in a straight line through the cornea and lens; resulting in the image projected on the retina actually being upside down and reversed from left to right as compared to the visual fields. Thank goodness our brains can compensate for this!

The areas of the retina can be divided into halves, with the halves toward the temples of the head referred to as the temporal retinas and the halves toward the center, or nose, called the nasal retinas. Look at Figure 3.4 again. Notice that the information from the left visual field (falling on the right side of each retina) goes directly to the right visual cortex, while the information from the right visual field (falling on the left side of each retina) goes directly to the left visual cortex. This is because the axons from the temporal halves of each retina project to the visual cortex on the same side of the brain while the axons from the nasal halves cross over to the visual cortex on the opposite side of the brain. The optic chiasm is the point of crossover.

Let's go back now to the photoreceptors in the retina, the rods and cones responsible for different aspects of vision. The rods (about 120 million of them in each eye) are found all over the retina except in the very center, which contains only cones. Rods are sensitive to changes in brightness but not to changes in wavelength, so they see only in black and white and shades of gray. They can be very sensitive because many rods are connected to a single bipolar cell, so that if even only one rod is stimulated by a photon of light, the brain perceives the whole area of those rods as stimulated (because the brain is receiving the message from the single bipolar cell). But because the brain doesn't know exactly what part of the area (which rod) is actually sending the message, the visual acuity (sharpness) is quite low. That's why things seen in low levels of light, such as twilight or a dimly lit room, are fuzzy and grayish. Because rods are located on the periphery of the retina, they are also responsible for peripheral vision.

Because rods work well in low levels of light, they are also the cells that allow the eyes to adapt to low light. **Dark adaptation** occurs as the eye recovers its ability to see when going from a brightly lit state to a dark state. (The light-sensitive pigments that

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 97

allow us to see are able to regenerate or "recharge" in the dark.) The brighter the light was, the longer it takes the rods to adapt to the new lower levels of light (Bartlett, 1965). This is why the bright headlights of an oncoming car can leave a person less able to see for a while after that car has passed. Fortunately, this is usually a temporary condition because the bright light was on so briefly and the rods readapt to the dark night relatively quickly. Full dark adaptation, which occurs when going from more constant light to darkness such as turning out one's bedroom lights, takes about 30 minutes. As people get older this process takes longer, causing many older persons to be less able to see at night and in darkened rooms (Klaver et al., 1998). This age-related change can cause *night blindness*, in which a person has difficulty seeing well enough to drive at night or get around in a darkened room or house. Some research indicates that taking supplements such as vitamin A can reverse or relieve this symptom in some cases (Jacobsen et al., 1995).

When going from a darkened room to one that is brightly lit, the opposite process occurs. The cones have to adapt to the increased level of light, and they accomplish this **light adaptation** much more quickly than the rods adapt to darkness—it takes a few seconds at most (Hood, 1998). There are 6 million cones in each eye; of these, 50,000 have a private line to the optic nerve (one bipolar cell for each cone). This means that the cones are the receptors for visual acuity. Cones are located all over the retina but are more concentrated at its very center where there are no rods (the area called the *fovea*). Cones also need a lot more light to function than the rods do, so cones work best in bright light, which is also when people see things most clearly. Cones are also sensitive to different wavelengths of light, so they are responsible for color vision.

While this deer may see quite well when using its rods at night, the bright headlights of a car will activate the cones. The cones will adapt rather quickly, but it takes time for the deer's pupil to contract, leaving the deer blinded by the light until then.

PERCEPTION OF COLOR

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

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

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

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

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

In trichromatic theory, the three types of cones combine to form different colors much as these three colored lights combine.

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

light adaptation the recovery of the eye's sensitivity to visual stimuli in light after exposure to darkness.

trichromatic theory theory of color vision that proposes three types of cones: red, blue, and green.

CICCMC03_088-127hr.qxp 30-11-2010 18:31 Page 98

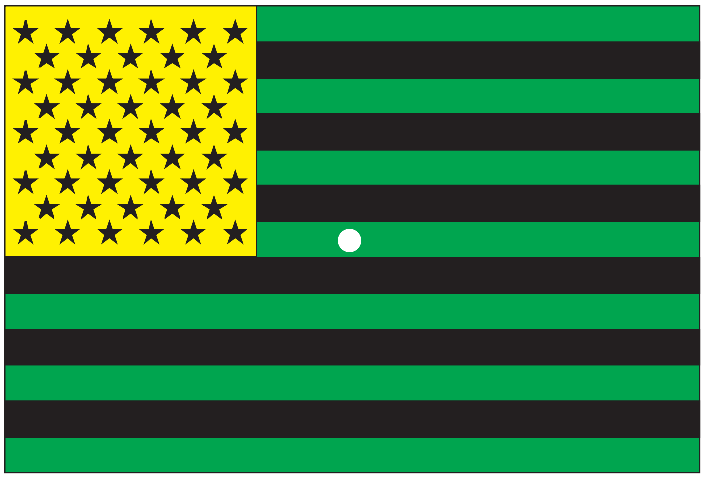


Figure 3.5 Color Afterimage

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

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

THE AFTERIMAGE The trichromatic theory would, at first glance, seem to be more than adequate to explain how people perceive color. But there's an interesting phenomenon that this theory cannot explain. If a person stares at a picture of the American flag for a little while—say, a minute—and then looks away to a blank white wall or sheet of paper, that person will see an afterimage of the flag. **Afterimages** occur when a visual sensation persists for a brief time even after the original stimulus is removed. The person would also notice rather quickly that the colors of the flag in the afterimage are all wrong—green for red, black for white, and yellow for blue. If you follow the directions for Figure 3.5, in which the flag is yellow, green, and black, you should see a flag with the usual red, white, and blue.

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

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

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

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

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

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

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

CICCMC03_088-127hr.qxp 30-11-2010 18:32 Page 99

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

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

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

COLOR BLINDNESS From the mention of red-green and yellow-blue color blindness, one might think that the opponent-process theory explains this problem. But in reality "color blindness" is caused by defective cones in the retina of the eye and as a more general term, *color-deficient vision* is more accurate, as most people with "color blindness" have two type of cones working and can see many colors.

There are really three kinds of color-deficient vision. In a very rare type, *monochrome color blindness*, people either have no cones or have cones that are not working at all. Essentially, if they have cones, they only have one type and, therefore, everything looks the same to the brain—shades of gray. The other types of color-deficient vision, or *dichromatic vision*, are caused by the same kind of problem—having one cone that does not work properly. *Protanopia* (red-green color deficiency) is due to the lack of functioning red cones and *deuteranopia* (another type of red-green color deficiency) results from the lack of functioning green cones. In both of these, the individual confuses reds and greens, seeing the world primarily in blues, yellows, and shades of gray. A lack of functioning blue cones is much less common and called *tritanopia* (blue-yellow color deficiency). These individuals see the world primarily in reds, greens, and shades of gray. To get an idea of what a test for color-deficient vision is like, look at Figure 3.6.

Why are most of the people with color-deficient vision men?

Why are most of the people with color-deficient vision men?

Color-deficient vision involving one set of cones is inherited in a pattern known as *sex-linked inheritance*. The gene for color-deficient vision is *recessive*. To inherit a recessive trait, you normally need two of the genes, one from each parent. LINK to Chapter Eight: Development Across the Life Span, p. 301. But the gene for color-deficient vision is attached to a particular chromosome (a package of genes) that helps to determine the sex of a person. Men have one X chromosome and one smaller Y chromosome (named for their shapes), whereas women have two X chromosomes. The smaller Y has fewer genes than the larger X, and one of the genes missing is the one that would suppress the gene for color-deficient vision. For a woman to have color-deficient vision, she must inherit two recessive genes, one from each parent, but a man only needs to inherit *one* recessive gene—the one passed on to him on his mother's X chromosome. His odds are greater; therefore, more males than females have color-deficient vision. **Read** on **mypsychlab.com**

Read and learn more about color blindness on **mypsychlab.com**

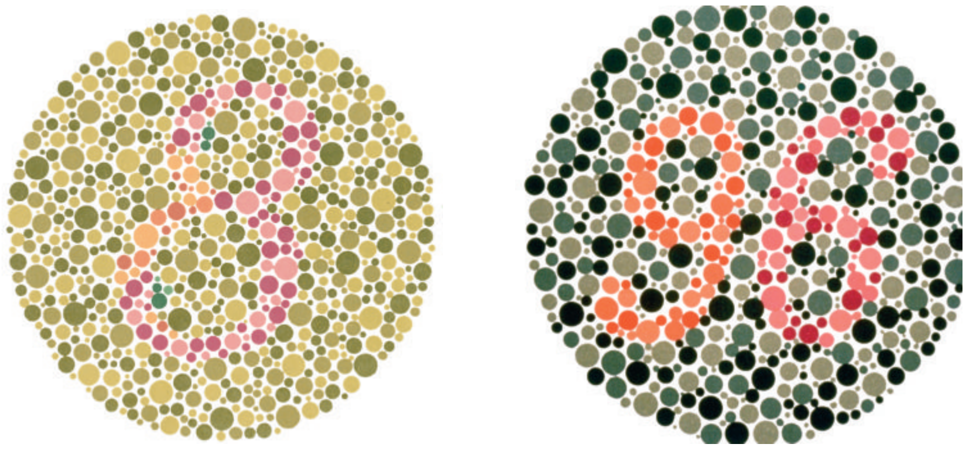


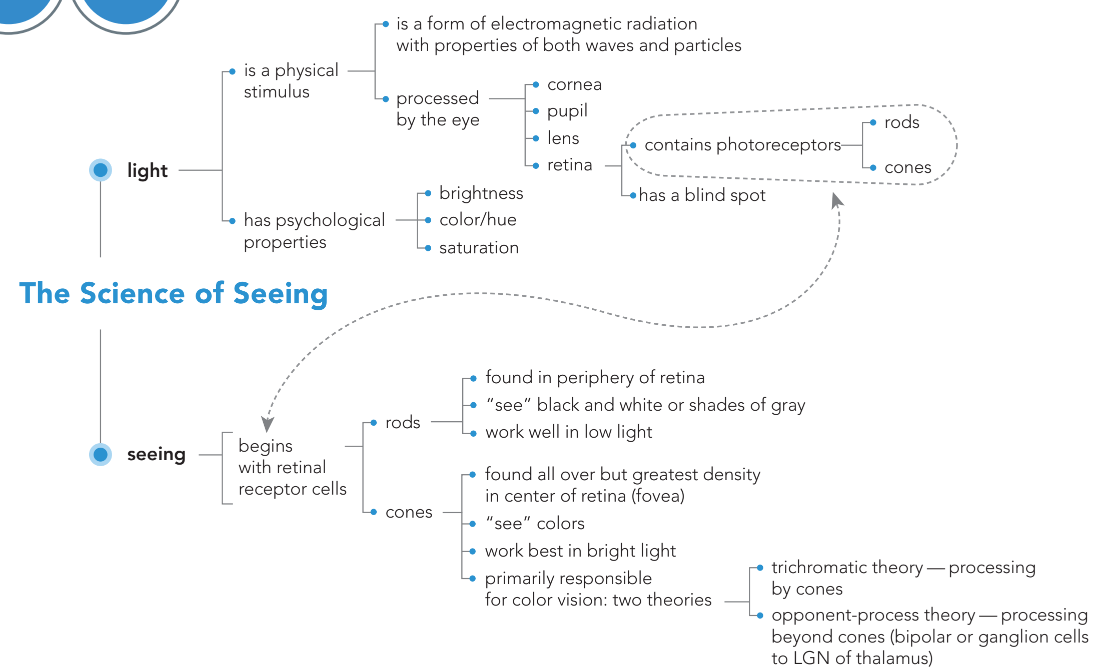
Figure 3.6 The Ishihara Color Test

In the circle on the left, the number 8 is visible only to those with normal color vision. In the circle on the right, people with normal vision will see the number 96, while those with red-green color blindness will see nothing but a circle of dots.

CICCMC03_088-127hr.qxp 30-11-2010 18:32 Page 100

3.2 3.3

CONCEPT MAP



PRACTICE quiz How much do you remember? ANSWERS ON PAGE AK-1.

Pick the best answer.

1. Which of the following terms refers to the perceived effect of the amplitude of light waves?
   - a. color
   - b. brightness
   - c. saturation
   - d. hue
2. Which of the following represents the correct path of light through the eye?
   - a. iris, cornea, lens, retina
   - b. cornea, vitreous humor, iris, lens, aqueous humor, retina
   - c. cornea, pupil, lens, vitreous humor, retina
   - d. cornea, lens, pupil, iris, retina
3. If you wanted to locate a dimly lit star better at night, what should you do?
   - a. Look directly at it because the cones will focus better at night.
   - b. Look off to the side, using the cones in the periphery of the retina.
   - c. Look directly at it because the rods can see sharply at night.
   - d. Look off to the side, using the rods in the periphery of the retina.
4. Which theory of color vision best accounts for afterimages?
   - a. trichromatic theory
   - b. opponent-process theory
   - c. both a and b
   - d. neither a nor b
5. Which statement about color-deficient vision is TRUE?
   - a. There are more men with color-deficient vision than women.
   - b. All people with color-deficient vision see only in black and white.
   - c. Some people with color-deficient vision see only in blue.
   - d. Some people with color-deficient vision see only in blue and red.

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

The Hearing Sense: Can You Hear Me Now?

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

The properties of sound are indeed similar to those of light, as both senses rely on waves. But the similarity ends there, as the physical properties of sound are different from those of light.

PERCEPTION OF SOUND: GOOD VIBRATIONS

3.4 What is sound, and how does it travel through the various parts of the ear?

Sound waves do not come in little packets the way light comes in photons. Sound waves are simply the vibrations of the molecules of air that surround us. Sound waves do have the same properties of light waves though—wavelength, amplitude, and