3 Sensation and Perception

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James Stone, Jr., was born with a rare and unusual neurological condition–he could feel no pain. You might think of him as lucky. Imagine never feeling any physical pain! Imagine all the things you could do without ever feeling any sense of discomfort: exercise with no feeling of exhaustion, fall down when snowboarding without feeling any pain, and never be bothered by cuts or bruises. The reality of it is that James's condition made his life a living hell. Because he could feel no pain, James was unable to care for himself or to be concerned about his own safety. As a result, even when he was a very young boy, James bit off his own fingers, chewed his lips raw, and never noticed when he had burned or cut himself. By the time James reached the age of three, his body was covered with scars.

James's condition was a great burden to his parents, who lived in great poverty and were forced to protect him with the few resources they had. They padded all areas of his bed and bedroom with foam rubber; they took turn staying awake at night so someone was always with him in case he hurt himself without noticing; they constantly checked James's body for bruises. And because of his condition, James never got to feel the warm touch of his parents' hands, the softness of the wind, or sun on his skin.

Although no one knows what happened to James as he grew up and became an adult, odds are that his unfortunate condition would have forced him into a life of misery with the constant need to pay attention to his physical condition, without any of the pleasures associated with human physical contact. (Based on Marion, 1990.)

There may have been times in your life during which you wished you would not feel pain—in an extreme sport competition, during a race, when you broke a bone or hit your thumb with a hammer. However, as the story James Stone, Jr., reveals, feeling pain is one of the most important sensations associated with human survival.

What is the difference between sensation and perception?

Sensation and perception are intimately related in everyday experience, but they are not the same. **Sensation** is the process by which the senses detect visual, auditory, and other sensory stimuli and transmit them to the brain. **Perception** is the process by which sensory information is actively organized and interpreted by the brain. Sensation furnishes the raw material of sensory experience; perception provides the finished product.

To a large extent we must learn to perceive, and people who are unable to feel pain or who cannot see or hear may never be able to develop useful perception even if their sense is restored.

In this chapter we will explore the five primary senses—vision, hearing, touch, taste, and smell—and some of the secondary ones, such as balance and pain. You will learn how the senses detect sensory information and how this information is actively organized and interpreted by the brain. We begin with a closer look at sensation.

Sensation: The Sensory World

Our senses serve as ports of entry for all information about our world. Virtually everything we call experience is detected initially by our senses. Yet it is amazing how little of this sensory world we actually sense. For example, we see only a thin slice of the vast spectrum of electromagnetic energy. With the unaided eye we cannot see microwaves, X-rays, or ultraviolet light. We are unable to hear the ultrasonic sound of a dog whistle, and our ears can detect a scant 20 percent of the sounds that a dolphin or bat can hear; nor can we see the outline of a warm-blooded animal from its infrared heat pattern at night, though rattlesnakes and other pit vipers can. Yet all of these sensory stimuli exist in the real, physical world.

Whichever of our senses we select for comparison, humans are not at the top of the list for quality or sensitivity. Some animals have a superior sense of hearing (bats and dolphins); others have sharper vision (hawks); still others have a superior sense of smell (bloodhounds); and so on. Even so, we humans have remarkable sensory abilities and superior abilities of perception.

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www.sciencenet.org.uk/database/Social/Senses/s00096b.html
Sensory Reception

www.ucl.ac.uk/~smgxt01/
Neurotransmitters in Sensory Systems

The Absolute Threshold: To Sense or Not to Sense

What is the difference between the absolute threshold and the difference threshold?

What is the softest sound you can hear, the dimmest light you can see, the most diluted substance you can taste? What is the lightest touch you can feel, the faintest odour you can smell? Researchers in sensory psychology and psychophysics have performed many experiments over the years to answer these questions. Their research has established measures for the senses known as *absolute thresholds.* Just as the threshold of a doorway is the dividing point between being outside a room and being inside it, the **absolute threshold** of a sense marks the difference between not being able to hear a sound (or see a light) and being just barely able to hear it (or see it). Psychologists have arbitrarily defined this absolute threshold as the minimum amount of sensory stimulation that can be detected 50 percent of the time. For example, the absolute thresholds established for the five primary senses in humans are equivalent to the following: (1) for vision, a candle flame 48 kilometres away on a clear night; (2) for hearing, a watch ticking six metres away; (3) for taste, one teaspoon of sugar dissolved in nine litres of water; (4) for smell, a single drop of perfume in a three-room house; and (5) for touch, a bee's wing falling a distance of one centimetre onto your cheek.

Important as it is, the absolute threshold, once crossed, says nothing about the broad range of sensory experiences. Do we or don't we sense it? That is the only question the absolute threshold answers. But read on—there are other questions to be answered.

The Difference Threshold: Detecting Differences

If you are listening to music, the very fact that you can hear it means that the absolute threshold has been crossed. But how much must the volume be turned up or down for you to notice a difference? Or, if you are carrying a load of books, how much weight must be added or subtracted for you to be able to sense that your load is heavier or lighter? The **difference threshold** is a measure of the smallest increase or decrease in a physical stimulus that is required to produce the **just noticeable difference (JND)**. The JND is the smallest change in sensation that we are able to detect 50 percent of the time. If you were holding a 2-kilogram weight and 500 grams were added, you could easily tell the difference. But if you were holding 50 kilograms and one additional 500-gram weight were added, you could not sense the difference. Why not? After all, the weight added was the same.

More than 100 years ago, Ernst Weber observed that the JND for all our senses depends on a proportion or percentage of change rather than on a fixed amount of change. This observation became known as **Weber's law**. A weight we are holding must increase or decrease by 2 percent for us to notice the difference. According to Weber's law, the greater the original stimulus, the more it must be increased or decreased for us to tell the difference.

The difference threshold is not the same for all the senses. We need a very large (20 percent) difference to detect some changes in taste. In contrast, if you were listening to music, you would notice a difference if a tone changed in pitch by only 0.3 percent.

Aren't some people more sensitive to sensory changes than others? Yes they are. The difference thresholds for the various senses are not the same for all people. In fact, there are huge individual differences. Expert wine tasters would know if a particular vintage was a little too sweet, even if it varied by only a fraction of the 20 percent change. Professionally trained musicians would know if they were singing or playing slightly out of tune long before the 0.3 percent difference in pitch appeared. Actually, Weber's law best fits people with average sensitivities, and

sensation: The process through which the senses pick up visual, auditory, and other sensory stimuli and transmit them to the brain; sensory information that has registered in the brain but has not been interpreted.

perception: The process by which sensory information is actively organized and interpreted by the brain.

absolute threshold: The minimum amount of sensory stimulation that can be detected 50 percent of the time.

difference threshold: The smallest increase or decrease in a physical stimulus required to produce a difference in sensation that is noticeable 50 percent of the time.

just noticeable difference (JND): The smallest change in sensation that we are able to detect 50 percent of the time.

Weber's law: The law stating that the just noticeable difference (JND) for all our senses depends on a proportion or percentage of change in a stimulus rather than on a fixed amount of change.

sensory stimuli that are neither very strong (loud thunder) nor very weak (a faint whisper).

Signal Detection Theory

You may have realized that the classic methods for measuring sensory thresholds have a serious limitation. They focus exclusively on the physical stimulus—how strong or weak it is or how much the stimulus must change for the difference to be noticed. But there is significant variation among individuals in sensory sensitivities; and within the same individual, sensory capabilities vary both across time and according to the conditions. Factors that affect a person's ability to detect a sensory signal are (besides the strength of the stimulus) the motivation to detect it, previous experience, the expectation that it will occur, and the level of alertness (or fatigue).

Another approach takes into account these factors. **Signal detection theory** is the view that the detection of a sensory stimulus involves both noticing a stimulus from background "noise" and a decision as to whether the stimulus is actually present. Deciding whether a stimulus is present depends partly on the probability that the stimulus will occur and partly on the potential gain or loss associated with deciding that it is present or absent.

Suppose you were given the description of a cousin you had never seen before and were asked to pick her up at the gate when her plane arrived at the airport. Your task would be to scan a sea of faces for someone fitting the description and then to decide which of the several people who fit the description was actually your cousin. All the other faces and objects in your field of vision would be considered background noise. How certain you felt before you would be willing to approach someone would depend on several factors—for example, the embarrassment you might feel approaching the wrong person as opposed to the distress you would feel if you failed to find your cousin.

Signal detection theory has special relevance to people in many occupations—air traffic controllers, police officers, military personnel on guard duty, medical professionals, and poultry inspectors, to name a few. Whether these professionals detect certain stimuli can have important consequences for the health and welfare of us all (Swets, 1992, 1998).

Transduction: Transforming Sensory Stimuli into Neural Impulses

How are sensory stimuli in the environment experienced as sensations?

You may be surprised to learn that our eyes do not actually see; nor do our ears hear. Our sense organs provide only the beginning point of sensation, which must be completed by the brain. As you learned in Chapter 2, specific clusters of neurons in specialized parts of the brain must be stimulated for us to see, hear, taste, and so on. The brain itself cannot respond directly to light, sound waves, odours, and tastes. How, then, does it get the message? The answer involves the sensory receptors.

All our senses are equipped with specialized cells called **sensory receptors**, which detect and respond to various stimuli—light, sound waves, odours, and so on. Through a process known as **transduction**, the receptors change the sensory stimulation into neural impulses. The neural impulses are then transmitted to their own special locations in the brain, such as the visual cortex for vision and the primary auditory cortex for hearing. We experience a sensation only when the appropriate part of the brain is stimulated. Our sense receptors provide the essential links between the physical sensory world and the brain.

Sensory Adaptation

All of our senses are more receptive, more finely tuned, to changes in sensory stimuli than to sameness. After a time, the sensory receptors grow accustomed to constant, unchanging levels of stimuli—sights, sounds, smells—so that we notice them less and less, or not at all. This process of becoming less sensitive to an unchanging sensory stimulus over time is known as **sensory adaptation**.

Have you ever taken part in the polar bear swim that is held every year on New Year's Day in Vancouver? If you have, when you first entered the water the temperature receptors in your skin would vigorously signal "ice water." But gradually, sensory adaptation would occur and the water would feel comfortable. Well, maybe not—it's a little *too* cold. Similarly, you have undoubtedly noticed the distinctive odour of your home when you first walk through the door. But after a few minutes you are not aware of it. A continuous odour will stimulate the smell recep-

Remember It!

The Sensory World

1. The process through which the senses detect sensory information and transmit it to the brain is called (sensation/perception).
2. The point at which you can barely sense a stimulus 50 percent of the time is called the (absolute/difference) threshold.
3. The difference threshold is the same for all individuals. (true/false)
4. Which of the following is not true of sensory receptors?
   a. They are specialized to detect certain sensory stimuli.
   b. They transduce sensory stimuli into neural impulses.
   c. They are located in the brain.
   d. They provide the link between the physical sensory world and the brain.
5. The process by which a sensory stimulus is converted into a neural impulse is called ____________________.
6. Each morning when Jackie goes to work at the dry cleaners she smells the strong odour of cleaning fluid. After she is there for a few minutes, she is no longer aware of it. What accounts for this?
   a. Signal detection theory
   b. Sensory adaptation
   c. Transduction
   d. The just noticeable difference

Answers: 1. sensation 2. absolute 3. false 4. c 5. transduction 6. b

People who swim in icy water experience a degree of sensory adaptation, which helps their bodies adjust to the frigid temperature. What other examples of sensory adaptation can you think of?

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tors to respond only for a while. Then, if there is no change in the odours, the receptors will steadily diminish their firing rate, and smell adaptation will occur. However, sensory adaptation is not likely to occur in the presence of very strong stimuli—the smell of ammonia, an ear-splitting sound, or the taste of rancid food.

Vision

For most of us, vision is the most valued sensory experience, and it is the sense that has been most investigated. Before looking at how we see, consider *what* we see. We cannot see any object unless light is reflected from it or given off by it.

LINK IT!

www.yorku.ca/eye/
The Joy of Visual Perception: A Web Book

signal detection theory: The view that detection of a sensory stimulus involves both discriminating a stimulus from background "noise" and deciding whether the stimulus is actually present.

sensory receptors: Specialized cells in each sense organ that detect and respond to sensory stimuli—light, sound, odours, etc.—and transduce (convert) the stimuli into neural impulses.

transduction: The process by which sensory receptors convert sensory stimulation—light, sound, odours, etc.—into neural impulses.

sensory adaptation: The process of becoming less sensitive to an unchanging sensory stimulus over time.

Light: What We See

Light, one form of electromagnetic rays, is made up of tiny light particles called *photons,* which travel in waves. The vast majority of these waves are either too long or too short for humans and other animals to see. Our eyes can respond only to a very narrow band of electromagnetic waves, a band called the **visible spectrum** (see Figure 3.1).

The length of a light wave determines the colour we perceive. The shortest light waves we can see appear violet, and the longest ones we can see appear red. *What* we see is confined to the visible spectrum, but *how* we see depends on the many parts of the eye and brain that bring us the world of sight.

The Eye: Window to the Visual Sensory World

Our eyes are our most important sensory connections to the world. Vision provides most of the information on which our brain feeds. Look at the parts of the eye (shown in Figure 3.2), and read in the text the role each part plays in vision.

The Cornea, Iris, and Pupil: Up Front in the Eye

How do the cornea, the iris, and the pupil function in vision?

The round, globe-shaped human eyeball measures about 2.2 centimetres in diameter. Bulging from its front surface is the **cornea**—the tough, trans-

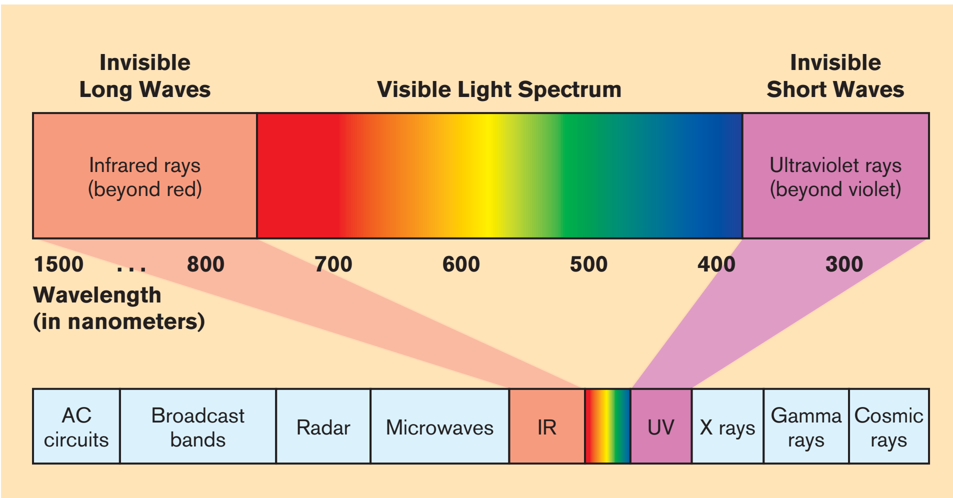


FIGURE 3.1
The Electromagnetic Spectrum The electromagnetic spectrum is composed of waves ranging in wavelength from many miles long (radio and other broadcast bands) to only 10 trillionths of an inch (cosmic rays). Our eyes can perceive only a very thin brand of electromagnetic waves, known as the visible spectrum.

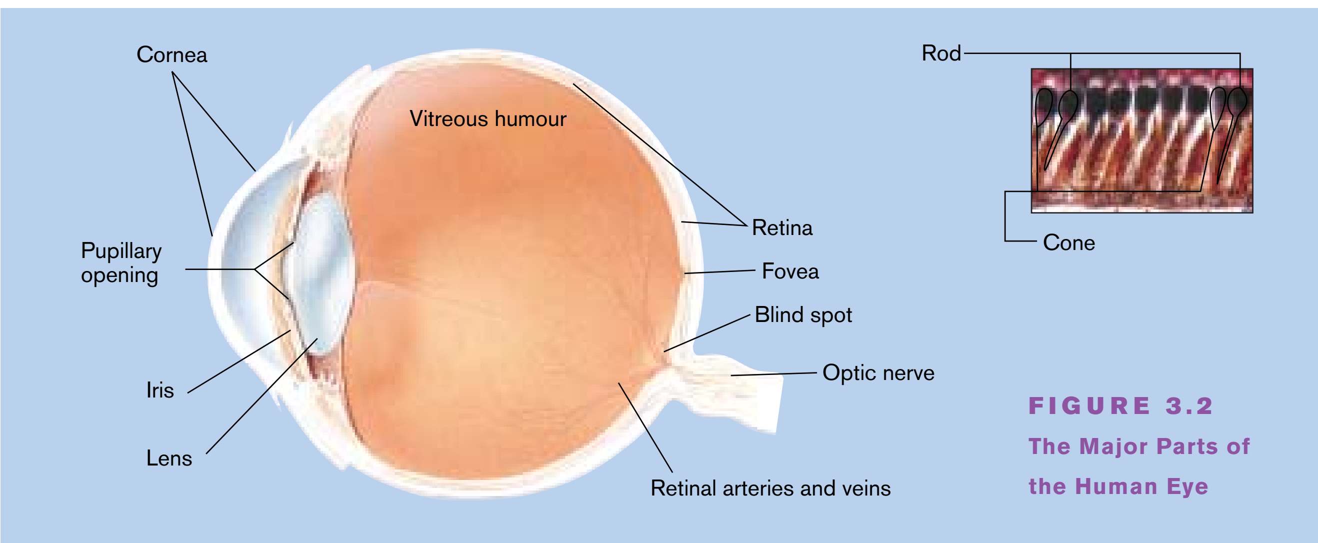
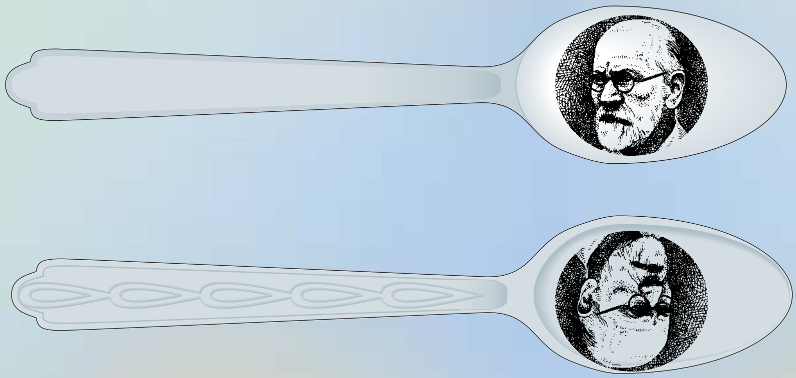


FIGURE 3.2
The Major Parts of the Human Eye

Try It!

How the Retina Works

Take an ordinary teaspoon—one in which you can see your reflection. Looking at the bottom (the convex surface) of the spoon, you will see a large image of your face that is right side up—the way the image enters the eye. Turn the spoon over and look in the inside (the concave surface) and you will see your face upside down and reversed left to right—the way the image appears on the retina. The brain, however, perceives images right side up.



parent, protective layer covering the front of the eye. About the size of a dime, the cornea performs the first step in vision by bending the light rays inward. It herds the light rays through the pupil—the small, dark opening in the centre of the iris.

The iris is the circular, coloured part of the eye, which is even more unique to individuals than their fingerprints (Farah, 2000; Johnson, 1996). Two muscles in the iris dilate and contract the pupil, thus regulating the amount of light entering the eye. Although the pupil never closes completely, in very bright light it can contract to the size of the head of a pin; in very dim light it can dilate to the size of a pencil eraser (Freese, 1977). We have no control over the dilation and contraction of our pupils; the motion is a reflex, completely automatic.

The pupils respond to emotions as well as to light. When we look at someone or something highly desirable, our pupils dilate as if to take in more of the view (Hess, 1965). Pupils also dilate when we are frightened, telling a lie, or sexually aroused. Our pupil size is also related to mental effort—the more intense the mental activity, the larger our pupils become (Janisse & Peavler, 1974).

From Lens to Retina: Focusing Images

What are the lens and the retina?

Suspended just behind the iris and the pupil, the **lens** is composed of many thin layers and looks like a transparent disc. The lens performs the task of focusing on objects closer than 6.5 metres. It flattens as it focuses on objects viewed at a distance; it bulges in the centre as it focuses on close objects. This flattening and bulging action is referred to as **accommodation**. As we grow older, the lens loses some elasticity—that is, it loses the ability to change its shape to accommodate for near vision, a condition called *presbyopia* ("old eyes"). This is why many people over 40 must hold a book or newspaper at arm's length or use reading glasses to magnify the print.

The lens focuses the image we see onto the **retina**—a membrane about the size of a small postage stamp and as thin as onion skin. The retina contains the sensory receptors for vision. The image projected onto the retina is upside down and reversed left to right. You can demonstrate this for yourself in *Try It!*

visible spectrum: The narrow band of electromagnetic rays that are visible to the human eye.

cornea (KOR-nee-uh): The transparent covering of the coloured part of the eye that bends light rays inward through the pupil.

lens: The transparent structure behind the iris that changes in shape as it focuses images on the retina.

accommodation: The changing in shape of the lens as it focuses objects on the retina; it becomes more spherical for near objects and flatter for far objects.

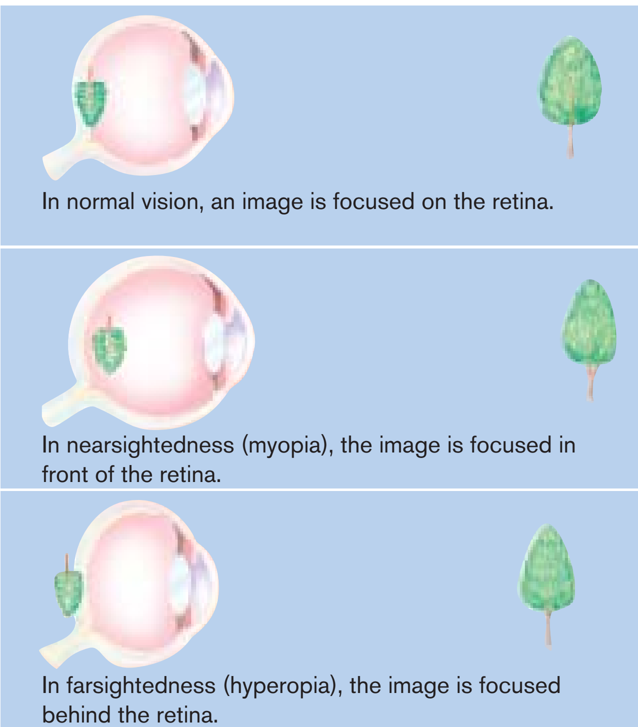
retina: The tissue at the back of the eye that contains the rods and the cones and onto which the retinal image is projected.

In some people, the distance through the eyeball (from the lens to the retina) is either too short or too long for proper focusing. Nearsightedness (myopia) occurs when the lens focuses images of distant objects in front of, rather than on, the retina. A person with this condition will be able to see near objects clearly, but distant images will be blurred. Farsightedness (hyperopia) occurs when the focal image is longer than the eye can handle, as if the image should focus behind the retina (see Figure 3.3). The individual is able to see far objects clearly, but close objects are blurred. Both conditions are correctable with eyeglasses or contact lenses, and nearsightedness is now correctable with a surgical procedure known as radial keratotomy.

The Rods and Cones: Receptors for Light and Colour

What roles do the rods and cones play in vision?

At the back of the retina is a layer of light-sensitive receptor cells—the **rods** and the **cones**. The rods look like slender cylinders; the cones are shorter and more rounded. There are about 120 million rods and 6 million cones in each retina.



In normal vision, an image is focused on the retina.

In nearsightedness (myopia), the image is focused in front of the retina.

In farsightedness (hyperopia), the image is focused behind the retina.

FIGURE 3.3

Normal Vision, Nearsightedness, and Farsightedness

The cones enable us to see colour and fine detail in adequate light. They do not function in very dim light. There are three types of cones, each sensitive to red, green, or blue (Roorda & Williams, 1999).

If we were to plot an imaginary line through the middle of your pupil, the line would strike the centre of the retina at the **fovea**, a pit-like area about the size of the period at the end of this sentence (refer to Figure 3.2). When you look directly at an object, the image of the object is focused on the centre of your fovea. The clearest point of your vision, the fovea is the part of the retina that you use for fine detail work.

The fovea, which is only $\frac{1}{100}$ of a centimetre in diameter, contains no rods but has some 30 000 cones tightly packed together (Beatty, 1995). Cones are most densely packed at the centre of the fovea, and their density decreases sharply just a few degrees beyond the fovea's centre and levels off more gradually to the periphery of the retina (Abramov & Gordon, 1994; Farah 2000).

The rods respond to black and white; while they encode all other visible wavelengths, they do so in shades of grey instead of in colour. More sensitive to light than the cones, the rods enable us to see in very dim light and provide us with night vision. A single rod can respond to the smallest possible quantity of light (Stryer, 1987). Though the rods are more sensitive to light and enable us to see in dim light, they do not provide the sharp, clear images that the cones make possible.

Dark Adaptation

Step from bright sunlight into a darkened movie theatre and at first you can hardly tell which seats are occupied and which are empty. After a few moments in the dark, your eyes begin to adapt and you can see dimly. Yet it takes half an hour or more for your eyes to adapt completely. After complete **dark adaptation**, you can see light that is 100 000 times less bright than daylight. You may have thought that dark adaptation was a direct result of the dilation of your pupils, but this accounts for only a 16-fold difference in your sensitivity to light.

When you leave a movie theatre, your eyes are "dark-adapted," so the return to bright sunlight is a "blinding" experience. However, it takes only about 60 seconds, not half an hour, to become light-adapted again. In light adaptation, a reflexive action occurs; the pupils immediately become smaller, permitting less light to enter the eyes.

From the Retina to the Brain: From Visual Sensation to Visual Perception

What path does the neural impulse take from the retina to the visual cortex?

The rods and cones are the receptors in the eye. They change light waves into neural impulses that are eventually fed through a pencil-sized cable that extends through the wall of the retina and leaves the eye on its way to the brain.

Where the cable runs through the retinal wall, there can be no rods or cones, and so we are blind in that spot in each eye. After the cable leaves the retinal wall, it becomes known as the **optic nerve**. You can find your own blind spot if you perform *Try It!*

After leaving each eye, the optic nerves come together at a point where some of the nerve fibres cross to the opposite side of the brain. The visual fibres from the right half of each retina go to your left hemisphere, and the visual fibres from the left half of each retina go to the right hemisphere. This switching allows visual information from a single eye to be represented on the visual cortex of both hemispheres of the brain. It also plays an important part in depth perception.

The optic nerve then travels to the thalamus, where neural fibres transmit the impulses to the primary visual cortex. About one-quarter of the primary visual cortex is dedicated exclusively to analyzing input from the fovea, which, as we have seen, is a very small but extremely important part of the retina.

Colour Vision: A Multicoloured World

What are the three dimensions that combine to provide the colours we experience?

Some light waves striking an object are absorbed by it, and others are reflected from it. We see only the wavelengths that are reflected, not those that are absorbed. Our everyday visual experience goes far beyond the colours in the rainbow. We detect thousands of subtle colour shadings. What enables us to make these fine colour distinctions? Researchers have identified three dimensions that combine to provide the rich world of colour we experience: (1) The chief dimension is **hue**, which refers to the actual colour we view—red, green, and so forth. (2) **Saturation** refers to the purity of a colour. A colour becomes less saturated, or less pure, as other wavelengths of light are mixed with it. (3) **Brightness** refers to the intensity of the light

Try It!

Find Your Blind Spot

To locate your blind spot, hold this book at arm's length. Close your right eye and look directly at the magician's eyes. Now slowly bring the book closer, keeping your eye fixed on the magician. When the rabbit disappears, you have found the blind spot in your left eye.

You might wonder why the blind spot in each eye is not perceived as a black hole in each visual field. The reason is that we usually have both eyes open, and each eye provides a slightly different view. The right eye can see the tiny area that is blind to the left eye, and vice versa.

rods: The light-sensitive receptors in the retina that provide vision in dim light in black, white, and shades of grey.

cones: The receptor cells in the retina that enable us to see colour and fine detail in adequate light, but that do not function in dim light.

fovea (FO-vee-uh): A small area of the retina that provides the clearest and sharpest vision because it has the largest concentration of cones.

dark adaptation: The eye's increasing ability to see in dim light; results partly from dilation of the pupils.

optic nerve: The nerve that carries visual information from the retina to the brain.

hue: The property of light commonly referred to as "colour" (red, blue, green, and so on), determined primarily by the wavelength of light reflected from a surface.

saturation: The degree to which light waves producing a colour are of the same wavelength; the purity of a colour.

brightness: The dimension of visual sensation that is dependent on the intensity of light reflected from a surface and that corresponds to the amplitude of the light wave.

energy we perceive. Figure 3.4 illustrates the dimensions of hue, saturation, and brightness.

Theories of Colour Vision: How We Sense Colour

What two major theories attempt to explain colour vision?

Two major theories have been offered to explain colour vision. Both were formulated before the development of laboratory technology capable of testing them. The **trichromatic theory**, first proposed by Thomas Young in 1802, was modified by Hermann von Helmholtz about 50 years later. This theory states that there are three kinds of cones in the retina and that each kind makes its maximum chemical response to one of three colours—blue, green, or red, as shown in Figure 3.5. Research in the 1950s and 1960s by Nobel Prize winner George Wald (1964; Wald et al., 1954) supports the trichromatic theory. Wald discovered that even though all cones have basically the same structure, the retina does indeed contain three kinds of cones.

The trichromatic theory alone, however, cannot explain how we are able to perceive such a rich variety of colours.

The other major attempt to explain colour vision is the **opponent-process theory**, which was first proposed by physiologist Ewald Hering in 1878 and revised in 1957 by Leon Hurvich and Dorthea

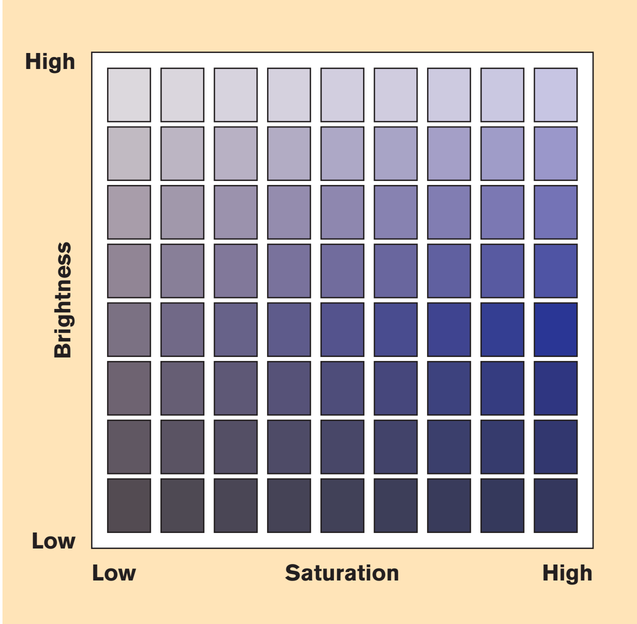


FIGURE 3.4
Hue, Saturation, and Brightness Three dimensions combine to produce the rich world of colour we experience. They are (1) hue, the actual colour we see (blue, green, and so on); (2) saturation, the purity of a colour; and (3) brightness, the intensity of the light energy reflected from a surface. The colours shown here are of the same hue but differ in saturation and brightness.

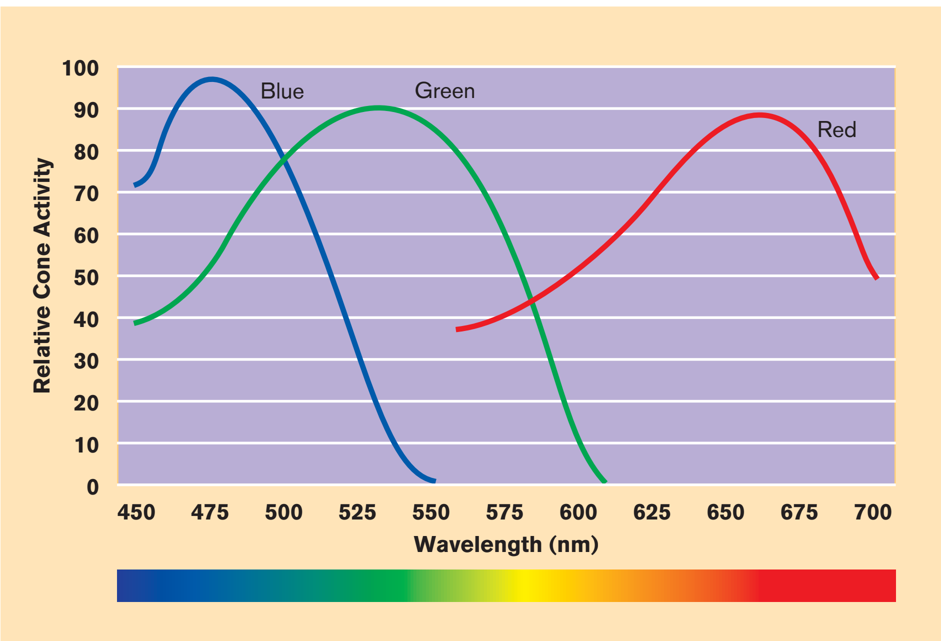


FIGURE 3.5
Relative Sensitivity of the Three Types of Cones Colour vision is largely dependent on three types of cones. Each type responds maximally to a restricted range of wavelengths. The maximal response for one cone type is to short wavelengths of 450–500 nm (blue), for another type it is to medium wavelengths of 500–570 nm (green), and for another type it is to long wavelengths of 620–700 nm (red).

Jamison. According to this theory, the cells increase or decrease their rate of firing when different colours are present. The red/green cells increase their firing rate when red is present and decrease it when green is present. The yellow/blue cells increase to yellow and decrease to blue. Another type of cell increases to white light and decreases to the absence of light. Think of the opponent-process theory as opposing pairs of cells on a seesaw. As one of this pair goes up, the other goes down. The relative firing rates of the three pairs of cells transmit colour information to the brain.

Does the opponent process operate in the cones, or elsewhere? Researchers now believe that the cones pass on information about wavelength colour to higher levels of visual processing. DeValois and DeValois (1975) proposed that the opponent processes might operate at the ganglion cells in the retina and in the higher brain centres rather than at the level of the receptors, the cones.

If you look long enough at one colour in the opponent-process pair and then look at a white surface, your brain will give you the sensation of the opposite colour—a negative **afterimage**. After you have stared at one colour in an opponent-process pair (red/green, yellow/blue, black/white), the cell responding to that colour tires and the opponent cell begins to fire, producing the afterimage. Demonstrate this for yourself in *Try It!*

Colour Blindness: Weakness for Sensing Some Colours

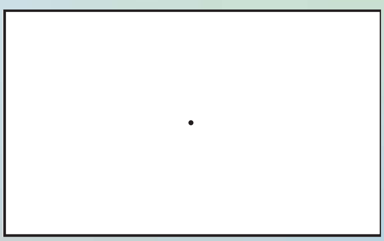
Not all of us see the world in the same colours. If normal genes for the three colour pigments are not present, there will be some form of **colour blindness**—the inability to distinguish some colours or, in rare cases, the total absence of colour vision. Total colour blindness affects only about 1 in 100 000 people (Nathans et al., 1989). We know what the world looks like to a colour-blind person because of research with people who have normal vision in one eye but some form of colour blindness in the other. Most colour vision defects are actually weaknesses, or colour confusion, rather than colour blindness. Many people who have some type of colour defect are not even aware of it.

Until recently, scientists believed that in order to have normal colour vision, a person must inherit three genes for colour: one gene for blue on chromosome 7 and one gene each for red and green on the X chromosome. Recent DNA evidence has revealed that this is not the case and that the number of genes for red and green colour pigment range from two to nine

Try It

Testing the Opponent-Process Theory

Stare at the dot in the green and black flag for about one minute. Then shift your gaze to the dot in the white space. You will see the Canadian flag in its true colours—the opponent-process colours of red and white.



trichromatic theory: The theory of colour vision suggesting that there are three types of cones, which are maximally sensitive to red, green, or blue, and that varying levels of activity in these receptors can produce all of the colours.

opponent-process theory: The theory that certain cells in the visual system increase their firing rate to signal one colour and decrease their firing rate to signal the opposing colour (red/green, yellow/blue, white/black).

afterimage: The visual sensation that remains after a stimulus is withdrawn.

colour blindness: The inability to distinguish some or all colours in vision, resulting from a defect in the cones.

On the top a hot air balloon is shown as it would appear to a person with normal colour vision; on the bottom is the same balloon as it would appear to a person with red-green colour blindness.

(Neitz & Neitz, 1995). This finding suggests that colour vision exists on a continuum, from red-green colour blindness in those missing either one or both of the genes for red and green pigment, to exceptional red-green colour vision for those with multiple colour genes on the X chromosome. Some form of what is commonly referred to as "red-green colour blindness" is found in about 8 percent of males, compared with less than 1 percent of females (Neitz et al., 1996). The large difference is due to the fact that males have only one X chromosome. The photos on the next page show how a balloon would look to someone with red-green colour blindness.

Before leaving the topic of vision, let us dispel the myth that some mammals, especially dogs, lack colour vision. Research shows that some form of colour vision is present in every species of mammals (Jacobs, 1993).

Hearing

Many years ago the frightening science fiction movie *Alien* was advertised this way: "In space no one can hear you scream!" Although the movie was fiction, the statement is true. Light can travel through the vast nothingness of space, a vacuum, but sound cannot. In the following section, you will learn why.

Remember It!

Vision

1. Match the parts of the eye with their descriptions.

____ 1) The coloured part of the eye	a. retina
____ 2) The opening in the iris that dilates and constricts	b. cornea
____ 3) The transparent covering of the iris	c. pupil
____ 4) The transparent structure that focuses an inverted image on the retina	d. iris
____ 5) The thin, photosensitive membrane at the back of the eye on which the lens focuses an inverted image	e. lens

2. The receptor cells in the retina that enable us to see in dim light are the (cones/rods); the cells that enable us to see colour and sharp images are (cones/rods).
3. Most people who are colour blind see no colour at all. (true/false)

Answers: 1. 1) d 2) c 3) b 4) e 5) a 2. rods; cones 3. false

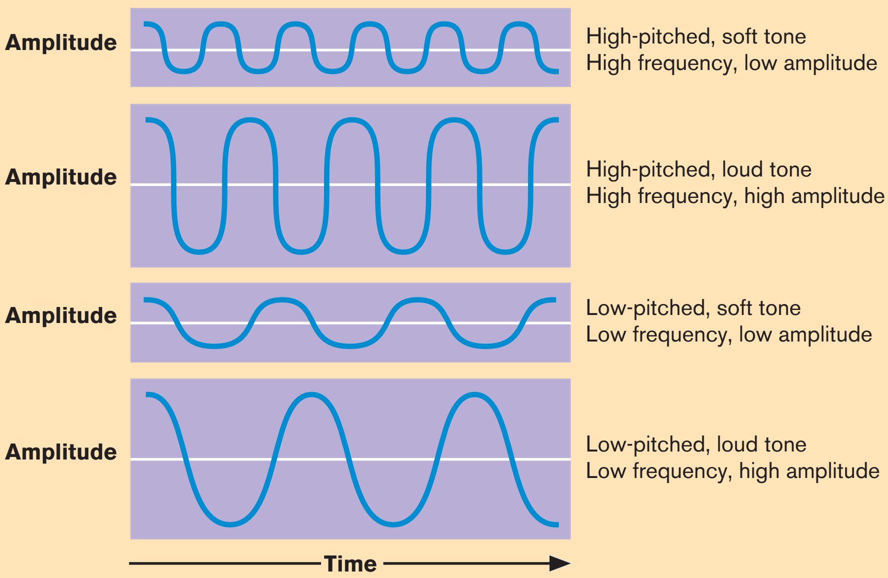


FIGURE 3.6
The Frequency and Amplitude of a Sound Wave
The frequency of a sound wave–the number of cycles completed per second–determines the pitch of the sound. Loudness is determined by amplitude–the energy or height of the sound wave.

Sound: What We Hear

What determines the pitch and the loudness of sound, and how is each quality measured?

Sound requires a medium through which to move, such as air, water, or a solid object. This was first demonstrated in 1660 by Robert Boyle, who suspended a ringing pocket watch by a thread inside a specially designed jar. When Boyle pumped all the air out of the jar, he could no longer hear the watch ringing. But when he pumped the air back into the jar, he could again hear the watch ringing.

If you have ever attended a very loud rock concert, you not only heard but actually felt the mechanical vibrations. The pulsating speakers may have caused the floor, your seat, the walls, and the air around you to shake or vibrate. You were feeling the moving air molecules being pushed toward you in waves as the speakers blasted their vibrations outward.

Frequency is an important characteristic of sound and is determined by the number of cycles completed by a sound wave in one second. The unit used to measure frequency, or cycles per second, is the hertz (Hz). The pitch—how high or low the sound—is chiefly determined by frequency: the higher the frequency (the more vibrations per second), the higher the sound.

The human ear can hear sound frequencies from low bass tones of around 20 Hz up to high-pitched sounds of about 200 Hz. Amazingly, dolphins can respond to sounds up to 100 000 Hz.

The loudness of a sound is determined largely by its **amplitude**. Amplitude depends on the energy of the sound wave. Loudness is determined mainly by the force or pressure with which the air molecules are moving. Figure 3.6 shows how sound waves vary in frequency and amplitude. We can measure the pressure level (loudness) of sounds using a unit called the *bel,* named for the Canadian inventor Alexander Graham Bell. Because the bel is a rather large unit, we usually express the measure in tenths of a bel, or **decibels** (dB). The threshold of human hearing is set at 0 dB, which does not mean the absence of sound but the softest sound that can be heard in a very quiet setting. Each increase of 10 dB makes a sound 10 times louder. A whisper is about 20 dB, but that is 100 times louder (10 dB × 10) than 0 dB. A normal conversation, around 60 dB, is 10 000 times louder

frequency: Measured in the unit hertz, the number of sound waves or cycles per second, determining the pitch of the sound.

amplitude: Measured in decibels, the magnitude or intensity of a sound wave, determining the loudness of the sound; in vision, the amplitude of a light wave affects the brightness of a stimulus.

decibel (DES-ih-bel): A unit of measurement of the intensity or loudness of sound based on the amplitude of the sound wave.

than a soft whisper at 20 dB. Figure 3.7 shows the comparative decibel levels for a variety of sounds.

If pitch and loudness were the only perceptual dimensions of sound, we could not tell the difference between two instruments if both were playing exactly the same note at the same decibel level. A third characteristic of sound, **timbre**, refers to the distinct quality of a sound that distinguishes it from other sounds of the same pitch and loudness. Unlike the pure sound of a tuning fork, which has only one frequency, most sounds we hear consist of several different frequencies.

The frequencies that form the sound pattern above any tone a musical instrument is playing are called *overtones,* or *harmonics.* Overtones are not actually heard as tones, but they give musical instruments their characteristic quality of sound, or timbre. The rich, full sound of a French horn is due to the large number of overtones present above the note being played. The almost pure sound of the flute is produced because relatively few overtones are generated above the notes sounded on that instrument.

LINK IT!

ear.berkeley.edu/auditory_lab/
University of California at Berkeley, Department of Psychology, Auditory Perception Lab

www.campanellaacoustics.com/faq.htm
Acoustics FAQ (Frequently Asked Questions)

The Ear: More to It Than Meets the Eye

How do the outer, middle, and inner ears function in hearing?

The part of the body that we call the ear plays only a minor role in **audition** in humans. In fact, if your visible outer ears were cut off, your hearing would suffer very little (Warren, 1999). Let us travel more deeply within the ear and learn how each part contributes to our ability to hear.

The Structure of the Ear: The Outer, Middle, and Inner Ears

The oddly shaped, curved flap of cartilage and skin called the *pinna* is the visible part of the **outer ear** (see Figure 3.8). Inside the ear, your auditory canal is about 2.5 centimetres long. Its entrance is lined with hairs. At the end of the auditory canal is the eardrum (the tympanic membrane), a thin, flexible membrane about a centimetre in diameter. The eardrum moves in response to the sound waves that strike it.

The **middle ear** is no larger than an aspirin tablet. Inside its chamber are the ossicles, the three smallest bones in your body, each "about the size of a grain of rice" (Strome & Vernick, 1989). Named for their shapes, the three connected ossicles—the hammer, the anvil, and the stirrup—link the eardrum to the oval window. The ossicles amplify the sound some 22 times (Békésy, 1957).

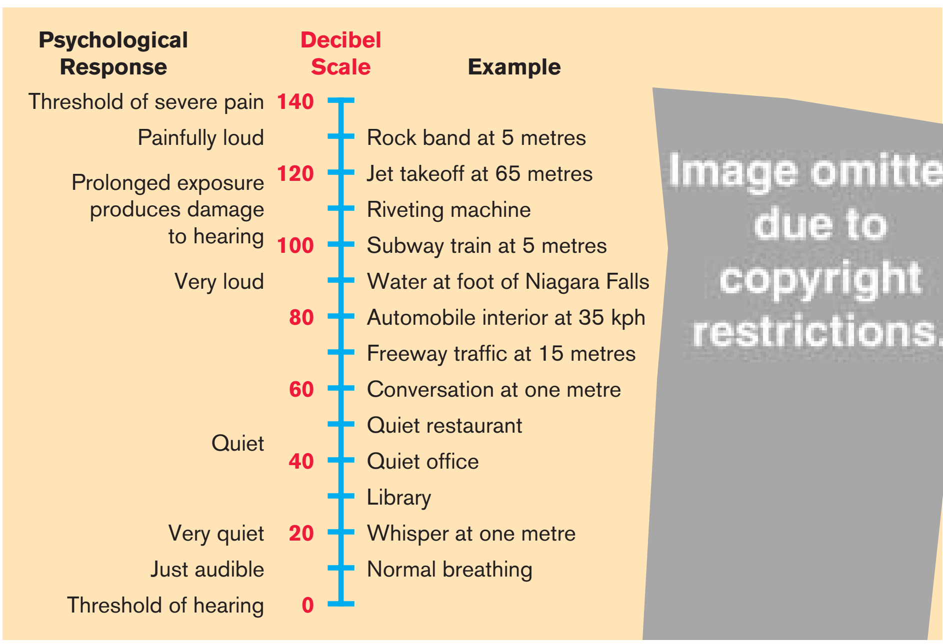


FIGURE 3.7
Decibel Levels of Various Sounds The loudness of a sound (its amplitude) is measured in decibels. Each increase of 10 decibels makes a sound 10 times louder. A normal conversation at one metre measures about 60 decibels, which is 10 000 times louder than a soft whisper of 20 decibels. Any exposure to sounds of 130 dB or higher puts a person at immediate risk for hearing damage.

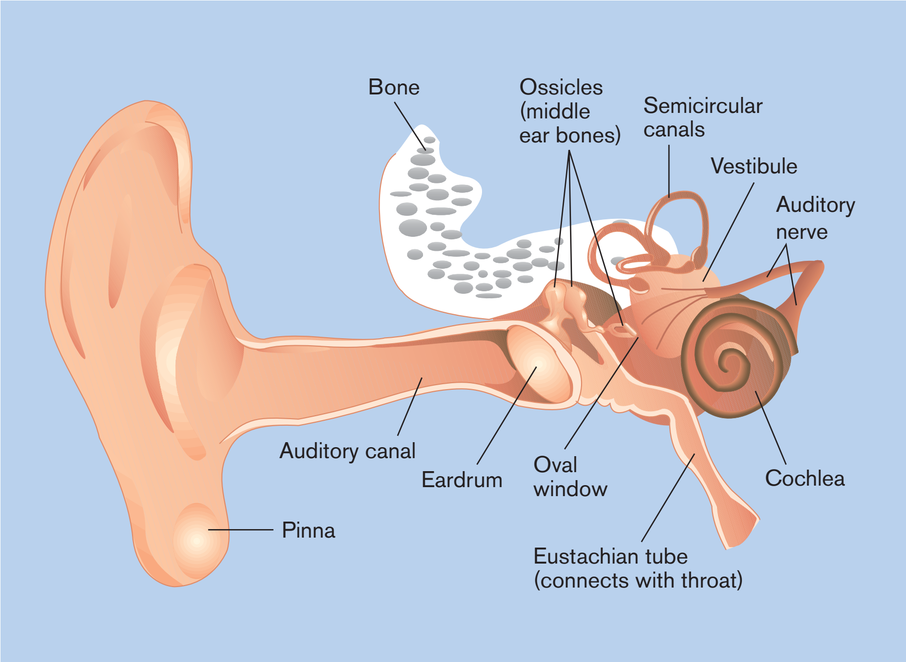


FIGURE 3.8
Anatomy of the Human Ear
Sound waves pass through the auditory canal to the eardrum, causing it to vibrate and set in motion the ossicles in the middle ear. When the stirrup pushes against the oval window, it sets up vibrations in the inner ear. This moves the fluid in the cochlea back and forth and sets the hair cells in motion, causing a message to be sent to the brain via the auditory nerve.

The **inner ear** begins at the inner side of the oval window in the base of the **cochlea**, a fluid-filled, snail-shaped, bony chamber. When the stirrup pushes against the oval window, it sets up vibrations that move the fluid in the cochlea back and forth in waves. The movement of the fluid sets in motion the thin basilar membrane that runs through the cochlea. Attached to the basilar membrane are about 15 000 sensory receptors called **hair cells**, each with a bundle of tiny hairs protruding from it. The tiny hair bundles are pushed and pulled by the motion of the fluid inside the cochlea. This produces an electrical impulse, which is transmitted to the brain by way of the auditory nerve (Hudspeth, 1983).

Having two ears, one on either side of the head, enables us to determine the direction from which sounds are coming (Konishi, 1993). Unless a sound is directly above, below, in front of, or behind us, it reaches one ear slightly before it reaches the other (Spitzer & Semple, 1991). The brain detects differences as small as $\frac{1}{10\,000}$ of a second and interprets them, telling us the direction of the sound (Rosenzweig, 1961). The source of a sound may also be determined by the difference in intensity of the sound reaching each ear (Middlebrooks & Green, 1991).

Theories of Hearing: How Hearing Works

What two major theories attempt to explain hearing?

In the 1860s, Hermann von Helmholtz helped develop **place theory**, one of the two major theories of hearing. This theory holds that each individual pitch we hear is determined by the particular spot or place along the basilar membrane that vibrates the most.

timbre (TIM-burr): The distinctive quality of a sound that distinguishes it from other sounds of the same pitch and loudness.

audition: The sensation of hearing; the process of hearing.

outer ear: The visible part of the ear, consisting of the pinna and the auditory canal.

middle ear: The portion of the ear containing the ossicles, which connect the eardrum to the oval window and amplify the vibrations as they travel to the inner ear.

inner ear: The innermost portion of the ear, containing the cochlea, the vestibular sacs, and the semicircular canals.

cochlea (KOK-lee-uh): The snail-shaped, fluid-filled organ in the inner ear that contains the hair cells (the sound receptors).

hair cells: Sensory receptors for hearing, found in the cochlea.

place theory: The theory that sounds of different frequencies or pitch cause maximum activation of hair cells at certain locations along the basilar membrane.

By observing the living basilar membrane, researchers have verified that different locations do indeed vibrate in response to differently pitched sounds (Ruggero, 1992). Even so, place theory cannot really explain how we perceive frequencies below 150 Hz.

Another attempt to explain hearing is **frequency theory**. According to this theory, the hair cell receptors vibrate the same number of times per second as the sounds that reach them. Thus, a tone of 500 Hz would stimulate the hair cells to vibrate 500 times per second as well. Frequency theory seems valid for low- and medium-pitched tones, but it has a major problem with high-frequency tones. Individual neurons cannot fire more than about 1 000 times per second. Therefore, they could not signal to the brain the higher-pitched tones of 1 000 to 20 000 Hz.

The *volley principle* suggests that groups, or volleys, of neurons, if properly synchronized, could together produce the firing rate required for tones somewhat higher than 1 000 Hz (Wever, 1949). Yet even with the help of the volley principle, frequency theory cannot explain how we hear tones with frequencies higher than about 4 000 Hz. Today, researchers believe that frequency theory best explains how we perceive low frequencies, and that place theory best explains how we perceive the remaining frequencies (Matlin & Foley, 1997; Warren, 1999).

Hearing Loss: Kinds and Causes

What are some major causes of hearing loss?

About two million people in Canada have hearing problems, and that number is growing rapidly. Hearing loss and deafness can be caused by disease, birth defects, injury, excessive noise, and old age. *Conductive* hearing loss, or conduction deafness, is usually caused by disease or injury to the eardrum or the bones of the middle ear, with the result that soundwaves cannot be conducted to the cochlea. People with conductive hearing loss can usually be helped with a hearing aid.

The vast majority of conductive hearing losses can be repaired medically or surgically by physicians specializing in disorders of the ear. And in rare cases, people can be fitted with a hearing aid that bypasses the middle ear and uses bone conduction to reach the cochlea. Many people over the age of 60 (more men than women) suffer from gradual hearing loss that involves damage either to the cochlea or to the auditory nerve. In cases where damage to the cochlea is not too severe, conventional hearing aids may be fitted to reduce the hearing loss (Bramblett, 1997). But hearing aids are useless if the damage is to the auditory nerve that connects the cochlea to the brain.

There are some indications that lifelong exposure to excessive noise may be more of a factor than aging

Remember It!

Hearing

1. Pitch is chiefly determined by ____________; loudness is chiefly determined by ____________.
   a. amplitude; frequency
   b. wavelength; frequency
   c. intensity; amplitude
   d. frequency; amplitude
2. Pitch is measured in (hertz/decibels); loudness is measured in (decibels/hertz).
3. Match the part of the ear with the structures it contains.

   ____ 1) ossicles — a. outer ear
   ____ 2) pinna, auditory canal — b. middle ear
   ____ 3) cochlea, hair cells — c. inner ear
4. The receptors for hearing are found in the
   a. ossicles.
   b. auditory canal.
   c. auditory membrane.
   d. cochlea.
5. The two major theories that attempt to explain hearing are
   a. conduction theory and place theory.
   b. hair cell theory and frequency theory.
   c. place theory and frequency theory.
   d. conduction theory and hair cell theory.
6. According to the text, lifelong exposure to excessive noise may be more of a factor in hearing loss than aging is. (true/false)

Answers: 1. d 2. hertz; decibels 3. 1) b 2) a 3) c 4. d 5. c 6. true in explaining hearing loss (Kalb, 1997). Perhaps this is why the Mabaan people of the Sudan don't seem to suffer much hearing loss as they age. When hearing tests were conducted on that group, it was found that some 80-year-olds could hear as well as 20-year-olds in industrialized countries. The Mabaan pride themselves on their sensitive hearing and consider it important never to raise their voices. Even their festivals and celebrations are quiet affairs, featuring dancing and soft singing. The loudest sounds they usually hear in their everyday world are made by their own domestic animals, such as sheep or roosters (Bennett, 1990).

Smell and Taste

Smell: Sensing Scents

Consider what it would be like to live in a world without smell. "Not really so bad," you might say. "Although I could not smell flowers, perfume, or my favourite foods, I would never again have to endure the foul odours of life. It's a trade-off, so what's the difference?"

The difference is large indeed. Your ability to detect odours close at hand and at a distance is an aid to survival. You smell smoke and can escape before the flames of a fire envelop you. Your nose broadcasts an odour alarm to the brain when certain poisonous gases or noxious fumes are present. But the survival value of odour detection in humans does not stop there. Smell, aided by taste, is the last line of defence—your final chance to avoid putting spoiled food or drink into your body.

It is well known that odours alone have a powerful ability to call forth old memories and rekindle strong emotional feelings, even decades after events in our lives. This is not surprising when we consider that the olfactory system sends information to the limbic system, an area in the brain that plays an important role in emotions and memories as well (Horvitz, 1997).

There are large individual differences in smell sensitivity. Perfumers and whiskey blenders can distinguish about 100 000 odour compounds; the average person with training can distinguish from 10 000 to about 40 000 (Dobb, 1989).

The Mechanics of Smell: How the Nose Knows

What path does a smell message take on its journey from the nose to the brain?

Olfaction—the sense of smell—is a chemical sense. We cannot smell a substance unless some of its molecules vaporize—pass from a solid or liquid into a gaseous state. Heat speeds up the evaporation of molecules, which is why food that is cooking has a stronger and more distinct odour than uncooked food. When odour molecules vaporize, they become airborne and make their way up our nostrils to the **olfactory epithelium**. The olfactory epithelium consists of two patches of tissue, one at the top of each nasal cavity, that together contain about 10 million olfactory neurons—the receptor cells for smell. Each of these neurons contains only 1 of the 1 000 different types of odour receptors (Bargmann, 1996). The intensity of the smell stimulus—how strong or weak it is—is apparently determined by the number of olfactory neurons firing at the same time (Freeman, 1991). Figure 3.9 shows a diagram of the human olfactory system.

Odours have a powerful ability to evoke memories and stir up emotions.

Image omitted due to copyright restrictions.

frequency theory: The theory that hair cell receptors vibrate the same number of times as the sounds that reach them, thereby accounting for the way variations in pitch are transmitted to the brain.

olfaction (ol-FAK-shun): The sensation of smell; the process of smell.

olfactory epithelium: A patch of tissue at the top of the nasal cavity, that contains about 10 million receptors for smell.

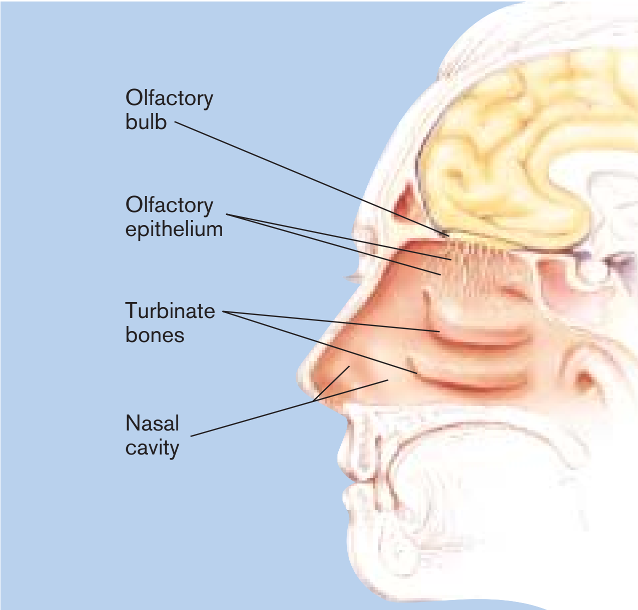


FIGURE 3.9

The Olfactory Sense **Odour molecules travel up the nostrils to the olfactory epithelium, which contains the receptor cells for smell. Olfactory receptors are special neurons with axons that form the olfactory nerve. The olfactory nerve relays smell messages to the olfactory bulbs and on to other parts of the brain.**

The olfactory neurons are different from all other sensory receptors. They are special types of neurons that come into direct contact with sensory stimuli and reach directly into the brain. Unlike all other neurons, olfactory neurons have a short life span—between 30 and 60 days—and are continuously being replaced (Buck, 1996). The axons of the olfactory receptor cells relay smell messages directly to the **olfactory bulbs**—two brain structures the size of matchsticks that rest above the nasal cavities (refer to Figure 3.9). From the olfactory bulbs, messages are relayed to different parts of the brain.

LINK IT!

www.cf.ac.uk/biosi/staff/jacob/teaching/sensory/olfact1.html
Olfaction

neuroscience.about.com/science/neuroscience/library/blxSystOlf.htm
Supplementary Olfactory Resources

Pheromones

Many animals excrete chemicals called **pheromones**, which can have a powerful effect on the behaviour of other members of the same species. Animals use pheromones to mark off territories and to signal sexual receptivity (Dobb, 1989).

Some studies suggest that humans, although not consciously aware of it, may also be receptive to pheromones when it comes to mating. Viennese researcher Karl Grammer (cited in Holden, 1996) analyzed the saliva of young men who had used an inhalant to sniff pheromones found in female vaginal secretion. Women's ovulatory secretions were the only ones to cause a rise in testosterone levels in the men's saliva. The men apparently recognized, though not consciously, which of the women were most likely to be fertile. A later study also indicates that humans can communicate by pheromones (Stern & McClintock, 1998).

Taste: What the Tongue Can Tell

What are the four primary taste sensations, and how are they detected?

A sizzling steak, hot buttered popcorn, chocolate cake—does your sense of taste alone tell you what these foods taste like? Surprisingly, no. **Gustation**, or the sense of taste, gives us only four distinct kinds of sensations—sweet, sour, salty, and bitter. When we say that a food tastes good or bad, we are actually referring to **flavour**—the combined sensory experience of taste, smell, and touch. As we taste, we feel the texture and temperature of foods we put in our mouths. But most of the pleasure we attribute to our sense of taste is actually due to smell, which comes from odour molecules forced up the nasal cavity by the action of the tongue, cheeks, and throat when we chew and swallow. Colour can also contribute to our sense of taste. In one study, many participants could not even recognize the taste of root beer when it was coloured red (Hyman, 1983). Can you identify some common foods by taste alone? *Try It!*

The Taste Receptors: Taste Detectors

If you look at your tongue in a mirror, you will see many small bumps called *papillae.* There are four different types of papillae, and three of them contain **taste buds**, which cluster around the cracks and

Try It!

Taste Test

Cover your eyes and hold your nose tightly. Ask a friend to feed you small pieces of food with a similar texture, such as raw potato, apple, and even onion. See if you can identify the food by taste alone. Most people cannot.

crevices between the papillae. Each taste bud is composed of 60 to 100 receptor cells, which resemble the petals of a flower (Kinnamon, 1988). Taste receptors are also found in the palate, in the mucous lining of the cheeks and lips, and in parts of the throat, including the tonsils (Bradley, 1971; G.H. Parker, 1922). The lifespan of the receptor cells for taste is very short, only about 10 days, and they are continually replaced (Beidler & Smallman, 1965).

Taste buds are most densely packed on the tip of the tongue, less densely packed on the rear edges, and absent from the centre of the tongue (Bartoshuk, 1989). But taste is poorly localized, and taste sensations appear to come from all over the mouth. Even people with damage over large areas of the mouth are usually unaware of the loss of taste buds, because very intense sensations can be produced by rather small areas of normal tissue (Bartoshuk et al., 1987).

For many years textbooks included a "tongue map" showing the four basic tastes spatially distributed over different areas of the tongue. But the tongue map is an error that resulted from a mistranslation of a 1901 article written in German. Researchers who have performed extensive spatial testing for the four taste sensations report that all four tastes can be detected by taste buds on all locations of the tongue (Bartoshuk & Beauchamp, 1994).

Although aging is typically accompanied by a decline in the other senses, people lose very little of their ability to detect the four primary taste sensations as they age (Bartoshuk et al., 1987). When older people complain that food doesn't taste as good as it once did, the reason is usually a loss of smell rather than a failing sense of taste (Bartoshuk, 1989).

Researchers, using videomicroscopy, have actually counted the number of taste buds on the tongues of different individuals (Miller & Reedy, 1990). Not surprisingly, people with a reduced ability to taste had the smallest number of taste buds per square centimetre—an average of 96. Medium tasters averaged nearly twice as many taste buds (184), and supertasters had more than four times as many taste buds (425). But the fact that supertasters do not taste all substances with greater intensity suggests that the number of taste buds alone does not explain general taste sensitivity.

Our Other Senses

Other senses are our sense of touch (the tactile sense), our sense of balance (the vestibular sense), and our kinesthetic sense.

The Skin Senses: Information from Our Natural Clothing

Our own natural clothing, the skin, is the largest organ of the body. It performs many important bio-

olfactory bulbs: Two matchstick-sized structures above the nasal cavities, where smell sensations first register in the brain.

pheromones: Chemicals excreted by humans and other animals that act as signals to and elicit certain patterns of behaviour from members of the same species.

gustation: The sensation of taste.

flavour: The combined sensory experience of taste, smell, and touch.

taste buds: The structures that are composed of 60 to 100 sensory receptors for taste.

Remember It!

Smell and Taste

1. The technical name for the process or sensation of smell is (gustation/olfaction).
2. The olfactory, or smell, receptors are located in the
   a. olfactory tract.
   b. olfactory nerve.
   c. olfactory epithelium.
   d. olfactory bulbs.
3. The four primary taste sensations are ________, ________, ________, and ________.
4. Our ability to identify foods with similar texture is most influenced by our sense of (taste/smell).
5. Each (papilla/taste bud) contains from 60 to 100 receptor cells.
6. Taste receptor cells have a very short life span and are continually replaced. (true/false)
7. Supertasters have the same number of taste buds as medium tasters and non-tasters. (true/false)

Answers: 1. olfaction 2. c 3. sweet, salty, sour, bitter 4. smell 5. taste bud 6. true 7. false

logical functions while also yielding much of what we know as sensual pleasure. Your skin can detect heat, cold, pressure, pain, and a vast range of touch sensations—caresses, pinches, punches, pats, rubs, scratches, and the feel of many different textures, from silk to sandpaper.

The Mechanism of Touch: How Touch Works

How does the skin provide sensory information?

Tactile information is conveyed to the brain when an object touches and depresses the skin, stimulating one or more of the several distinct types of nerve cell receptors. These sensitive nerve endings in the skin send the touch message through nerve connections to the spinal cord. The message travels up the spinal cord and through the brainstem and the lower brain centres, finally reaching the brain's somatosensory cortex. Only then do we become aware of where and how hard we have been touched. Remember from Chapter 2 that the somatosensory cortex is the strip of tissue at the front of the parietal lobes where touch, pressure, temperature, and pain register.

If we examine the skin from the outermost to the deepest layer, we find a variety of nerve endings that differ markedly in appearance. Most or all of these nerve endings appear to respond in some degree to all different types of tactile stimulation.

In the 1890s, one of the most prominent researchers of the tactile sense, Max von Frey, discovered the two-point threshold, which measures how far apart two points must be before we feel them as two separate touches. Demonstrate the two-point threshold yourself in the *Try It!* box below.

Try It!

Testing the Two-Point Threshold

Have someone touch the middle of your back with two toothpicks held about four centimetres apart. Do you feel one point or two? How far apart do the toothpicks have to be before you perceive them as two separate touch sensations? How far apart do they have to be on your face? on your hands? on your fingers? on your toes? Which of these body parts are the most sensitive? Which are the least sensitive?

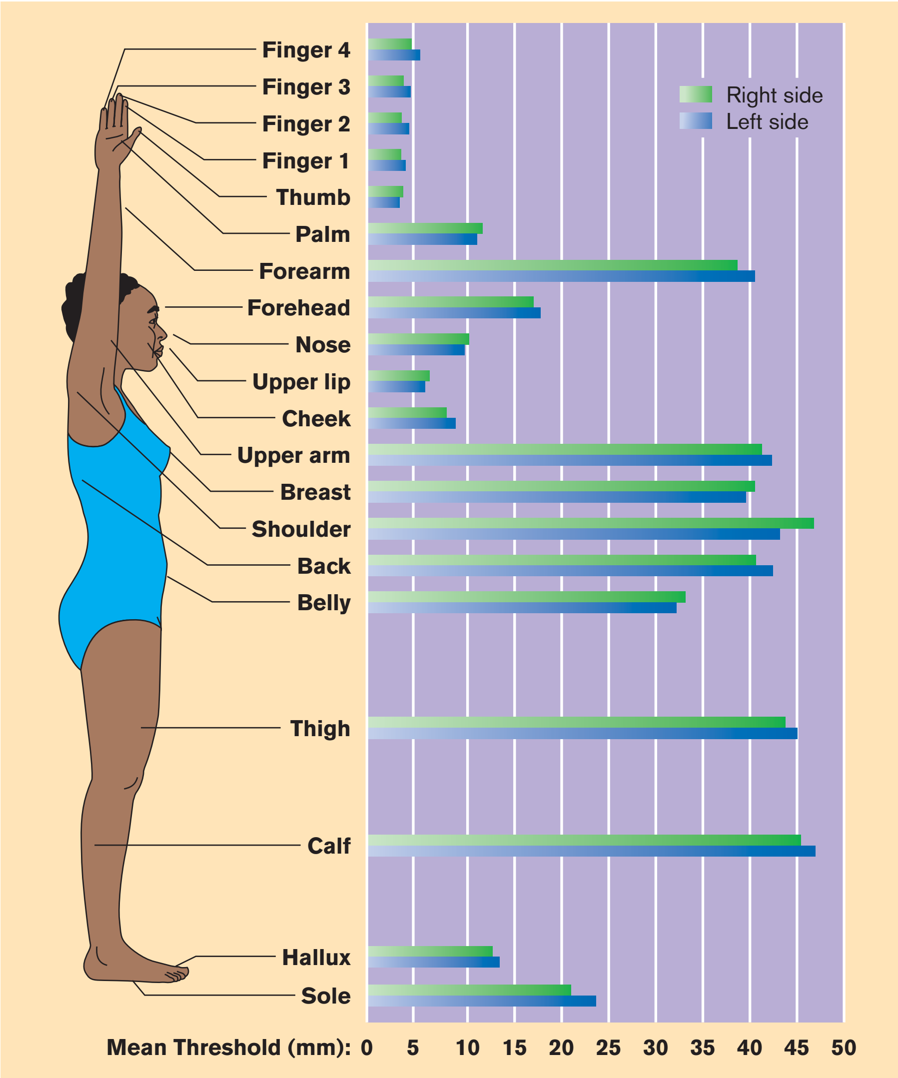


FIGURE 3.10

The Two-Point Threshold The two-point threshold measures how far apart two points must be to be felt as two separate touches. The drawing shows the average two-point thresholds for different parts of the body. The shortest bars on the graph indicate the greatest sensitivity; the longest bars, the least sensitivity. The thumb and fingers, being the most sensitive body parts, have the lowest two-point thresholds (less than 5 mm). The calves, being the least sensitive body parts, have two-point thresholds of about 45 mm. (After Weinstein, 1968).

Figure 3.10 illustrates two-point thresholds for different body parts, showing the actual distance apart at which two-point discriminations can be made by most people.

Recent Canadian research shows that even young infants (five and one-half months old) are sensitive to subtle changes in their mothers' touching, and that a mother's touch is perceived as a positive experience (Stack & Arnold, 1998; Stack & Lepage, 1996).

Pain: Physical Hurts

What beneficial purpose does pain serve?

Although our sense of touch brings us a great deal of pleasure, it delivers pain as well. Recall the opening story, in which we described the life of James Stone, Jr., the boy who could feel no pain. Although he had never had a headache or a toothache, and never felt the pain of a cut or a burn, he also was unable to feel the many adaptive cues revealed by pain. His arms and legs were twisted and bent. Some of his fingers were missing and bloody wounds would often cover his body, as he never noticed that he was repeatedly injuring himself.

This story shows that pain functions as a valuable warning and protective mechanism. It motivates us to tend to our injuries, restrict our activity, and seek medical help if we need it. Pain also teaches us to avoid pain-producing circumstances in the future.

tactile: Pertaining to the sense of touch.

Chronic pain, however, persists long after it serves any useful function and is a serious medical problem for many Canadians. The three major types of chronic pain are low-back pain, headache, and arthritis pain. For its victims, chronic pain is like a fire alarm that no one can turn off.

The Gate-Control Theory: Conducting Pains Great and Small

What is the gate-control theory of pain?

Pain is probably the least understood of all the sensations. We are not certain how pain works, but one major theory seeks to explain it—the **gate-control theory** of McGill researchers Melzack and Wall (1965, 1983). They contend that there is an area in the spinal cord that can act as a "gate" and either inhibit pain messages or transmit them to the brain. Only so many messages can go through the gate at any one time. We feel pain when pain messages carried by the small, slow-conducting nerve fibres reach the gate and cause it to open. Large, fast-conducting nerve fibres carry other sensory messages from the body; these can effectively tie up traffic at the gate so that it will close and keep many of the pain messages from getting through.

What is the first thing you do when you stub your toe or pound your finger with a hammer? If you rub or apply gentle pressure to the injury, you are stimulating the large, fast-conducting nerve fibres to send their message to the spinal gate first; this blocks some of the pain messages from the slower nerve fibres. Applying ice, heat, or electrical stimulation to the painful area also stimulates the large nerve fibres and closes the spinal gate.

In his newer formulation of the gate-control theory, Melzack (1999a; 1999b) argues that pain is a multidimensional experience produced by a widely distributed neural network. In other words, psychological, cognitive, and emotional factors can influence the perception of pain. Messages from the brain can thus inhibit the transmission of pain messages at the spinal gate and thereby affect the perception of pain. This may explain why some people can undergo surgery under hypnosis and feel little or no pain, and why athletes injured during games are so distracted that they often do not experience pain until some time after the injury.

Endorphins: Our Own Natural Pain Relievers

What are endorphins?

Throughout the world, people spend more effort and money trying to get rid of pain than for any other medical purpose. In fact, Canadians spend over $1 billion each year on treatments for chronic pain, ranging from over-the-counter medications to surgery and psychotherapy.

In Chapter 2 we read that our body produces its own natural painkillers, the **endorphins**, which block pain and produce a feeling of well-being (Hendler & Fenton, 1979). Endorphins are released when we are injured, when we experience stress or extreme pain, and when we laugh, cry, or exercise (Terman et al., 1984). "Runner's high" and an elevated mood after exercising are often attributed to an increase in endorphin levels (Goldberg, 1988).

Some people release endorphins even when they only *think* they are receiving pain medication. When hospital patients recovering from surgery ask for pain medication, they are sometimes given, instead, a placebo in the form of a sugar pill or an injection of saline solution. Nevertheless, 35 percent of the patients who receive placebos report relief from pain (Melzack & Wall, 1983). Why? When patients believe that they have received a drug for pain, apparently that belief stimulates the release of natural pain relievers, the endorphins.

Such may be the case when people use acupuncture, the ancient Chinese technique for relieving pain. Acupuncture seems to relieve pain by stimulating the

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The experience of pain is affected by cultural background, and this influence extends even to childbirth, which is endured more stoically by women in some cultures.

release of endorphins. The next time you experience pain, you may want to try some other pain-controlling techniques in *Try It!*

The Kinesthetic Sense: Keeping Track of Our Body Parts

What kind of information does the kinesthetic sense provide, and how is this sensory information detected?

The **kinesthetic sense** provides information about (1) the position of the body parts in relation to one another, and (2) the movement in various body parts. This information is detected by receptors in the joints, ligaments, and muscles. The other senses, especially vision, provide additional information about body position and movement, but our kinesthetic sense works well on its own. Thanks to our kinesthetic sense, we are able to perform smooth and skilled body movements without visual feedback or a studied, conscious effort. A companion sense, the vestibular sense, involves equilibrium, or the sense of balance.

The Vestibular Sense: Sensing Up and Down and Changes in Speed

What is the vestibular sense, and where are its sensory receptors located?

Our **vestibular sense** detects movement and provides information about where we are in space. The vestibular sense organs are located in the semicircular canals and the vestibular sacs in the inner ear. The **semicircular canals** sense the rotation of your head, such as when you are turning your head from side to side or when you are spinning around (see Figure 3.11). The tube-like canals are filled with fluid; rotating movements of the head in any direction send this fluid coursing through them. In the canals, the moving fluid bends the hair cells, which act as receptors and send neural impulses to the brain. Because there are three canals, each positioned on a different plane, the hair cells in one canal will bend more than the hair cells in the other canals, depending on the direction of rotation.

Try It!

Controlling Pain

If you experience pain, you can try any of the following techniques for controlling it:

- Distraction can be particularly effective for controlling brief or mild pain. Generally, activities or thoughts that require a great deal of attention will provide more relief than passive distractions.
- Counterirritation—stimulating or irritating one area of the body to mask or diminish pain in another area—can be accomplished with ice packs, heat, massage, mustard packs, or electrical stimulation.
- Relaxation techniques are useful for reducing the stress and muscular tension that usually accompany pain.
- Positive thoughts can help you cope with pain, whereas negative thoughts tend to increase your anxiety.
- Attention and sympathy from family members and friends should be kept at a moderate level; too much attention may prove to be so reinforcing that it serves to prolong pain.

gate-control theory: The theory that the pain signals transmitted by slow-firing nerve fibres can be blocked at the spinal gate if fast-firing fibres get their message to the spinal cord first, or if the brain itself inhibits the transmission of the pain messages.

endorphins (en-DOR-fins): Chemicals, produced naturally by the pituitary gland, that reduce pain and affect mood positively.

kinesthetic sense: The sense that provides information about the position of body parts and about body movement, detected by sensory receptors in the joints, ligaments, and muscles.

vestibular sense (ves-TIB-yu-ler): The sense that provides information about movement and our orientation in space through sensory receptors in the semicircular canals and the vestibular sacs, which detect changes in the movement and orientation of the head.

semicircular canals: Three fluid-filled tubular canals in the inner ear that provide information about rotating head movements.

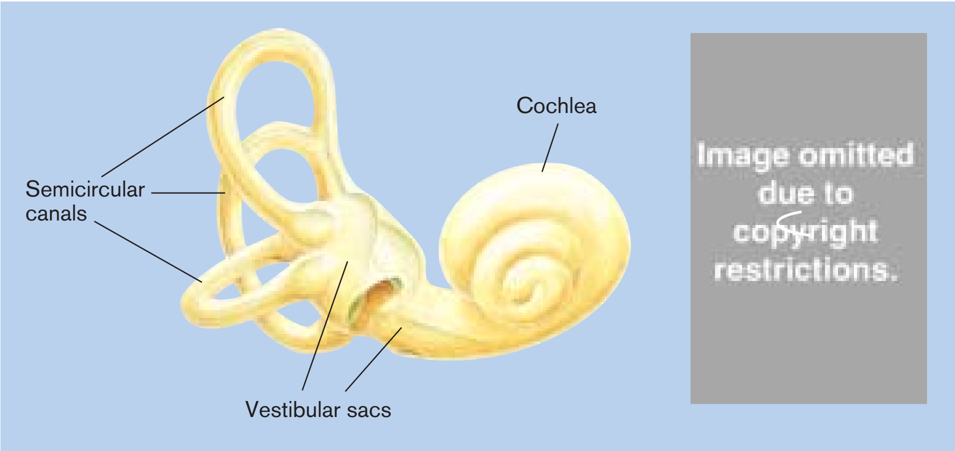


FIGURE 3.11 Sensing Balance and Movement We sense the rotation of the head in any direction because the movement sends fluid coursing through the tubelike semicircular canals in the inner ear. The moving fluid bends the hair cell receptors, which in turn send the message to the brain.

The semicircular canals and the vestibular sacs signal only *changes* in motion or orientation. If you were blindfolded and had no visual or other external cues, you would not be able to sense motion once your speed reached a constant rate. For example, in an airplane you feel the takeoff and landing or sudden changes in speed. But once the pilot levels off and maintains about the same speed, your vestibular organs do not signal to the brain that you are moving, even if you are travelling hundreds of kilometres per hour.

Remember It!

Other Senses

1. Each skin receptor responds only to touch, pressure, warmth, or cold. (true/false)
2. The two-point threshold varies for different body parts. (true/false)
3. People would be better off if they could not feel pain. (true/false)
4. The (kinesthetic/vestibular) sense provides information about the position of our body parts in relation to one another and about movement in those body parts.
5. The receptors for the (kinesthetic/vestibular) sense are located in the semicircular canals and vestibular sacs in the (middle ear/inner ear).

Answers: 1. false 2. true 3. false 4. kinesthetic 5. vestibular; inner ear

Perception: Ways of Perceiving

In the first part of this chapter, you learned how the senses detect visual, auditory, and other sensory information and transmit it to the brain. Now we will explore **perception**—the process by which this sensory information is actively organized and interpreted by the brain. We *sense* sounds in hertz and decibels, but we *perceive* melodies. We *sense* light of certain wavelengths and intensities, but we *perceive* a multicoloured world of objects and people. Sensations are the raw materials of human experiences; perceptions are the finished products.

We know that physical objects can be analyzed down to their smallest parts, even to the atoms that make up the object. Can perception be analyzed and understood in the same way—broken down into its smallest sensory elements? The answer is no, according to Gestalt psychology, a school of thought that began in Germany in the early 1900s.

The Gestalt Principles of Perceptual Organization

What are the Gestalt principles of perceptual organization?

The Gestalt psychologists maintained that we cannot understand our perceptual world by breaking down experiences into tiny parts and analyzing them separately. When sensory elements are brought together, something new is formed. They insisted that the whole is more than just the sum of its parts. The German word **Gestalt** has no exact English equivalent, but it roughly refers to the whole form, pattern, or configuration that we perceive.

How do we organize the world of sights, sounds, and other sensory stimuli in order to perceive the way we do? The Gestalt psychologists argued that we organize our sensory experience according to certain basic principles of perceptual organization. These principles include the figure–ground relationship and other principles of perceptual grouping.

Figure and Ground: One Stands Out

The **figure–ground** relationship is the most fundamental principle of perceptual organization and is, therefore, the best place to start analyzing how we perceive. As you view your world, some objects (the figure) seem to stand out from the background (the ground).

Many psychologists believe that figure–ground perceptual ability is **innate** (that is, an ability we do not have to learn). We know that figure–ground perception is present very early in life. It is also the first ability to appear in patients who were blind from birth and who became sighted as adults. We also know that figure–ground perception is not limited to vision. If you listen to a symphony orchestra or a rock band, the melody line tends to stand out as figure, while the chords and the rest of the accompaniment are heard as ground. An itch or a pain would immediately get your attention, while the remaining tactile stimuli you feel would fade to ground.

How can we be sure that knowing the difference between figure and ground is a result of our perceptual system, and that the difference isn't part of the sensory stimulus itself? The best proof is represented by reversible figures, where figure and ground seem to shift back and forth between two equal possibilities, as shown in Figure 3.12.

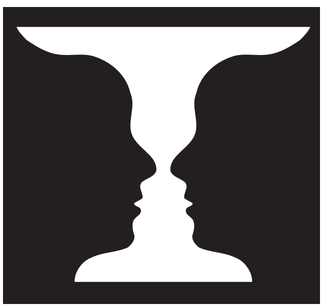


FIGURE 3.12 Reversing Figure and Ground In this illustration, you can see a white vase as figure against a black background, or two black faces in profile on a white background. Exactly the same visual stimulus produces two opposite figure–ground perceptions.

Sometimes a figure or an object blends so well with its background that we can hardly see it. When there are no sharp lines of contrast between a figure and its background, a figure is camouflaged. For many animals, camouflage provides protection from predators.

Gestalt Principles of Grouping: Perceptual Arrangements

The Gestalt psychologists believed that when we see figures or hear sounds, we organize them according to the simplest, most basic arrangement possible. They proposed the following principles of grouping: similarity, proximity, continuity, and closure (Wertheimer, 1958).

SIMILARITY We tend to group visual, auditory, and other stimuli according to the principle of similarity. Objects that have similar characteristics are perceived as a unit. In Figure 3.13(a), dots of a similar colour are perceived as belonging together to form horizontal rows (on the left) and vertical columns (on the right). When we listen to music, we group the instruments and perceive them as units—the violins, trumpets, and so on—on the basis of similarity in sound.

PROXIMITY Objects that are close together in space or time are usually perceived as belonging together, because of a principle of grouping called *proximity*. Because of their spacing, the lines in Figure 3.13(b) are perceived as four pairs of lines rather than as eight separate lines. Musical notes sounded close together in time are perceived as belonging together to produce musical phrases.

CONTINUITY The principle of continuity suggests that we perceive figures or objects as belonging together if they appear to form a continuous pattern, as in Figure 3.13(c). When two singers sing or two instruments are played in harmony, we perceive the notes in the melody line as belonging together, and

perception: The process by which sensory information is actively organized and interpreted by the brain.

Gestalt (geh-SHTALT): A German word roughly meaning *form* or *pattern*.

figure–ground: A principle of perceptual organization whereby the visual field is perceived in terms of an object (figure) standing out against a background (ground).

innate: Inborn, unlearned.

the notes in the harmony line as belonging together, even if they converge on the same note and then cross over.

CLOSURE The principle of closure attempts to explain our tendency to complete figures with gaps in them. Even though parts of the figure in Figure 3.13(d) are missing, we use closure and perceive them as a triangle. If you were listening to your favourite song on the radio and interference periodically interrupted it, you would fill in the gaps to perceive the whole song.

Perceptual Constancy

What is perceptual constancy, and what are its four types?

As we view people and objects from different angles and distances and under different lighting conditions, we tend to see them as maintaining the same size, shape, brightness, and colour. We call this phenomenon **perceptual constancy**.

Size Constancy: When Smaller Means Farther Away

When you say goodbye to friends and watch them walk away, the image they cast on your retina grows smaller and smaller until they finally disappear in the distance. But the shrinking-size information that the retina sends to your brain (the sensation) does not fool the perceptual system. As objects or people move farther away from us, we continue to perceive them as about the same size.

This perceptual phenomenon is known as **size constancy**. We do not make a literal interpretation about the size of objects from the **retinal image**—the image projected onto the retina of objects in the visual field. If we did, we would believe that objects we see become larger as they approach us and smaller as they move away from us. Some evidence suggests that size constancy is learned. People who are blind from birth and later become sighted usually have trouble perceiving visual sensations they have never experienced and grossly misjudge distances.

Shape Constancy: Seeing Round as Round from Any Angle

The shape or image of an object projected onto the retina changes according to the angle from which we view it. But our perceptual ability gives us **shape constancy**—the tendency to perceive objects as having a stable or unchanging shape regardless of changes in the retinal image resulting from differences in viewing angle. In other words, we perceive a door as rectangular and a plate as round from whatever angle we view them (see Figure 3.14).

Brightness Constancy: Perceiving Brightness in Sunlight and Shadow

We normally see objects as maintaining a constant level of brightness regardless of differences in lighting conditions—a phenomenon known as **brightness constancy**. Nearly all objects reflect some part of the light that falls upon them, and we know that white objects reflect more light than black objects. However, a black asphalt driveway actually reflects more light at noon in bright sunlight than a white shirt reflects indoors at night in dim lighting. Nevertheless, the driveway still looks black and the shirt still looks white. Why? We learn to infer the brightness of objects by comparing them with the brightness of all other objects viewed at the same time.

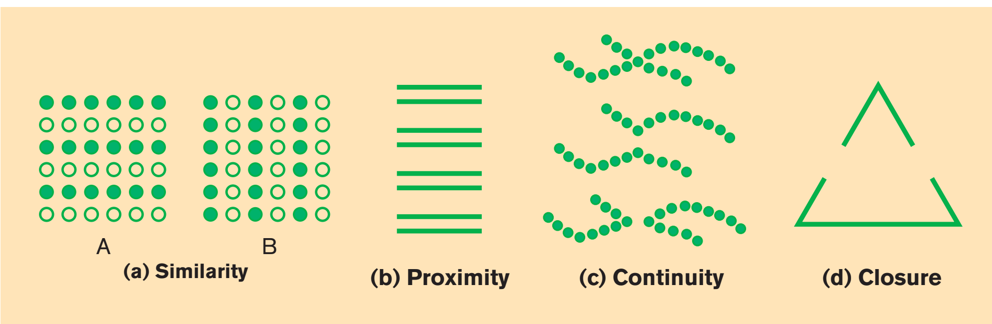


FIGURE 3.13 Gestalt Principles of Grouping Gestalt psychologists proposed four principles of perceptual grouping: similarity, proximity, continuity, and closure.

FIGURE 3.14
Shape Constancy **The door projects very different images on the retina when viewed from different angles. But because of shape constancy, we continue to perceive the door as rectangular.**

Colour Constancy: When Colours Stay the Same in Sunlight or Shadow

Colours can change considerably under different lighting conditions. But when objects are familiar to us, they appear to look about the same colour under different conditions of illumination. This is called **colour constancy**. Like brightness constancy, colour constancy depends on the comparisons we make between differently coloured objects we view at the same time (Brou et al., 1986).

Imagine what a strange world you would live in if it were not for the perceptual constancies. If your brain made a literal interpretation of all retinal images, the familiar sizes, shapes, and colours you view would appear to change back and forth before your eyes. Fortunately, the perceptual constancies, so natural and commonplace, provide a stable perceptual world.

Depth Perception: Perceiving What's Up Close and What's Far Away

Depth perception is the ability to perceive the visual world in three dimensions and to judge distances accurately. We judge how far away from us are the objects we grasp and the people we reach out to touch. We climb and descend stairs without stumbling, and perform other visual tasks too numerous to list, all requiring depth perception.

Depth perception has three dimensions, yet each eye is able to provide us with only two dimensions. The images cast upon the retina do not contain depth; they are flat, just like a photograph. How, then, do we perceive depth so vividly?

Binocular Depth Cues: The Cues Only Two Eyes Reveal

What are the binocular depth cues?

Some cues to depth perception depend on our two eyes working together. These are called **binocular depth cues**, and they

perceptual constancy: The tendency to perceive objects as maintaining stable properties, such as size, shape, and brightness, despite differences in distance, viewing angle, and lighting.

size constancy: The tendency to perceive objects as the same size regardless of changes in the retinal image.

retinal image: The image of objects in the visual field projected onto the retina.

shape constancy: The tendency to perceive objects as having a stable or unchanging shape regardless of differences in viewing angle.

brightness constancy: The tendency to see objects as maintaining the same brightness regardless of differences in lighting conditions.

colour constancy: The tendency to see objects as maintaining about the same colour regardless of differences in lighting conditions.

depth perception: The ability to see in three dimensions and to estimate distance.

binocular depth cues: Depth cues that depend on two eyes working together; convergence and binocular disparity.

Remember It!

Ways of Perceiving

1. Camouflage blurs the distinction between
   a. sensation and perception.
   b. figure and ground.
   c. continuation and closure.
   d. proximity and similarity.
2. The Gestalt principle of (continuity/closure) refers to our tendency to complete figures with gaps in them.
3. Which of the perceptual constancies cause us to perceive objects as being different from the retinal image they project?
   a. brightness constancy and colour constancy
   b. colour constancy and shape constancy
   c. shape constancy and size constancy
   d. colour constancy and size constancy
4. Which of the constancies depend on our comparing one object with other objects viewed under the same lighting conditions?
   a. brightness constancy and colour constancy
   b. colour constancy and shape constancy
   c. shape constancy and size constancy
   d. colour constancy and size constancy

Answers: 1. b 2. closure 3. c 4. a

include convergence and binocular disparity. **Convergence** occurs when our eyes turn inward as we focus on nearby objects—the closer the object, the greater the convergence. Hold the tip of your finger about 30 centimetres in front of your nose and focus on it. Now slowly begin moving your finger toward your nose. Your eyes will turn inward so much that they virtually cross when the tip of your finger meets the tip of your nose. Many psychologists believe that the tension of the eye muscles as they converge conveys information to the brain that serves as a cue for distance and depth perception.

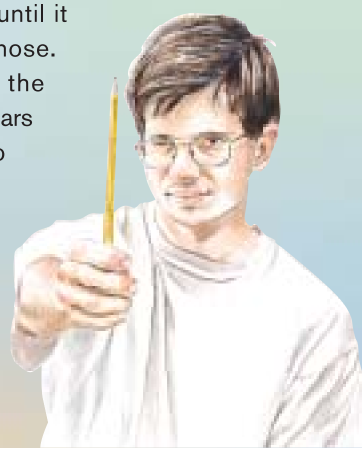
Fortunately, our eyes are just far enough apart, about six centimetres or so, to give each eye a slightly different view of the objects we focus on and, consequently, a slightly different retinal image. The difference between the two retinal images, known as **binocular disparity** (or retinal disparity), provides an important cue for depth and distance. The farther away from us the objects we view (up to six metres or so), the less the disparity or difference between the two retinal images. The brain integrates these two slightly different retinal images and gives us the perception of three dimensions (Wallach, 1985b). Ohzawa and colleagues (1990) suggest that there are specific neurons in the visual cortex that are particularly suited to detecting disparity. Ordinarily we are not aware that each eye provides a slightly different view of the objects we see. You can prove this for yourself in *Try It!*

Try It!

Testing Binocular Disparity

Hold your forefinger or a pencil at arm's length straight in front of you. Close your left eye and focus on the pencil. Now quickly close your right eye at the same time that you open your left eye. Repeat this procedure, closing one eye just as you open the other. The pencil will appear to move from side to side in front of your face.

Now slowly bring the pencil closer and closer until it almost reaches your nose. The closer you bring the pencil, the more it appears to move from side to side. This is because there is progressively more disparity between the two retinal images as we view objects closer and closer.



Convergence and binocular disparity provide depth or distance cues only for nearby objects. Fortunately, each eye by itself provides cues for objects at greater distances.

Monocular Depth Cues: The Cues One Eye Can Detect

What are seven monocular depth cues?

Close one eye and you will see that you can still perceive depth. The visual depth cues perceived by one eye alone are called **monocular depth cues**. The following is a description of seven monocular depth cues, many of which artists have used to give the illusion of depth to their paintings.

- *Interposition.* Some psychologists consider interposition, or overlapping, to be the most powerful depth cue of all (Haber, 1980). When one object partly blocks our view of another, we perceive the partially blocked object as farther away.
- *Linear perspective.* Linear perspective is a depth cue in which parallel lines that are known to be the same distance apart appear to grow closer together or converge as they recede into the distance. Linear perspective was used extensively by the Renaissance artists (in the 1400s).
- *Relative size.* Larger objects are perceived as being closer to us, and smaller objects as being farther away, as shown in Figure 3.15. We know that most adults are between 160 and 185 centimetres tall, so when images of the people we view are two, three, or many times smaller than their normal size, we perceive them as being two, three, or as many times farther away.
- *Texture gradient.* Texture gradient is a depth cue in which near objects appear to have a sharply defined texture, while similar objects appear progressively smoother and fuzzier as they recede into the distance.
- *Atmospheric perspective.* Atmospheric perspective, sometimes called "aerial perspective," is a depth cue in which objects in the distance have a bluish tint and appear more blurred than objects close at hand.
- *Shadow or shading.* When light falls on objects, shadows are cast. We can distinguish bulges from indentions by the shadows they cast. This ability appears to be learned (Hess, 1961).
- *Motion parallax.* When we ride in a moving vehicle and look out the side window, the objects we see outside appear to be moving in the opposite

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Parallel lines appear to converge as they recede into the distance. This effect is known as linear perspective.

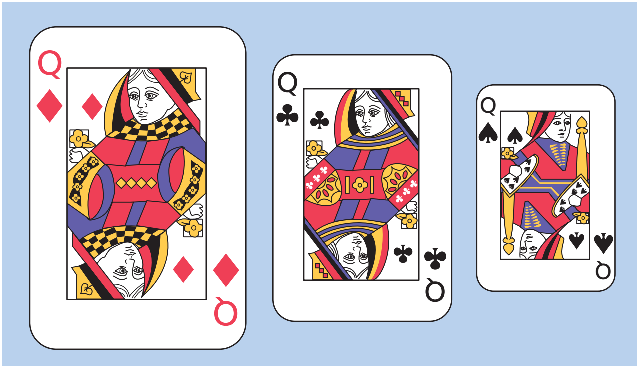

FIGURE 3.15
Relative Size: A Monocular Depth Cue **If we assume that these playing cards are all the same size, we perceive the largest card as closest and the smaller cards as progressively farther away.**

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The texture of objects can provide depth cues. The flowers in the foreground appear sharp and well-defined, whereas those in the distance are blurred and fuzzy.

convergence: A binocular depth cue in which the eyes turn inward as they focus on nearby objects–the closer an object, the greater the convergence.

binocular disparity: A binocular depth cue resulting from differences between the two retinal images cast by objects at distances up to about six metres.

monocular depth cues (mah-NOK-yu-ler): Depth cues that can be perceived by only one eye.

direction. The objects also seem to be moving at different speeds—those closest to us appear to be moving faster than objects in the distance. This phenomenon, called "motion parallax," provides another monocular cue to depth perception. Objects very far away, such as the moon and the sun, appear to move in the *same* direction as we are moving.

Figure 3.16 summarizes the binocular and monocular depth cues.

Extraordinary Perceptions

We perceive ambiguous figures, impossible figures, and illusions as well.

Ambiguous Figures: More Than One Way to See Them

When we are faced for the first time with the ambiguous figure, we have no experience to call on. Our perceptual system is puzzled and tries to work its way out of the quandary by seeing the ambiguous figure first one way and then another, but not both at once. We never get closure with ambiguous figures, which seem to jump back and forth beyond our control.

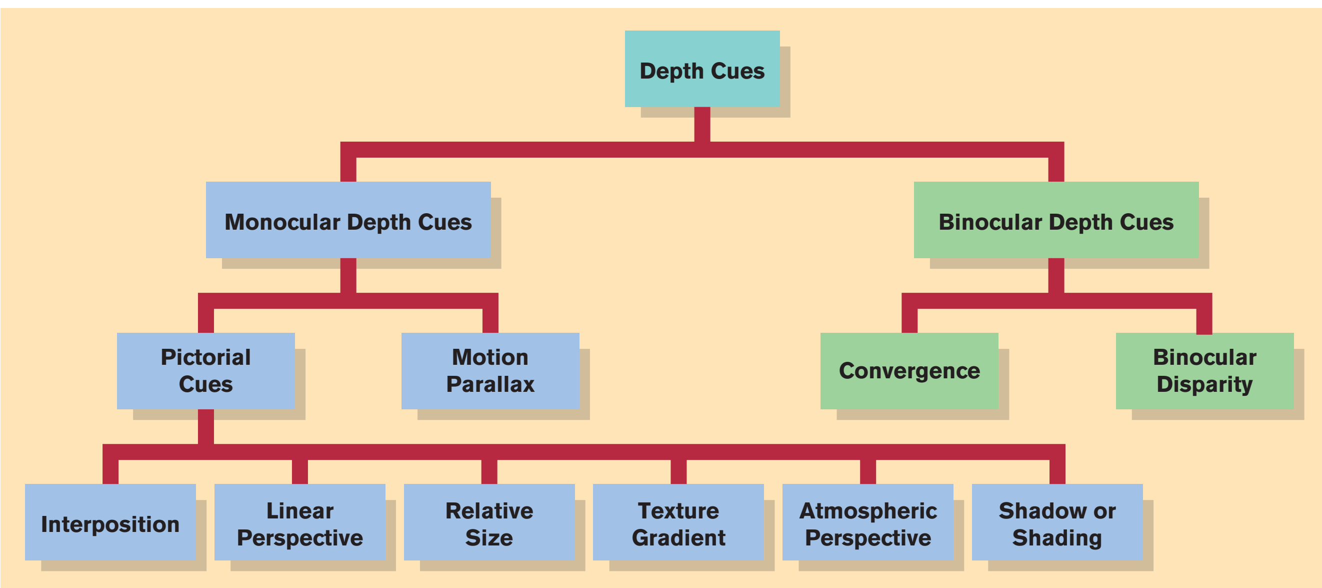
In some ambiguous figures, two different objects or figures are seen alternately. The best known of these, "Old Woman/Young Woman," by E.G. Boring, is shown in Figure 3.17. If you direct your gaze to the left of the drawing, you are likely to see an attractive young woman, her face turned away. But the young woman disappears when you suddenly perceive the image of the old woman. Such examples of object ambiguity offer striking evidence that our perceptions are more than the mere sum of sensory parts. It is hard to believe that the same drawing (the same sum of sensory parts) can convey such dramatically different perceptions.

Impossible Figures: This Can't Be

At first glance, the pictures of impossible figures do not seem so unusual—not until we examine them more closely. Would you invest your money in a com-

FIGURE 3.17
"Old Woman/Young Woman" by E.G. Boring The most famous ambiguous figure can be seen alternately as a young woman or an old woman depending on where your eyes fixate.

FIGURE 3.16
Binocular and Monocular Depth Cues Depth cues that require two eyes working together are binocular; those that require only one eye are monocular.



pany that manufactured three-pronged tridents as shown in Figure 3.18? Such an object could not be made as pictured because the middle prong appears to be in two different places at the same time. However, this type of impossible figure is more likely to fool the depth-perception sensibilities of people from Western cultures. People in some African cultures do not represent three-dimensional visual space in their art, and they do not perceive depth in drawings that contain pictorial depth cues. These people see no ambiguity in drawings similar to the three-pronged trident, and they can draw the figure accurately from memory much more easily than people from Western cultures (Bloomer, 1976).

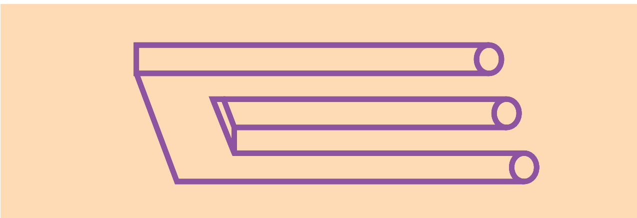


FIGURE 3.18

The Three-Pronged Trident **This is an impossible figure because the middle prong appears to be in two places at the same time.**

Illusions: False Perceptions

An **illusion** is a false perception or a misperception of an actual stimulus in the environment. We can misperceive size, shape, or the relationship of one element to another. We need not pay to see illusions performed by magicians: illusions occur naturally and we see them all the time. An oar in the water appears to be bent where it meets the water. The moon looks much larger at the horizon than it does overhead. Why? One explanation of the moon illusion involves relative size. The suggestion is that the moon looks very large on the horizon because it is viewed in comparison to trees, buildings, and other objects. When viewed overhead, the moon cannot be compared with other objects, and it appears smaller. People have been speculating about the moon illusion for 22 centuries and experimenting for 50 years to determine its cause, but there is still no agreement (Hershenson, 1989).

THE MÜLLER-LYER ILLUSION Look at Figure 3.19(a). Which line is longer? Actually, they are the same length. The same is true of 3.19(b). British psychologist R. L. Gregory (1978) has suggested that the Müller-Lyer illusion is actually a misapplication of size constancy. When two lines are the same length, the line we perceive to be farther away will look longer.

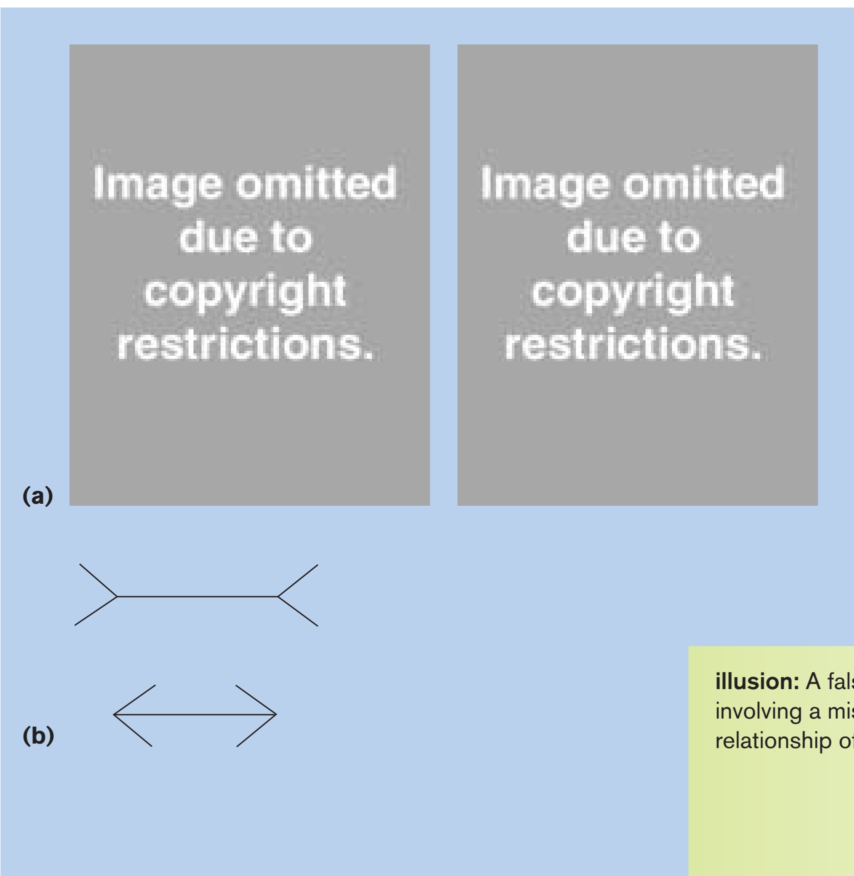


FIGURE 3.19

The Müller-Lyer Illusion **Although the two vertical lines in (a) are the same length, the line on the left seems to project forward and appears closer than the line on the right, which seems to recede. The two horizontal lines in (b) are identical in length. When two lines are the same length, the one perceived as farther away will appear longer. (Based on Gregory, 1978.)**

illusion: A false perception of actual stimuli involving a misperception of size, shape, or the relationship of one element to another.

THE PONZO ILLUSION The Ponzo illusion also plays an interesting trick. Look at Figure 3.20. Which obstruction on the railway tracks looks larger? You have undoubtedly guessed by now, contrary to your perceptions, that A and B are the same size. Again, our perceptions of size and distance, which we trust and which are normally accurate in informing us about the real world, can be wrong. If we saw two obstructions on real railway tracks identical to the ones in the illusion, the one that looked larger would indeed be larger. So the Ponzo illusion is not a natural illusion but rather a contrived one. In fact, all these illusions are really misapplications of principles that nearly always work properly in our normal everyday experience.

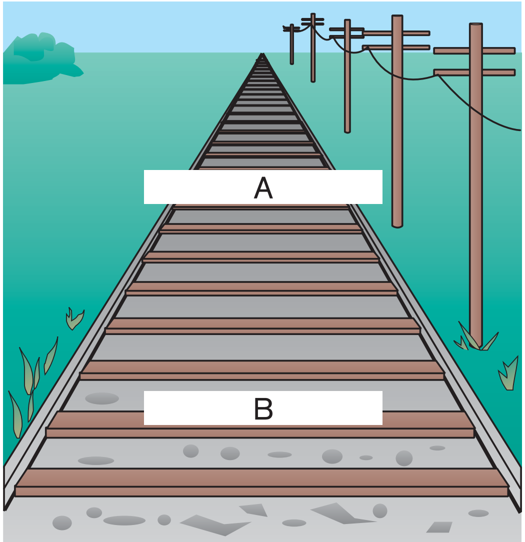


FIGURE 3.20
The Ponzo Illusion
The two white bars superimposed on the railway track are actually identical in length. Because A appears farther away than B, we perceive it as longer.

CULTURAL DIFFERENCES IN VISUAL ILLUSIONS Note that our susceptibility to visual illusions is not necessarily inborn. Several studies have examined the influence of culture or experience on people's perceptions of visual illusions. Segall and his colleagues (1966) tested over 1800 adults and children from 15 different countries and found "marked differences in illusion susceptibility across cultural groups" (p. 137). People from all cultures showed some tendency to see the illusions but experience different perceptions. Zulus from Africa who have round houses and see few corners of any kind were not as fooled by the Muller-Lyer illusion. In similar research, Pedersen and Wheeler (1983) studied Native American responses to the Muller-Lyer illusion among Navajos and found that those who had lived in round houses, like the Zulus, tended not to see the illusion.

Remember It!

Depth Perception and Illusion

1. Retinal disparity and convergence are two (monocular/binocular) depth cues.
2. Match the appropriate monocular depth cue with each example.
   ____ 1) One building partly blocking another
   ____ 2) Railway tracks converging in the distance
   ____ 3) Closer objects appearing to move faster than far objects
   ____ 4) Far objects looking smaller than near objects

   a. motion parallax
   b. linear perspective
   c. interposition
   d. relative size
4. An illusion is
   a. an imaginary sensation.
   b. an impossible figure.
   c. a misperception of a real stimulus.
   d. a figure–ground reversal.

Answers: 1. binocular 2. 1) c 2) b 3) a 4) d 3. stroboscopic motion 4. c

Additional Influences on Perception

Why don't all people perceive sights, sounds, odours, and events in the same way? The reason is that our perceptions involve more than just the sensory stimuli themselves.

Bottom-Up and Top-Down Processing

In what types of situations do we rely more on bottom-up or top-down processing?

Psychologists distinguish between two distinct information-processing techniques that we use in recognizing patterns—bottom-up processing and top-down processing.

Bottom-up processing begins with the individual components of a stimulus that are detected by the sensory receptors. The information is then transmitted to areas in the brain where it is combined and assembled into the whole patterns that we perceive.

In **top-down processing**, on the other hand, past experience and knowledge of the context plays a role in forming our perceptions. In other words, what we perceive is more than the sum of the individual elements taken in by our sensory receptors. If you have ever tried to decipher a prescription written by your doctor (bottom-up processing), you may have been amazed that your pharmacist could fill it. But prior knowledge and experience enabled the pharmacist to use top-down processing.

Of course, we use both bottom-up and top-down processing when we form perceptions. In situations unfamiliar to us, we are likely to use bottom-up processing. In familiar situations, where we have some prior knowledge and experience, we tend to use top-down processing.

So far we have considered perceptions that are formed above the threshold of our awareness and perceptions that arise from our known sensory abilities. Can we be influenced by persuasive messages below our level of awareness, through subliminal persuasion? And are we able to gain information by some means other than our known sensory channels, through extrasensory perception?

Subliminal Persuasion: Does It Work?

Over 30 years ago, it was reported that moviegoers in a New Jersey theatre were exposed to advertising messages flashed on the screen so briefly that they were not aware of them. An advertising executive, James Vicary, argued that the words "Eat Popcorn" and "Drink Coca-Cola" were projected on the screen for only 1/3000 of a second every five seconds during the movie. The purpose of the messages was to influence the audience to buy popcorn and Coca-Cola, not by getting their conscious attention, but by sending persuasive messages below their level of awareness—a technique called **subliminal persuasion**. During the six-week period the messages ran, popcorn sales supposedly rose by 57.5 percent and Coca-Cola sales rose by more than 18 percent (McConnell et al., 1958).

Technically, **subliminal perception** would be defined as the perception of sensory stimuli that are below the absolute threshold. But the subliminal persuasion experiment was limited to messages flashed so quickly that they could never be normally perceived at all. Can we actually perceive information that is completely below our level of awareness? Some people say we can (for example, see Channouf et al., 1999), and today subliminal persuasion is aimed at selling much more than popcorn and Coke. Subliminal self-help tapes, popularized by the New Age movement, are brisk sellers.

Is subliminal persuasion in audiotapes effective? This question was asked by Timothy Moore (1995) at Glendon College, York University. He found that audiotapes that claimed to influence behaviour with subliminal messages were not effective. Similarly, Merikle and Skanes (1992), at the University of Waterloo, investigated whether weight-loss tapes would influence eating behaviour. The researchers dismissed them as ineffective in therapy. So why do some users insist that tapes have helped them quit smoking or lose weight? The change is likely due to the power of suggestion or the placebo effect, and not the messages on the tapes (Pratkanis et al., 1994).

bottom-up processing: Information processing in which individual components or bits of data are combined until a complete perception is formed.

top-down processing: Application of previous experience and conceptual knowledge to first recognize the whole of a perception and thus easily identify the simpler elements of that whole.

subliminal persuasion: Sending persuasive messages below the recipient's level of awareness.

subliminal perception: Perceiving sensory stimulation that is below the absolute threshold.

Apply It!

Noise and Hearing Loss: Bad Vibrations

Hearing loss is increasing rapidly in the industrialized world, and the main reason is NOISE. Jet engines, power mowers, radios, firecrackers, motorcycles, chain saws, and other power tools are well-known sources of noise that can injure the ear. For centuries we have known that noise can cause hearing loss.

We are in more danger of losing our hearing off the job than at the work site. Without proper protection, recreational hunting, rock concerts, and some sports events can cause more damage to hearing than industrial noise.

Exposure to hazardous noise can begin long before we are old enough to listen to a Sony Walkman, experience a rock concert, or attend a baseball game at a covered or domed stadium. Some babies and toddlers get an early start on hearing loss. Axelsson and Jerson (1985) tested seven squeaking toys that, at a distance of 10 centimetres, squeaked out pure sound levels loud enough to put toddlers at risk for hearing loss with "minutes of exposure each day."

If older children play with toy weapons, noise-induced hearing loss can occur within seconds. The same researchers tested several toy weapons and found that at a distance of 50 centimetres, the guns produced explosive sound levels ranging from 144 to 152 dB. All exceeded the 130 dB peak level that is considered the upper limit for exposure to short-lived explosive sounds.

Explosions, gun blasts, and other extremely loud noises may burst the eardrums, or fracture or dislocate the tiny ossicles in the middle ear. Often these injuries can be repaired surgically, but noise injuries to the inner ear cannot (Bennett, 1990). It doesn't take an explosion or years of exposure to noise to injure hair cells. Rock musician Kathy Peck lost 40 percent of her hearing in one evening after her band opened a stadium concert for Duran Duran.

In 1986 the rock group The Who entered the *Guiness Book of World Records* as the loudest rock band ever, blasting out deafening sound intensities that measured 120 dB at a distance of 164 feet from the speakers. Unless their ears were protected, every person within that 164-foot radius probably suffered some irreversible damage to the ears. And the band members? Pete Townshend of The Who has severely damaged hearing and, in addition, is plagued by tinnitus, an annoying condition in which there is a continuous ringing in the ears.

How can you tell when noise levels are high enough to jeopardize your hearing? You are putting yourself at risk if you have difficulty talking over the noise level, or if the noise exposure leaves you with a ringing in your ears or a temporary hearing loss (Dobie, 1987).

Experts maintain that exposure to noise of 90 dB (a lawn mower, for example) for more than eight hours in a 24-hour period can damage hearing. For every increase of 5 dB, maximum exposure time should be cut in half—four hours for 95 dB, two hours for 100 dB, and one hour for 105 dB.

What can you do to protect yourself from noise?

- If you must be exposed to loud noise, use earplugs (not the kind used for swimming) or earmuffs to reduce noise by as much as 15 to 30 dB (Dobie, 1987).
- If you must engage in an extremely noisy activity, such as cutting wood with a chain saw, limit periods of exposure so that stunned hair cells can recover.
- Keep the volume down on Walkman-type radios or tape players. If the volume control is numbered 1 to 10, a volume above 4 probably exceeds standards for noise. If you have a ringing in your ears, if sounds seem muffled, or if you have a tickling sensation after you remove your headset, you may have sustained some hearing loss.
- Begin humming before you are exposed to loud noise. Humming will set in motion the very tiny muscles in the middle ear; this will dampen the sound and provide some measure of protection (Borg & Counter, 1989).

Image omitted due to copyright restrictions.

Extrasensory Perception: Does It Exist?

Perception refers to the process by which we organize and interpret sensory input. Is it possible to perceive information that does *not* come through the senses? Is there such a thing as **extrasensory perception (ESP)**—gaining information about objects, events, or another's thoughts through some means other than the known sensory channels? Can some people read minds or foretell the future? How many of you have gone to see a fortune teller or called "Jojo's Psychic Hotline"? Extrasensory perception is part of a larger area of interest known as **parapsychology**—the study of psychic phenomena. Reported cases of ESP fall into three rough categories—telepathy, clairvoyance, and precognition.

Telepathy means gaining awareness of the thoughts, the feelings, or the activities of another without the use of the senses—in other words, reading a person's mind. *Clairvoyance* means gaining information about objects or events without use of the senses, such as knowing the contents of a letter without opening it. *Precognition* refers to an awareness of an event before it occurs. Most of the reported cases of precognition in everyday life have occurred while people were dreaming. One researcher revealed the poor record of well-known psychics who made New Year's predictions for the *National Enquirer* between 1978 and 1985. Only two of their 425 predictions proved to be accurate (Strentz, 1986). But probably the most telling blow against precognition is the failure of any of these psychics to predict some of the most astounding world events of the century.

Because psychic phenomena violate what we know about the real, measurable, physical world, scientists and skeptics naturally demand proof of their existence (Hansel, 1966, 1980; Randi, 1980). Time after time, investigators have discovered trickery when examining the claims of psychics that they can read minds or communicate with the dead.

What is the truth about psychic phenomena? Do they exist but have not yet been proved to exist, or do they exist but cannot be verified under laboratory conditions, or do they not exist at all? What do you believe?

Earlier we noted that sensation and perception are so closely linked in everyday experience that it is hard to be certain where one ends and the other begins. In this chapter you have seen many examples of what is sensed and what is perceived. Our perceptual system is continuously trying to complete what we merely sense.

extrasensory perception (ESP): Gaining awareness of or information about objects, events, or another's thoughts through some means other than the known sensory channels.

parapsychology: The study of psychic phenomena, which include extrasensory perception (ESP) and psychokinesis.

KEY TERMS

absolute threshold, p. 73
accommodation, p. 77
afterimage, p. 81
amplitude, p. 83
audition, p. 84
binocular depth cues, p. 97
binocular disparity, p. 98
bottom-up processing, p. 103
brightness, p. 79
brightness constancy, p. 96
cochlea, p. 85
colour blindness, p. 81
colour constancy, p. 97
cones, p. 78
convergence, p. 98
cornea, p. 76
dark adaptation, p. 78
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THINKING CRITICALLY

Evaluation

Using what you have learned about the factors that contribute to hearing loss, prepare a statement indicating what the government should do to control noise pollution, even to the extent of banning certain noise hazards. Consider the workplace, the home, toys, machinery, rock concerts, and so on.

Point/Counterpoint

Recent polls indicate that nearly 49 percent of people believe in ESP. Prepare a sound, logical argument supporting one of the following positions:

a. There is evidence to suggest that ESP exists.
b. There is no evidence to suggest that ESP exists.

Psychology in Your Life

Vision and hearing are generally believed to be the two most highly prized senses. How would your life change if you lost your sight? How would your life change if you lost your hearing? Which sense would you find more traumatic to lose? Why?

SUMMARY & REVIEW

Sensation: The Sensory World

What is the difference between sensation and perception?

Sensation is the process through which the senses pick up sensory stimuli and transmit them to the brain. Perception is the process by which this sensory information is actively organized and interpreted by the brain.

What is the difference between the absolute threshold and the difference threshold?

The absolute threshold is the minimum amount of sensory stimulation that can be detected 50 percent of the time. The difference threshold is a measure of the smallest increase or decrease in a physical stimulus that can be detected 50 percent of the time.

How are sensory stimuli in the environment experienced as sensations?

For each of our senses, there are sensory receptors, which detect and respond to sensory stimuli. Through a process known as *transduction,* the receptors convert sensory stimuli into neural impulses, which are then transmitted to their own special locations in the brain.

Vision

How do the cornea, the iris, and the pupil function in vision?

The cornea bends light rays inward through the pupil—the small, dark opening in the eye. The iris dilates and contracts the pupil to regulate the amount of light entering the eye.

What are the lens and the retina?

The lens changes its shape as it focuses images of objects from varying distances on the retina, a thin membrane containing the sensory receptors for vision.

What roles do the rods and cones play in vision?

The cones detect colour, provide our sharpest vision, and function best in high illumination. The rods enable us to see in dim light. Rods respond to black and white, and they encode all other visible wavelengths in shades of grey.

What path does the neural impulse take from the retina to the visual cortex?

The rods and the cones transduce light waves into neural impulses that pass from the bipolar cells to the ganglion cells, whose axons form the optic nerve. At the optic chiasma, some of the fibres of the optic nerve cross to the opposite side of the brain, before reaching the thalamus. From the thalamus, the neural impulses travel to the visual cortex.

What are the three dimensions that combine to provide the colours we experience?

The three dimensions are hue, saturation, and brightness.

What two major theories attempt to explain colour vision?

Two major theories that attempt to explain colour vision are the trichromatic theory and the opponent-process theory.

Hearing

What determines the pitch and the loudness of sound, and how is each quality measured?

The pitch of a sound is determined by frequency, which is measured in hertz. The loudness of a sound is determined largely by the amplitude of the sound wave and is measured in decibels.

How do the outer, middle, and inner ears function in hearing?

Sound waves enter the pinna, the visible part of the outer ear, and travel to the end of the auditory canal, causing the eardrum to vibrate. This sets in motion the ossicles in the middle ear, which amplify the sound waves. The vibration of the oval window causes activity in the inner ear, setting in motion the fluid in the cochlea and moving the hair cell receptors, which transduce the vibrations into neural impulses. The auditory nerve carries the neural impulses to the brain.

What two major theories attempt to explain hearing?

Two major theories that attempt to explain hearing are place theory and frequency theory.

What are some major causes of hearing loss?

Some major causes of hearing loss are disease, birth defects, aging, injury, and noise.

Smell and Taste

What path does a smell message take on its journey from the nose to the brain?

The act of smelling begins when odour molecules reach the smell receptors in the olfactory epithelium at the top of the nasal cavity. The axons of these receptors form the olfactory nerve, which relays the smell message to the olfactory bulbs. From there the smell message travels to other parts of the brain.

What are the four primary taste sensations, and how are they detected?

The four primary taste sensations are sweet, salty, sour, and bitter. The receptor cells for taste are found in the taste buds on the tongue and in other parts of the mouth and throat.

Our Other Senses

How does the skin provide sensory information?

Nerve endings in the skin (the sensory receptors) respond to different kinds of stimulation, including heat and cold, pressure, pain, and a vast range of touch sensations. The neural impulses ultimately register in the somatosensory cortex.

What beneficial purpose does pain serve?

Pain can be a valuable warning and protective mechanism, motivating us to tend to an injury, to restrict our activity, and to seek medical help if needed.

What is the gate-control theory of pain?

Melzack and Wall's gate-control theory holds that pain signals transmitted by slow-conducting fibres can be blocked at the spinal gate (1) if fast-conducting fibres get their message to the gate first, or (2) if the brain itself inhibits their transmission.

What are endorphins?

Endorphins, released when we are stressed or injured, are the body's natural painkillers; they block pain and produce a feeling of well-being.

What kind of information does the kinesthetic sense provide, and how is this sensory information detected?

The kinesthetic sense provides information about the position of body parts and movement in those body parts. The position or motion is detected by sensory receptors in the joints, ligaments, and muscles.

What is the vestibular sense, and where are its sensory receptors located?

The vestibular sense provides information about movement and our orientation in space. Sensory receptors in the semicircular canals and in the vestibular sacs detect changes in the movement and orientation of the head.

Perception: Ways of Perceiving

What are the Gestalt principles of perceptual organization?

Gestalt principles of perceptual organization include the figure–ground relationship and four principles of perceptual grouping—similarity, proximity, continuity, and closure.

What is perceptual constancy, and what are its four types?

Perceptual constancy is the tendency to perceive objects as maintaining the same size, shape, brightness, and colour despite changes in lighting conditions or changes in the retinal image that result when objects are viewed from different angles and distances.

What are the binocular depth cues?

The binocular depth cues are convergence and binocular disparity; they depend on two eyes working together for depth perception.

What are seven monocular depth cues?

The monocular depth cues—those that can be perceived by one eye—include interposition, linear perspective, relative size, texture gradient, atmospheric perspective, shadow or shading, and motion parallax.

Additional Influences on Perception

In what types of situations do we rely more on bottom-up processing or top-down processing?

We use bottom-up processing more in unfamiliar situations, top-down processing more in situations in which we have some prior knowledge and experience.