CHAPTER 5

Sensation and Perception

All our knowledge has its origins in our perceptions.
—Leonardo da Vinci

CHAPTER OUTLINE

In August 1933, three reporters for the *St. John Telegraph* travelled to Moncton to investigate reports of a mysterious hill where cars ran uphill on their own. This was not the first time such stories had emerged. As early as 1880, area farmers noted that horses seemed to be straining with a loaded cart even though they appeared to be going downhill. If the carts were unhitched at the bottom of the hill, they would roll uphill on their own, as would barrels or bales! It was as if some mysterious magnetic force were pulling these items uphill.

The three reporters were skeptical and spent the morning looking for the hill with strange magnetic powers. Indeed, they stopped at the bottom of every hill in and around Moncton waiting to see their 1931 Ford Roadster roll uphill. After hours of frustrating searching they stopped at the base of Lutes Mountain and got out of the car to stretch. To their surprise, the roadster calmly rolled uphill away from them.

There are at least six magnetic or gravity hills in Canada and hundreds around the world. Not a single site has any unusual magnetic field.

- **What are the issues here?**
- **What do we need to know?**
- **Where can we find the information to answer these questions?**

Helen Keller (*left*) "hears" her teacher Anne Sullivan by reading Sullivan's lips with her fingers.

Source: AP/Wide World Photos Helen Keller/ Anne Sullivan

> Sometimes, it is true, a sense of isolation enfolds me like a cold mist as I sit alone and wait at life's shut gate. Beyond, there is light, and music, and sweet companionship; but I may not enter. Fate, silent, pitiless, bars the way. . . . Silence sits immense upon my soul. (Keller, 1955, p. 62)

So wrote Helen Keller, deprived of both vision and hearing by an acute illness when she was 19 months old. For those of us who take for granted the use of these senses, it is hard to imagine what it would be like to sink into a dark and silent universe, cut off from all sight and sound. Helen Keller was saved from this abyss by her teacher, Anne Sullivan, who taught and communicated with her by tapping signs onto the little girl's palm. One day, Sullivan tapped "water" onto Helen's palm as she placed the child's hand under the gushing spout of a pump.

> That living word awakened my soul, gave it light, hope, joy, set it free! That was because I saw everything with a strange new sight that had come to me. . . . It would have been difficult to find a happier child than I was. (p. 103)

Helen Keller went on to write her celebrated book, *The Story of My Life*, while an undergraduate at Radcliffe College, and she became an inspiration and advocate for people with disabilities.

Nature gives us a marvellous set of sensory contacts with our world. If our sense organs are not defective, we experience light waves as brightnesses and colours, air vibrations as sounds, chemical substances as odours or tastes, and so on. However, such is not the case for people with a rare and mysterious condition called **synaesthesia**, which means, quite literally, "mixing of the senses" (Cytowic, 2002; Harrison & Baron-Cohen, 1997). They may experience sounds as colours or tastes as touch sensations that have different shapes. Women are more likely to be synaesthetes than men (1 in 1,150 vs. 1 in 7,150, respectively; Rice et al., 2005). Interestingly, Maurer and her colleague (Maurer & Mondloch, 2006) have suggested that we are all born synaesthetic—the neural pathways of infants are fairly undifferentiated and lead to cross-modal perceptions.

The Russian psychologist A. R. Luria (1968) studied a highly successful writer and musician whose life was a perpetual stream of mixed-up sensations. On one occasion, Luria asked him to report on his experiences while listening to electronically generated musical tones. To a medium-pitch tone, the man experienced a brown strip with red edges, together with a sweet and sour flavour. A very high-pitched tone evoked the following sensation: "It looks something like a fireworks tinged with a pink-red hue. The strip of colour feels rough and unpleasant, and it has an ugly taste—rather like that of a briny pickle. . . . You could hurt your hand on this."

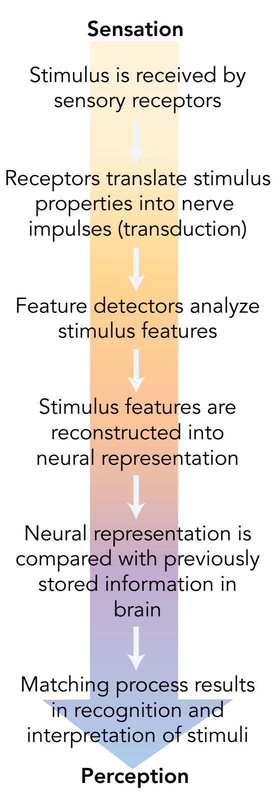

FIGURE 5.1

Sensory and perceptual processes proceed from the reception and translation of physical energies into nerve impulses to the active process by which the brain receives the nerve impulses, organizes and confers meaning on them, and constructs a perceptual experience.

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1. Describe the five stages that constitute the process of sensory processing and perception of information.

Sensory-impaired people such as those who experience synaesthesia provide glimpses into different aspects of how we "sense" and "understand" our world. These processes, previewed in Figure 5.1, begin when specific types of stimuli activate specialized sensory receptors. Whether the stimulus is light, sound waves, a chemical molecule, or pressure, your sensory receptors must translate this information into the only language your nervous system understands—the language of nerve impulses. Once this translation occurs, specialized neurons break down and analyze the specific features of the stimuli. At the next stage, these numerous stimulus "pieces" are reconstructed into a neural representation that is then compared with previously stored information, such as our knowledge of what particular objects look, smell, or feel like. This matching of a new stimulus with our internal storehouse of knowledge allows us to recognize the stimulus and give it meaning. We then consciously experience a perception.

In some ways, sensation and perception blend together so completely that they are difficult to separate, for the stimulation we receive through our sense organs is instantaneously organized and transformed into the experiences that we refer to as perceptions. Nevertheless, psychologists do distinguish between them. **Sensation** is the stimulus-detection process by which our sense organs respond to and translate environmental stimuli into nerve impulses that are sent to the brain. **Perception**—making "sense" of what our senses tell us—is the active process of organizing this stimulus input and giving it meaning (Pashler & Yantis, 2002).

2. How do psychologists differentiate between sensation and perception?

Because perception is an active and creative process, the same sensory input may be perceived in different ways at different times. For example, read the two sets of symbols in Figure 5.2. The middle symbols in both sets of curved lines are exactly the same and they send identical input to your brain, but you probably perceive them differently. Your interpretation, or perception, of the characters is influenced by their *context*—that is, by the characters that preceded and followed them, and by your learned expectation of what normally follows the letter A and the number 12. This is a simple illustration of how perception takes us a step beyond sensation.

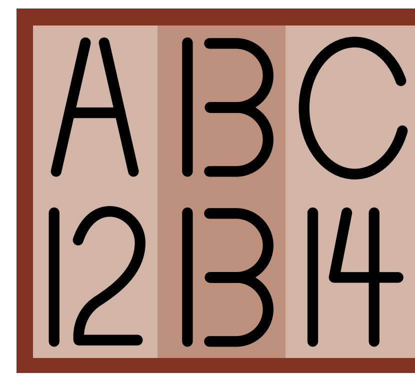

FIGURE 5.2

Quickly read these two lines of symbols out loud. Did your perception of the middle symbol in each line depend on the symbols that surrounded it?

SENSORY PROCESSES

Locked within the silent, dark recesses of your skull, your brain cannot "understand" light waves, sound waves, or the other forms of energy that make up the language of the environment. Contact with the outer world is possible only because certain neurons have developed into specialized sensory receptors that can transform these energy forms into the code language of nerve impulses.

As a starting point, we might ask: How many senses are there? Certainly there appear to be more than the five classical senses with which we are familiar: vision, audition (hearing), touch, gustation (taste), and olfaction (smell). For example, there are senses that provide information about balance and body position. Also, the sense of touch can be subdivided into separate senses of pressure, pain, and temperature. Receptors deep within the brain monitor the chemical composition of our blood. The immune system also has sensory functions that allow it to detect foreign invaders and to receive stimulation from the brain (Nossal & Hall, 1995).

Like those of other organisms, human sensory systems are designed to extract from the environment the information that we need to function and survive. Although our survival does not depend upon having eyes like eagles or owls, noses like bloodhounds, or ears as sensitive as those of the worm-hunting robin, we do have specialized sensors that can detect many different kinds of stimuli with considerable sensitivity. The scientific area of **psychophysics**, which studies relations between the physical characteristics of stimuli and sensory capabilities, is concerned with two kinds of sensitivity. The first concerns the absolute limits of sensitivity. For example, what is the softest sound or the weakest salt solution that humans can detect? The second kind of sensitivity has to do with differences between stimuli. What is the smallest difference in brightness that we can detect? How much difference must there be in two tones before we can tell that they are not identical?

3. What two kinds of sensory capabilities are studied by psychophysics researchers?

Stimulus Detection: The Absolute Threshold

How intense must a stimulus be before we can detect its presence? Researchers answer this question by systematically presenting stimuli of varying intensities and asking people whether they can detect them. Because we are often unsure of whether we have actually sensed very faint stimuli, researchers designate the **absolute threshold** as the lowest intensity at which a stimulus can be detected correctly 50 percent

4. What is the absolute threshold, and how is it technically defined and measured?

TABLE 5.1 Some Approximate Absolute Thresholds for Various Senses

Sense Modality	Absolute Threshold
Vision	Candle flame seen at approximately 50 km on a clear, dark night
Hearing	Tick of a watch under quiet conditions at approximately six metres
Taste	1 teaspoon of sugar in approximately 7.5 litres of water
Smell	One drop of perfume diffused into the entire volume of a large apartment
Touch	Wing of a fly or bee falling on your cheek from a distance of one centimetre

SOURCE: Based on Galanter, 1962.

of the time. Thus the *lower* the absolute threshold, the *greater* the sensitivity. From studies of absolute thresholds, the general limits of human sensitivity for the five major senses can be estimated. Some examples are presented in Table 5.1. As you can see, many of our senses are surprisingly sensitive. Yet some other species have absolute thresholds that seem incredible by comparison. For example, a female silkworm moth that is ready to mate needs to release 2.8 billionths of a gram of an attractant chemical molecule per second to attract every male silkworm moth within a radius of 1.6 kilometres.

Signal Detection Theory

I can remember lying in bed as a child after seeing a horror movie, straining my ears to detect any unusual sound that might signal the presence of a monster in the house. My vigilance caused me to detect faint and ominous sounds that probably would have gone unnoticed had I seen a comedy or a western earlier in the evening. Perhaps you have had a similar experience.

At one time it was assumed that each person had a more or less fixed level of sensitivity for each sense. But psychologists who study stimulus detection found that people's apparent sensitivity can fluctuate quite a bit. They concluded that the concept of a fixed absolute threshold is inaccurate because there is no single point on the intensity scale that separates non-detection from detection of a stimulus. There is instead a range of uncertainty, and people set their own **decision criterion**, a standard of how certain they must be that a stimulus is present before they will say they detect it. The decision criterion can also change from time to time, depending on such factors as fatigue, expectation, and the potential significance of the stimulus. **Signal detection theory** is concerned with the factors that influence sensory judgments.

In a typical signal detection experiment, participants are told that after a warning light appears, a barely perceptible tone may or may not be presented. Their task is to tell the experimenter whether they heard the tone. Under these conditions, there are four possible outcomes, as shown in Figure 5.3. When the tone is in fact presented, the participant may say "yes" (a hit) or "no" (a miss). When no tone is presented, the participant may also say "yes" (a false alarm) or "no" (a correct rejection).

At low stimulus intensities, both the participant's and the situation's characteristics influence the decision criterion (Methot & Huitema, 1998; Pitz & Sachs, 1984). Bold participants who frequently say "yes" have more hits, but they also have more false alarms than do conservative participants. Participants also can be influenced to become bolder or more conservative by manipulating the rewards and costs for giving correct or incorrect responses. Increasing the rewards for hits or the costs for misses results in lower detection thresholds (more "yes" responses at low intensities). Thus a Navy radar operator may be more likely to notice a faint blip on her screen during a wartime mission, when a miss might have disastrous consequences, than during a peacetime voyage. Conversely, like physicians who will not perform a risky medical procedure without strong evidence to support their diagnosis, participants become more conservative in their "yes" responses as costs for false alarms are increased, resulting in higher detection thresholds (Irwin & McCarthy, 1998). Signal detection research shows us that perception is, in part, a decision.

Participant's response	Stimulus: Present	Stimulus: Absent
"Yes"	Hit	False alarm
"No"	Miss	Correct rejection

FIGURE 5.3

This matrix shows the four possible outcomes in a signal detection experiment in which participants decide whether a stimulus has been presented or not presented. The percentages of responses that fall within each category can be affected both by characteristics of the participants and by the nature of the situation.

5. Why do signal detection theorists view stimulus detection as a decision? What are the four possible outcomes of such a decision?

6. What kinds of personal and situational factors influence signal detection decision criteria?

FOCUS ON NEUROSCIENCE

The Neuroscience of Subliminal Perception and Prosopagnosia

Background

A **subliminal stimulus** is one that is so weak or brief that, although it is received by the senses, it cannot be perceived consciously—the stimulus is well below the absolute threshold. There is little question that subliminal stimuli can register in the nervous system (Kihlstrom, 1990; MacLeod, 1998; Merikle & Daneman, 1998). But can such stimuli affect attitudes and behaviour without our knowing it? The answer appears to be yes—to a limited extent.

In the late 1950s, James Vicary, a public-relations executive, arranged to have subliminal messages flashed on a theatre screen during a movie. The messages urged the audience to "drink Coca-Cola" and "eat popcorn." Vicary's claim that the subliminal messages increased popcorn sales by 50 percent and soft drink sales by 18 percent aroused a public furor. Consumers and scientists feared possible abuse of subliminal messages to covertly influence the buying habits of consumers, and even to achieve mind control and brainwashing. The National Association of Broadcasters reacted by outlawing subliminal messages on American television.

The outcries were, in large part, false alarms. Several attempts to reproduce Vicary's results under controlled conditions failed, and many other studies conducted in laboratory settings, on television and radio, and in movie theatres indicated that there is little reason to be seriously concerned about significant or widespread control of consumer behaviour through subliminal stimulation (Dixon, 1981; Drukin, 1998). Ironically, Vicary admitted years later that his study was a hoax, designed to revive his floundering advertising agency. Nonetheless, his false report stimulated a great deal of useful research on the power of subliminal stimuli to influence behaviour. As far as consumer behaviour is concerned, the conclusion is that persuasive stimuli above the absolute threshold are far more influential than subliminal attempts to sneak into our subconscious mind, perhaps because we are more certain to "get the message."

Though consumer behaviour cannot be controlled subliminally, can such stimuli affect more subtle phenomena, such as attitudes? Here the effects are stronger (Arndt et al., 1997; Greenwald & Benaji, 1995). In one study, Jon Krosnick (1992) showed participants nine slides of a particular person and then measured their attitudes toward the target person. For half of the participants, each photograph was immediately preceded by an unpleasant picture (e.g., a face on fire) that was presented subliminally. The remaining participants were shown pleasant subliminal stimuli, such as smiling babies. Participants shown the associated unpleasant subliminal stimuli expressed somewhat negative attitudes toward the person, indicating a process of subconscious attitude conditioning, whereas those who saw the positive subliminal stimuli did not.

Evidence consistent with subliminal perception can be seen when examining patients who have very specific types of brain damage. For example, individuals with **prosopagnosia** are unable to recognize familiar faces. In essence, they have a type of visual agnosia that is specific for faces. Such individuals typically have cortical damage in areas involved with object perception. In some cases, they may be aware that they are looking at a face, but they cannot tell you who the individual is. Nonetheless, they may be able to categorize the visual stimulus as a face, and some patients can correctly "guess" who the face belongs to. How can this happen if the stimuli cannot be perceived?

Consider the following study by Steeves, Culham, Duchaine, Pratesi, Valyear, Schindler, Humphrey, Milner, & Goodale (2006). Steeves et al. studied patient D.F., a 47-year-old woman who suffered brain damage at age 34 from accidental carbon monoxide poisoning. D.F. has a great deal of difficulty recognizing the size, shape, and orientation of objects, but she is able to perceive colour. Thus, she is often able to recognize objects (e.g., an orange versus a tomato) based on colour and texture information alone. Similarly, people may be identified by non-facial cues such as clothing choice, voice pitch, etc. Earlier studies using fMRI imaging (Culham, 2004; James et al., 2003) had identified specific lesions in D.F.'s cortex. In particular, damage was observed in the lateral occipital area (LOA) in both hemispheres. The LOA has been associated with object perception in the intact cortex. D.F. and three control participants with no brain damage were shown a series of face and object stimuli while imaging with fMRI. Activation was examined in the LOA and in a second area associated with facial processing: the fusiform gyrus. Here we find the Fusiform Facial Area (FFA), a brain region specifically associated with facial perception.

For all participants, including D.F., there was greater brain activation in the FFA when viewing faces than when viewing scenes. However, the control participants showed greater activation in the LOA as well when viewing faces. This area was damaged in D.F. Despite this damage, D.F. was able to accurately categorize the stimuli as faces versus objects 95 percent of the time. In a second test, D.F. was shown a series of 30 images (5 faces and 25 objects) and asked to describe what they were. All five faces were accurately identified as a face, but not one of the objects was correctly described. In a

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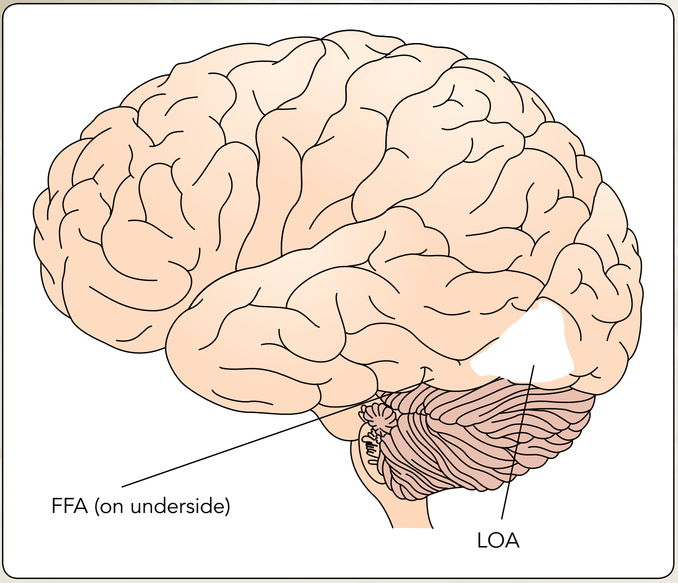

Approximate locations of the lateral occipital area (LOA) and the fusiform facial area (FFA). The FFA is actually on the underside or ventral surface of the cortex.

third test, all participants were shown a series of 60 famous individuals (e.g., John F. Kennedy, Princess Diana) and asked to name them or to provide information about the individual if they could not come up with the name. The controls correctly identified 93 percent of the images; D.F. could not identify a single one.

There are three points we should take away from this study. First, it would appear that higher-order facial recognition is a complex process involving several brain regions including the LOA and the FFA, in addition to the primary visual cortex. Nonetheless, an individual such as D.F. can glean a certain amount of information about visual stimuli even when one of these areas is severely damaged. It is likely that D.F. uses certain heuristic rules to "identify" faces (e.g., elongated oval targets with skin tone are likely to be faces) even though she is not really aware that the stimulus is, in fact, a face. Second, this research emphasizes the importance of the case study to investigate psychological phenomena. D.F. is a unique individual who provides an extraordinary opportunity to examine the role of brain regions in visual processing. In addition, the combination of behavioural testing and fMRI imaging allows the researchers to precisely identify the regions and deficits involved with this disorder.

Finally, the study highlights the subtle manner in which subliminal stimuli may have an effect. Philip Merikle and his colleagues (e.g., Merikle & Skanes, 1992; Merikle et al., 2001) have argued that the effect is one of biasing perception—subliminal cues can bias what we perceive at a conscious level and may alter our conscious experience of those stimuli. In a recent study, Todorov & Bargh (2002) demonstrated that subliminal presentations of aggressively toned words cause people to judge the ambiguous behaviours of others as more aggressive and to increase their own tendency to behave more aggressively. We may not be consciously aware of stimuli, but perhaps like D.F. aspects of the stimuli are processed at a different level and available for us to use in subsequent decisions.

The Difference Threshold

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7. What is the technical definition of a difference threshold? How does Weber's law help us compare jnd sensitivities in the various senses?

Distinguishing between stimuli can sometimes be as important as detecting stimuli in the first place. When we try to match the colours of paints or clothing, very subtle differences can be quite important. Likewise, a slight variation in taste might signal that food is tainted or spoiled. Professional wine tasters and piano tuners make their livings by being able to make very slight discriminations between stimuli.

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8. What accounts for sensory adaptation? Of what survival value is adaptation?

The **difference threshold** is defined as the smallest difference between two stimuli that people can perceive 50 percent of the time. The difference threshold is sometimes called the *just noticeable difference (jnd)*. Fortunately, as the German physiologist Ernst Weber (pronounced Veh-ber) discovered in the 1830s, there is some degree of lawfulness in the range of sensitivities within our sensory systems. **Weber's law** states that the difference threshold, or jnd, is directly proportional to the magnitude of the stimulus with which the comparison is being made, and can be expressed as a *Weber fraction*. For example, the jnd value for weights is a Weber fraction of approximately 1/50 (Teghtsoonian, 1971). This means that if you lift a weight of 50 grams, a comparison weight must weigh at least 51 grams in order for you to be able to judge it as heavier. If the weight were 500 grams, a second weight would have to weigh at least 510 grams (i.e., 1/50 = 10 g/500 g) for you to discriminate between them.

Although Weber's law breaks down at extremely high and low intensities of stimulation,[1] it holds up reasonably well within the most frequently encountered range, therefore providing a reasonable barometer of our abilities to discern differences in the various sensory modalities. Table 5.2 lists Weber fractions for the various senses. The smaller the fraction, the greater the sensitivity to differences. As highly visual creatures, humans show greater sensitivity in their visual sense than they do in, for example, their sense of smell. Undoubtedly, many creatures who depend upon their sense of smell to track their prey would show quite a different order of sensitivity. Weber fractions also show that humans are highly sensitive to differences in the pitch of sounds, but far less sensitive to loudness differences.

TABLE 5.2 Weber Fractions for Various Sensory Modalities

Sensory Modality	Weber Fraction
Audition (tonal pitch)	1/333
Vision (brightness, white light)	1/60
Kinesthesis (lifted weights)	1/50
Pain (heat produced)	1/30
Audition (loudness)	1/20
Touch (pressure applied to skin)	1/7
Smell (India rubber)	1/4
Taste (salt concentration)	1/3

SOURCES: Geldard, 1962; Teghtsoonian, 1971.

Sensory Adaptation

Because changes in our environment are often most newsworthy, sensory systems are finely attuned to *changes* in stimulation. Sensory neurons are engineered to respond to a constant stimulus by *decreasing* their activity, and the diminishing sensitivity to an unchanging stimulus is called **sensory adaptation**.

Adaptation (sometimes called *habituation*) is a part of everyday experience. After a while, monotonous background sounds are largely unheard. The feel of your wristwatch against your skin recedes from awareness. If you dive into a swimming pool, the water may feel cold at first because your body's temperature sensors respond to the change in temperature. With time, however, you become used to the water temperature.

Adaptation occurs in all sensory modalities, including vision. Indeed, were it not for tiny involuntary eye movements that keep images moving about the retina, stationary objects would simply fade from sight if we stared at them (Martinez-Conde, MacKnik, & Hubel, 2004). In an ingenious demonstration of this variety of adaptation, R. M. Pritchard (1961) attached a tiny projector to a contact lens worn by the participant (Figure 5.4a). This procedure guaranteed that visual images presented through the projector would maintain a constant position on the retina, even when the eye moved. When a stabilized image was projected through the lens onto the retina, participants reported that the image appeared in its entirety for a time, then began to vanish and reappear as parts of the original stimulus (Figure 5.4b).

Although sensory adaptation may reduce our overall sensitivity, it is adaptive, because it frees our senses from the constant and the mundane to pick up informative changes in the environment. Such changes may turn out to be important to our well-being or survival.

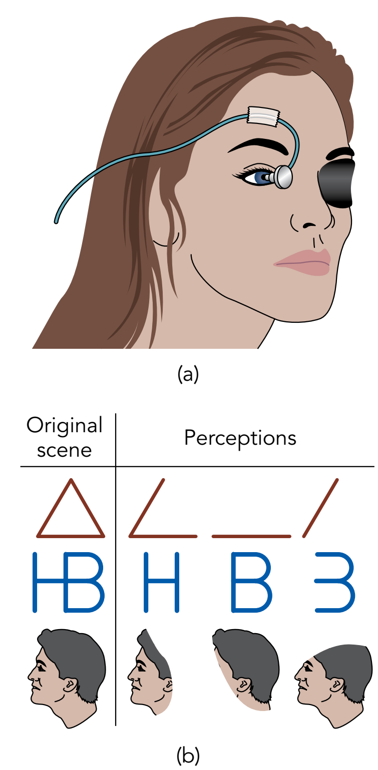


FIGURE 5.4
(a) To create a stabilized retinal image, a person wears a contact lens to which a tiny projector has been attached. Despite eye movements, images will be cast on the same region of the retina. (b) Under these conditions, the stabilized image is clear at first, then begins to fade and reappear in meaningful segments as the receptors fatigue and recover.
Adapted from Pritchard, 1961.

[1]This breakdown led Gustav Fechner to develop his own, more general, law in 1851. Fechner's Law states that perceived sensation is proportional to the logarithm of physical stimulus intensity.

In Review

- *Sensation refers to the activities by which our sense organs receive and transmit information, whereas perception involves the brain's processing and interpretation of the information.*
- *Psychophysics is the scientific study of how the physical properties of stimuli are related to sensory experiences. Sensory sensitivity is concerned in part with the limits of stimulus detectability (absolute threshold) and the ability to discriminate between stimuli (difference threshold). The absolute threshold is the intensity at which a stimulus is detected 50 percent of the time. Signal detection theory is concerned with factors that influence decisions about whether or not a stimulus is present.*
- *Research indicates that subliminal stimuli, which are not consciously perceived, can influence perceptions and behaviour in subtle ways, but not strongly enough to justify concerns about the subconscious control of behaviour through subliminal messages. The use of subliminal self-help materials sometimes results in positive behaviour changes that may be a product of expectancy factors rather than the subliminal messages themselves.*
- *The difference threshold, or just noticeable difference (jnd), is the amount by which two stimuli must differ for them to be perceived as different 50 percent of the time. Studies of the jnd led to Weber's law, which states that the jnd is proportional to the intensity of the original stimulus and is constant within a given sense modality.*
- *Sensory systems are particularly responsive to changes in stimulation, and adaptation occurs in response to unchanging stimuli.*

THE SENSORY SYSTEMS

Vision

The normal stimulus for vision is electromagnetic energy, or light waves, which are measured in *nanometres* (nm, or one billionth of a metre). In addition to that tiny portion that humans can perceive, the electromagnetic spectrum includes X-rays, television and radio signals, and infrared and ultraviolet rays (Figure 5.5). Bees are able to "see" ultraviolet light, and rattlesnakes can detect infrared energy. Our visual system is sensitive only to wavelengths extending from about 700 nm (red) down to about 400 nm (blue-violet). (You can remember the order of the spectrum, from higher wavelengths to lower ones, with the name ROY G. BIV—red, orange, yellow, green, blue, indigo, and violet.)

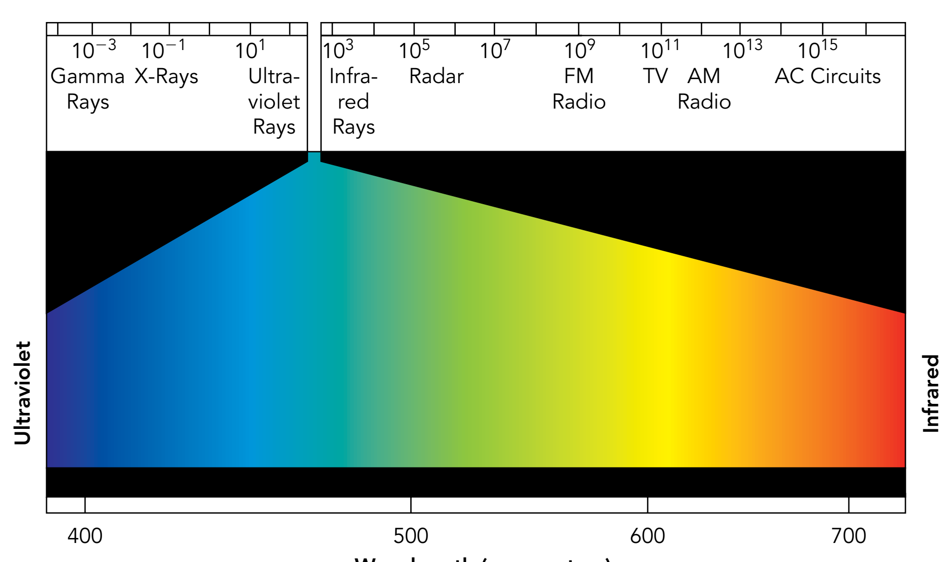
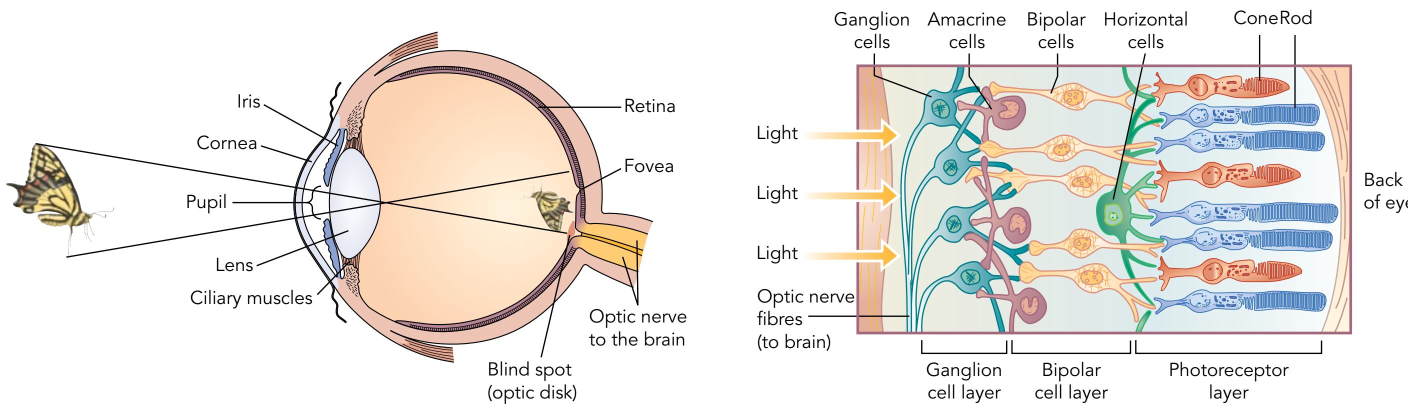


FIGURE 5.5
The full spectrum of electromagnetic radiation. Only the narrow band between 400 and 700 nanometres (nm) is visible to the human eye. One nanometre = 1,000,000,000th of a metre.



(a)

(b)

FIGURE 5.6

(a) This cross-section shows the major parts of the human eye. The iris regulates the size of the pupil. The ciliary muscles regulate the shape of the lens. The image entering the eye is reversed by the lens and cast on the retina, which contains the photoreceptor cells. The optic disk, where the optic nerve exits the eye, has no receptors and produces a "blind spot" as demonstrated in Figure 5.7. (b) Photoreceptor connections in the retina. The rods and cones synapse with bipolar cells, which in turn synapse with ganglion cells, whose axons form the optic nerve. The horizontal and amacrine cells allow sideways integration of retinal activity across areas of the retina.

The Human Eye

Light waves enter the eye through the *cornea,* a transparent protective structure at the front of the eye (Figure 5.6). Behind the cornea is the *pupil,* an adjustable opening that can dilate or constrict to control the amount of light that enters the eye. The pupil's size is controlled by muscles in the coloured *iris* that surrounds the pupil. Low levels of illumination cause the pupil to dilate, letting more light into the eye to improve optical clarity; bright light triggers constriction of the pupil.

Behind the pupil is the **lens**, an elastic structure that becomes thinner to focus on distant objects and thicker to focus on nearby objects. Just as the lens of a camera focuses an image on a photosensitive material (film), so the lens of the eye focuses the visual image on the light-sensitive **retina**, a multi-layered tissue at the rear of the fluid-filled eyeball. As seen in Figure 5.6a, the lens reverses the image from right to left and top to bottom when it is projected upon the retina, but the brain reconstructs the visual input into the image that we perceive.

The ability to see clearly depends on the lens's ability to focus the image directly onto the retina (Pedrotti & Pedrotti, 1997). If you have good vision for nearby objects but have difficulty seeing faraway objects, you probably suffer from **myopia** (nearsightedness). In nearsighted people, the lens focuses the visual image *in front of* the retina (too near the lens), resulting in a blurred image for faraway objects. This condition generally occurs becase the eyeball is longer (front to back) than normal. In contrast, some people have excellent distance vision but have difficulty seeing close-up objects clearly. **Hyperopia** (farsightedness) occurs when the lens does not thicken enough and the image is therefore focused on a point *behind* the retina (too far from the lens). The aging process typically causes the eyeball to become shorter over time, contributing to the development of hyperopia and the need for many middle-aged people to acquire reading glasses (after complaining that their arms are not long enough to read newspapers and telephone books). Ironically, this age-related shortening of the eyeball often improves the vision of myopic people, for, as the retina moves closer to the lens, it approaches the point where the "nearsighted" lens is projecting the image (Orr, 1998). Eyeglasses and contact lenses are designed to correct for the natural lens's inability to focus the visual image directly onto the retina.

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9. How does the lens affect visual acuity, and how does its dysfunction cause the visual problems of myopia and hyperopia?

Photoreceptors: The Rods and Cones

The retina, a multi-layered screen that lines the back surface of the eyeball and contains specialized sensory neurons, is actually an extension of the brain (Bullier, 2002). The retina contains two types of light-sensitive receptor cells, called rods

10. How are the rods and cones distributed in the retina, and how do they contribute to brightness perception, colour vision, and visual acuity?

and cones because of their shapes (Figure 5.6b). There are about 120 million rods and 6 million cones in the human eye.

The **rods**, which function best in dim light, are primarily black-and-white brightness receptors. They are about 500 times more sensitive to light than are the cones, but they do not give rise to colour sensations. The retinas of some night creatures, such as the owl, contain only rods, so they have exceptional vision in very dim light but no colour vision during the day (Dossenbach & Dossenbach, 1998). The **cones**, which are colour receptors, function best in bright illumination. Some creatures that are active only during the day, such as the the pigeon and the chipmunk, have only cones in their retinas, so they see the world in living colour but have very poor night vision (Dossenbach & Dossenbach, 1998). Animals that are active during both day and night, as humans are, have a mixture of rods and cones. In humans, rods are found throughout the retina except in the **fovea**, a small area in the centre of the retina that contains only cones. Cones decrease in concentration as one moves away from the centre of the retina, and the periphery of the retina contains mainly rods.

Rods and cones send their messages to the brain via two additional layers of cells. **Bipolar cells** have synaptic connections with the rods and cones. The bipolar cells, in turn, synapse with a layer of about one million **ganglion cells**, whose axons are collected into a bundle to form the **optic nerve**. Thus input from more than 126 million rods and cones is eventually funnelled into only 1 million traffic lanes leading out of the retina toward higher visual centres. Figure 5.6b shows how the rods and cones are connected to the bipolar and ganglion cells. One interesting aspect of these connections is the fact that the rods and cones not only form the *rear* layer of the retina, but their light-sensitive ends actually point *away from* the direction of the entering light so that they receive only a fraction of the light energy that enters the eye. Furthermore, the manner in which the rods and cones are connected to the bipolar cells accounts for both the greater importance of rods in dim light and our greater ability to see fine detail in bright illumination, when the cones are most active. Typically, many rods are connected to the same bipolar cell. They therefore can combine or "funnel" their individual electrical messages to the bipolar cell, where the additive effect of the many signals may be enough to fire it. That is why we can more easily detect a faint stimulus, such as a dim star, if we look slightly to one side so that its image falls not on the fovea but on the peripheral portion of the retina, where the rods are packed most densely.

Like the rods, the cones that lie in the periphery of the retina also share bipolar cells. In the fovea, however, the densely packed cones each have their own "private line" to a single bipolar cell. As a result, our **visual acuity**, or ability to see fine detail, is greatest when the visual image projects directly onto the fovea. Such focusing results in the firing of a large number of cones and their private-line bipolar cells. Some birds of prey, such as eagles and hawks, are blessed with not one, but two foveas in each eye, contributing to a visual acuity that allows them to see small prey on the ground as they soar thousands of feet above the earth (Tucker, 2000).

The optic nerve formed by the axons of the ganglion cells exits through the back of the eye not far from the fovea, producing a *blind spot*, where there are no photoreceptors. You can demonstrate the existence of your blind spot by following the directions for the demonstration in Figure 5.7. Ordinarily, we are unaware of the blind spot because our perceptual system "fills in" the missing part of the visual field (Rolls & Deco, 2002).

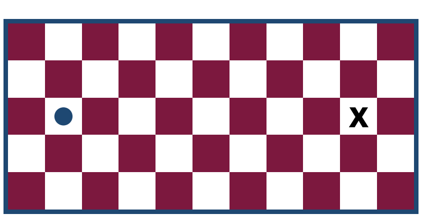


FIGURE 5.7

Close your left eye and, from a distance of about 30 centimetres, focus steadily on the dot with your right eye as you slowly move the book toward your face. At some point the image of the X will cross your optic disk (blind spot) and disappear. It will reappear after it crosses the blind spot. Note how the checkerboard remains wholly visible even though part of it falls on the blind spot. Your perceptual system "fills in" the missing information.

Visual Transduction: From Light to Nerve Impulses

The process whereby the characteristics of a stimulus are converted into nerve impulses is called **transduction**. Rods and cones translate light waves into nerve impulses through the action of protein molecules called **photopigments** (Stryer, 1987; Wolken, 1995). The absorption of light by these molecules produces a chemical reaction that changes the rate of neurotransmitter release at the receptor's synapse with the bipolar cells (Burns & Arshavsky, 2005). The greater the change in transmitter release, the stronger the signal passed on to the bipolar cell and, in turn, to the ganglion cells whose axons form the optic nerve. If nerve responses are triggered at each of the three levels (rod or cone, bipolar cell, and ganglion cell), the message is instantaneously on its way to the visual relay station in the thalamus, and then on to the visual cortex of the brain.

11. What is transduction, and how does this process occur in the photoreceptors of the eye?

Brightness Vision and Dark Adaptation

As noted earlier, rods are far more sensitive than cones under conditions of low illumination. Nonetheless, the brightness sensitivity of both the rods and the cones depends in part on the wavelength of the light. Research has shown that rods have a much greater brightness sensitivity than cones throughout the colour spectrum *except* at the red end, where rods are relatively insensitive. Cones are most sensitive to low illumination in the greenish-yellow range of the spectrum. These findings have prompted many cities to change the colour of their fire engines from the traditional red (which rods are insensitive to) to yellow-green in order to increase the vehicles' visibility to both rods and cones in dim lighting. Similarly, airport landing lights are often blue because this wavelength is picked up particularly well by the rods during night vision, when the cones are relatively inoperative.

12. How is brightness sensitivity in rods and cones affected by the colour spectrum?

Although the rods are by nature sensitive to low illumination, they are not always ready to fulfill their function. Perhaps you have had the embarrassing experience of entering a movie theatre from bright sunlight, groping around in the darkness, and finally sitting down in someone's lap. Although one can meet interesting people this way, most of us prefer to stand in the rear of the theatre until our eyes adapt to the dimly lit interior.

13. What is the physiological basis for dark adaptation? What are the two components of the dark adaptation curve?

Dark adaptation is the progressive improvement in brightness sensitivity that occurs over time under conditions of low illumination. After absorbing light, a photoreceptor is depleted of its pigment molecules for a period of time. If the eye has been exposed to conditions of high illumination, such as bright sunlight, a substantial amount of photopigment will be depleted. During the process of dark adaptation, the photopigment molecules are regenerated, and the receptor's sensitivity increases greatly.

Vision researchers have plotted the course of dark adaptation as people move from conditions of bright light into darkness (Carpenter & Robson, 1999). By focusing light flashes of varying wavelengths and brightness on the fovea, which contains only cones, or on the periphery of the retina, where rods reside, they discovered the two-part curve shown in Figure 5.8. The first part of the curve is due to dark adaptation of the cones. As you can see, the cones gradually become sensitive to fainter lights as time passes, but after about 5 to 10 minutes in the dark, their sensitivity has reached its maximum. The rods, whose photopigments regenerate more slowly, do not reach their maximum sensitivity for about half an hour. It is estimated that after complete adaptation, rods are able to detect light intensities only 1/10,000 as great as those that could be detected before dark adaptation began (Stryer, 1987).

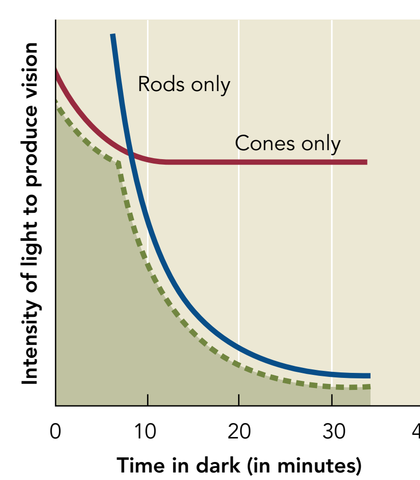


FIGURE 5.8

The course of dark adaptation is graphed over time. The curve has two parts, one for the cones and one for the rods. The cones adapt completely in about 10 minutes, whereas the rods continue to increase their sensitivity for another 20 minutes.

During World War II, psychologists familiar with the facts about dark adaptation provided a method for enhancing night vision in pilots who needed to take off at a moment's notice and see their targets under conditions of low illumination. Knowing that the rods are important in night vision and relatively insensitive to red wavelengths, they suggested that fighter pilots either wear goggles with red

FIGURE 5.9
Working in red light keeps the rods in a state of dark adaptation because rods are quite insensitive to that wavelength. Therefore they retain high levels of photopigment and remain sensitive to low illumination.

lenses or work in rooms lit only by red lights while waiting to be called for a mission. Because red light stimulates only the cones, the rods remain in a state of dark adaptation, ready for immediate service in the dark. That highly practical principle continues to be useful to this day (Figure 5.9).

Colour Vision

We are blessed with a world rich in colour. The majesty of a glowing sunset, the rich blues and greens of a tropical bay, the brilliant colours of fall foliage all produce visual delights for us. Human vision is finely attuned to colour; our difference thresholds for light wavelengths are so small that we are able to distinguish an estimated 7.5 million hue variations (Backhaus et al., 1998). Historically, two different theories of colour vision have tried to explain how this occurs.

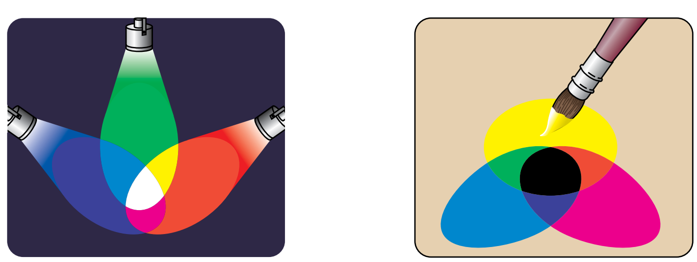
14. Describe the Young-Helmholtz trichromatic theory of colour vision. What kinds of evidence support this theory, and what two phenomena challenge it?

15. Describe the opponent-process theory. What evidence supports it?

16. How does the dual-process theory of colour vision combine the trichromatic and opponent-process theories?

The trichromatic theory. Around 1800, it was discovered that any colour in the visible spectrum can be produced by some combination of the wavelengths that correspond to the colours blue, green, and red in what is known as *additive colour mixture* (Figure 5.10a). This fact was the basis of an important trichromatic (three-colour) theory of colour vision advanced by Thomas Young, an English physicist, and Hermann von Helmholtz, a German physiologist. According to the Young-Helmholtz **trichromatic theory**, there are three types of colour receptors in the retina. Although all cones can be stimulated by most wavelengths to varying degrees, individual cones are most sensitive to wavelengths that correspond to either blue, green, or red (Figure 5.11). Presumably, each of these receptor classes sends messages to the brain, based on the extent to which they are activated by the light energy's wavelength. The visual system then combines the signals to recreate the original hue. If all three cones are equally activated, a pure white colour is produced.

Although the Young-Helmholtz theory was consistent with the laws of additive colour mixture, there are several facts that did not fit the theory. For example, according to the theory, yellow is produced by activity of red and green receptors. Yet certain people with red-green colour blindness are able to experience yellow.



(a) (b)

FIGURE 5.10
Additive and subtractive colour mixture are different processes. (a) Additive colour mixture. A beam of light of a specific wavelength directed onto a white surface is perceived as the colour that corresponds to that wavelength on the visible spectrum. If beams of light that fall at certain points within the red, green, or blue colour range are directed together onto the surface in the correct proportions, a combined or additive mixture of wavelengths will result and any colour in the visible spectrum can be produced (including white at the point where all three colours intersect). The Young-Helmholtz trichromatic theory of colour vision assumes that colour perception results from the additive mixture of impulses from cones that are sensitive to red, blue, and green (see text). (b) Subtractive colour mixture. Mixing pigments or paints produces new colours by subtraction—that is, by removing (i.e., absorbing) other wavelengths. Paints absorb (subtract) colours different from themselves while reflecting their own colour. For example, blue paint mainly absorbs wavelengths that correspond to non-blue hues. Mixing blue paint with yellow paint (which absorbs wavelengths other than yellow) will produce a subtractive mixture that emits wavelengths between yellow and blue (i.e., green). Theoretically, certain wavelengths of the three primary colours of red, yellow (not green, as in additive mixture), and blue can produce the whole spectrum of colours by subtractive mixture. Thus, in additive colour mixture, the primary colours are red, blue, and green; in subtractive colour mixture, they are red, yellow, and blue.

This finding suggested to other scientists that there must be a different means of perceiving yellow. A second phenomenon that posed problems for the trichromatic theory was the colour *afterimage,* in which an image in a different colour appears after a colour stimulus has been viewed steadily and then withdrawn. To experience one yourself, stare steadily at the object in Figure 5.12 for a full minute, then shift your gaze to a blank white space. Trichromatic theory cannot account for what you'll see.

Opponent-process theory. A second influential colour theory, formulated by Ewald Hering in 1870, also assumed that there are three types of cones. Hering's **opponent-process theory** proposed that each of the three cone types responds to *two* different wavelengths. One type responds to red *or* green, another to blue *or* yellow, and a third to black *or* white. For example, a red-green cone responds with one chemical reaction to a green stimulus and with its other chemical reaction (opponent process) to a red stimulus (Figure 5.11). You have experienced one of the phenomena that supports the existence of opponent processes if you did the exercise in Figure 5.12. The colour afterimage you saw in the blank space contains the colours specified by opponent-process theory: The black portion of the flag appeared as white, and the green portion "turned" red. According to opponent-process theory, as you stared at the black and green colours, the neural processes that register these colours became fatigued. Then when you cast your gaze on the white surface, which reflects all wavelengths, a "rebound" opponent reaction occurred as each receptor responded with its opposing white or red reactions.

Dual processes in colour transduction. Which theory—the trichromatic theory or the opponent-process theory—is correct? Two centuries of research have yielded a win-win verdict for both sets of theorists. Today's **dual-process theory** combines the trichromatic and opponent-process theories to account for the colour transduction process (Backhaus et al., 1998).

Trichromatic theorists such as Young and Helmholtz were right about the cones. The cones do indeed contain one of three different protein photopigments that are most sensitive to wavelengths roughly corresponding to the colours blue, red, and green (Abramov & Gordon, 1994). Different ratios of activity in the red-, blue-, and green-sensitive cones can produce a pattern of neural activity that corresponds to any hue in the spectrum (Backhaus et al., 1998). This process is similar to that which occurs on your television screen, where colour pictures (including white hues) are produced by activating combinations of tiny red, green, and blue dots in a process of additive colour mixture.

Hering's opponent-process theory was also partly correct, but opponent processes do not occur at the level of the cones, as he maintained. When researchers began to use microelectrodes to record from single cells in the visual system, they discovered that certain ganglion cells in the retina, as well as some neurons in visual relay stations and the visual cotrex, respond in an opponent-process fashion by altering their rate of firing (DeValois & DeValois, 1993). For example, if a red light is shone on the retina, an opponent-process ganglion cell may respond with a high rate of firing, but a green light will cause the same cell to fire at a very low rate. Other neurons respond in a similar opponent fashion to blue and yellow stimuli. The red-green opponent processes are triggered directly by input from the red- or green-sensitive cones in the retina (Figure 5.13). The blue-yellow opponent process is a bit more complex. Activity of blue-sensitive cones directly stimulates the "blue" process farther along in the visual system. And

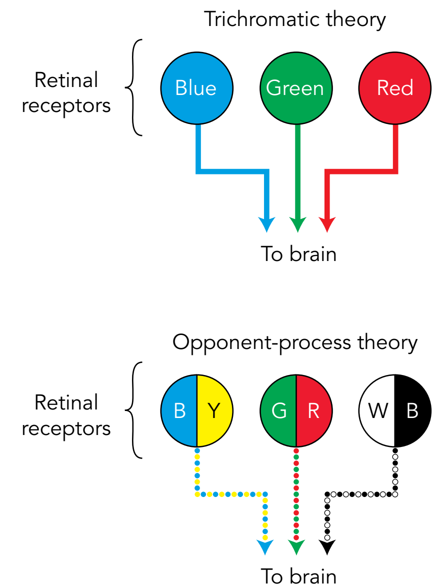


FIGURE 5.11

Two classic theories of colour vision. The Young-Helmholtz trichromatic theory proposed three different receptors, one for blue, one for red, and one for green. The ratio of activity in the three types of cones in response to a stimulus yields our experience of colour. Hering's opponent-process theory also assumed that there are three different receptors: one for yellow-blue, one for red-green, and one for black-white. Each of the receptors can function in two possible ways, depending on the wavelength of the stimulus. Again, the pattern of activity in the receptors yields our perception of the hue.

FIGURE 5.12

Negative colour afterimages demonstrate opponent processes occurring somewhere in the visual system. Stare steadily at the black dot in the centre of the flag for about a minute, then shift your gaze to a blank, white page. The opponent colours should appear.

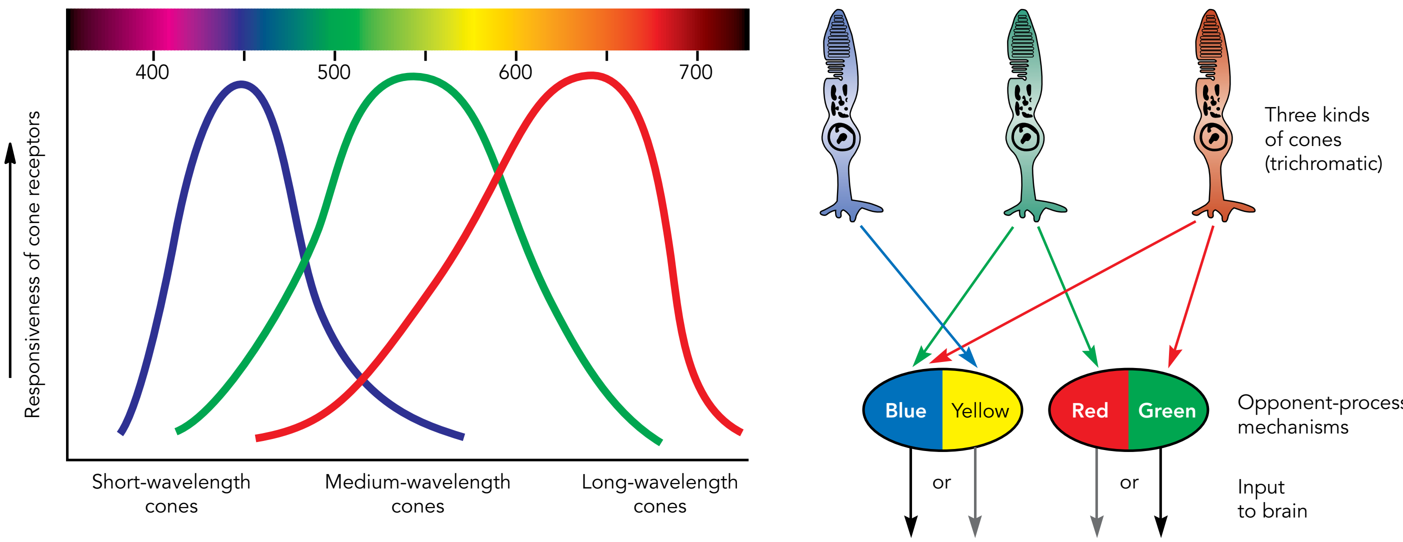


FIGURE 5.13

Colour vision involves both trichromatic and opponent processes that occur at different places in the visual system. Consistent with trichromatic theory, three types of cones are maximally sensitive to short (blue), medium (green), and long (red) wavelengths, respectively. However, opponent processes occur further along in the visual system, as opponent cells in the retina, visual relay stations, and the visual cortex respond differentially to red versus green, blue versus yellow, and black versus white stimuli. Shown here are the inputs from the cones that produce the red-green and blue-yellow opponent processes.

?

17. What are the two major types of colour-blindness? How are they tested?

yellow? The yellow opponent process is triggered not by a "yellow-sensitive" cone, as Hering proposed, but rather by simultaneous input from the red- and green-sensitive cones (Abramov & Gordon, 1994).

Colour-deficient vision. People with normal colour vision are referred to as *trichromats*. They are sensitive to all three systems: red-green, yellow-blue, and black-white. However, about 7 percent of the male population and 1 percent of the female population have a deficiency in the red-green system, the yellow-blue system, or both. This deficiency is caused by an absence of hue-sensitive photopigment in certain cone types. A *dichromat* is a person who is colour-blind in only one of the systems (red-green or yellow-blue). A *monochromat* is sensitive only to the black-white system and is totally colour-blind. Most colour-deficient people are dichromats and have their deficiency in the red-green system. Tests of colour-blindness typically contain sets of coloured dots such as those in Figure 5.14. Depending on the type of deficit, a colour-blind person cannot discern certain numbers embedded in the circles.

Analysis and Reconstruction of Visual Scenes

Once the transformation of light energy to nerve impulses occurs, the process of combining the messages received from the photoreceptors into the perception of a visual scene begins. As you read this page, nerve impulses from countless neurons are

FIGURE 5.14

These dotted figures are used to test for colour-deficient vision. The first one tests for yellow-blue colour-blindness, the second one for red-green colour-blindness. Because the dots in the picture are of equal brightness, colour is the only available cue for perceiving the numbers in the chips.

being analyzed and the visual image that you perceive is being reconstructed. Moreover, you know what these black squiggles on the page "mean." How does this occur?

Feature detectors. From the retina, the optic nerve sends nerve impulses to a visual relay station in the thalamus, the brain's sensory switchboard. From there, the input is routed to various parts of the cortex, particularly the **primary visual cortex** in the occipital lobe at the rear of the brain. Microelectrode studies have shown that there is a point-to-point correspondence between tiny regions of the retina and groups of neurons in the visual cortex. As you might expect, the fovea, where the one-to-one synapses of cones with bipolar cells produces high visual acuity, is represented by a disproportionately large area of the visual cortex. Somewhat more surprising is the fact that there is more than one cortical "map" of the retina; there are at least 10 duplicate mappings. Perhaps this is nature's insurance policy against damage to any one of them, or perhaps the duplicate maps are somehow involved in the integration of visual input.

Groups of neurons within the primary visual cortex are organized to receive and integrate sensory nerve impulses originating in specific regions of the retina. Some of these cells are known as **feature detectors**. They fire selectively in response to stimuli that have specific characteristics (Kanwisher, 1998). Discovery of these feature detectors won David Hubel and Torsten Wiesel of Harvard University the 1981 Nobel Prize. Using tiny electrodes to record the activity of individual cells of the visual cortex of animals (Figure 5.15), Hubel and Wiesel found that certain neurons fired most frequently when lines of certain orientations were presented. One neuron might fire most frequently when a horizontal line was presented; another neuron would fire most frequently to a line of a slightly different orientation, and so on "around the clock." For example, a letter "A" could be constructed from the response of feature detectors that responded to three different line orientations: /, \, and —.

The discovery of feature detectors revolutionized vision research. Since then, scientists have found cells that respond most strongly to bars, slits, and edges in certain positions. Within the cortex, this information is integrated and analyzed by successively more complex feature detector systems to produce our perception of objects (Palmer, 2002). This process is illustrated by the illusion shown in Figure 5.16.

Other classes of feature detectors respond to colour, to depth, or to movement (Livingstone & Hubel, 1994; Smith, Snowdon, & Milne, 1995). These feature detector "modules" subdivide a visual scene into its component dimensions and process them simultaneously. Thus, as a red, white, and green beach ball sails toward you, separate but overlapping modules within the brain simultaneously analyze its colours, shape, distance, and movement by engaging in **parallel processing** of the information and constructing a unified image of its properties (Tarr & Vuong, 2002). In addition, brief, high-frequency "bursts" of firing in sensory neurons may function as feature detectors and can signal the occurrence of important stimuli in the sensory field (Marsat & Pollack, 2006).

Visual association processes. The final stages in the process of constructing a visual representation occur when the information analyzed and recombined by the primary visual cortex is routed to other cortical regions known as the **visual association cortex**. Here successively more complex features of the visual scene are combined and interpreted in light of our memories and knowledge. If all goes correctly, a process that began with nerve impulses from the rods and cones now ends with us "recognizing" the beach ball for what it "is" and catching it. Quite another conscious experience and response probably would occur if we interpreted the oncoming object as a water balloon.

FIGURE 5.15

A partially anaesthetized monkey views an image projected onto the screen while an electrode embedded in its visual cortex records the activity of a single neuron. This research by Hubel and Wiesel led to the discovery of feature detectors that analyze visual stimulus features such as contours and shapes, movement, and colour.

18. What kinds of feature detectors exist in the visual system? What is meant by parallel processing of sensory information?

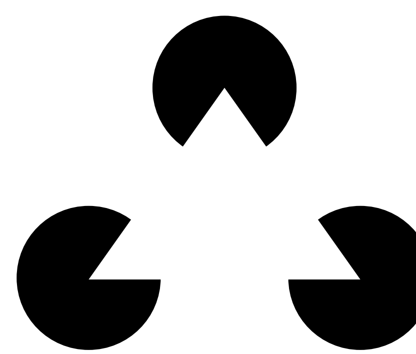


FIGURE 5.16

Is the white triangle "real"? It appears to be, because feature detectors that analyze the contours of the pie-shaped circles analyze the corners, and the brain fills in the "missing" lines. The contours are illusory, but they appear real. See what happens to the triangle if you cover up one or two of the circles.

In Review

- *The senses may be classified in terms of the energy to which they respond. Through the process of transduction, these energy forms are transformed into the common language of nerve impulses.*
- *The normal stimulus for vision is electromagnetic energy, or light waves. Light-sensitive visual receptor cells are located in the retina. The rods are brightness receptors, and the less numerous cones are colour receptors. Light energy striking the retina is converted into nerve impulses by chemical reactions in the photopigments of the rods and cones. Dark adaptation involves the gradual regeneration of photo pigments that have been depleted by brighter illumination.*
- *Colour vision is a two-stage process having both trichromatic and opponent-process components. The first stage involves the reactions of cones that are maximally sensitive to red, green, and blue wavelengths. In the second stage, colour information from the cones is coded through an opponent-process mechanism further along in the visual system.*
- *Visual stimuli are analyzed by feature detectors in the primary visual cortex, and the stimulus elements are reconstructed and interpreted in light of input from the visual association cortex.*

Audition

The stimuli for our sense of hearing are sound waves, a form of mechanical energy. What we call sound is actually pressure waves in air, water, or some other conducting medium. When a stereo's volume is high enough, you can actually see cloth speaker covers moving in and out. The resulting vibrations cause successive waves of compression and expansion among the air molecules surrounding the source of the sound. These sound waves have two characteristics: frequency and amplitude (Figure 5.17).

?
19. What are the two physical characteristics of sound waves, and which auditory qualities do these characteristics produce?

Frequency is the number of sound waves, or cycles, per second. The **hertz (Hz)** is the technical measure of cycles per second; one Hz equals one cycle per second. The sound waves' frequency is related to the pitch that we perceive; the higher the frequency (Hz), the higher the perceived pitch. Humans are capable of detecting sound frequencies from 20 Hz up to 20,000 Hz (about 12,000 Hz in older people). Most common sounds are in the lower frequencies. Among musical instruments, the piano can play the widest range of frequencies, from 27.5 Hz at the low end of the keyboard to 4,186 Hz at the high end. An operatic soprano's voice, in comparison, has a range of only 250 Hz to 1,100 Hz (Aiello, 1994).

Amplitude refers to the vertical size of the sound waves—that is, to the amount of compression and expansion of the molecules in the conducting medium. The sound wave's amplitude is the primary determinant of the sound's perceived loudness. Differences in amplitude are expressed as **decibels (db)**, a measure of the physical pressures that occur at the eardrum. The absolute threshold for hearing is arbitrarily designated as 0 db, and each increase of 10 db represents a tenfold increase in loudness. Table 5.3 shows various common sounds scaled in decibels.

Auditory Transduction: From Pressure Waves to Nerve Impulses

?
20. Describe how the middle and inner ear structures are involved in the auditory transduction process.

The transduction system of the ear is made up of tiny bones, membranes, and liquid-filled tubes designed to translate pressure waves into nerve impulses (Figure 5.18). Sound waves travel into an auditory canal leading to the eardrum, a movable membrane that vibrates in response to the sound waves. Beyond the eardrum is the middle ear, a cavity housing three tiny bones (the smallest in the body, in fact). The vibrating activity of these bones—the *hammer* (malleus), *anvil* (incus), and *stirrup* (stapes)—amplifies the sound waves more than 30 times. The first bone, the ham-

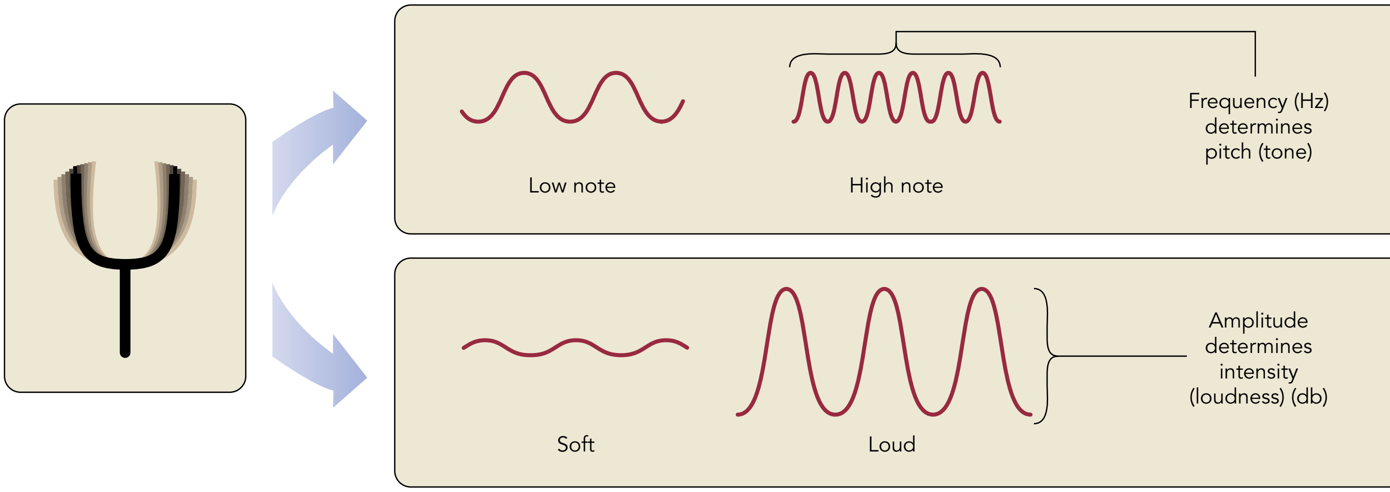


FIGURE 5.17

Sound waves are a form of mechanical energy. As the tuning fork vibrates, it produces successive waves of compression and expansion of air molecules. The number of maximum compressions per second (cycles per second) is its frequency, measured in hertz (Hz). The height of the wave above zero air pressure represents the sound's amplitude. Frequency determines pitch; amplitude determines loudness, measured in decibels (db).

mer, is attached firmly to the eardrum, and the stirrup is attached to another membrane, the *oval window,* which forms the boundary between the middle ear and the inner ear. The inner ear contains the **cochlea**, a coiled, snail-shaped tube about 3.5 cm in length that is filled with fluid and contains the **basilar membrane**, a sheet of tissue that runs its length. Resting on the basilar membrane is the **organ of Corti**, which contains thousands of tiny hair cells that are the actual sound receptors. The tips of the hair cells are attached to another membrane that overhangs the basilar membrane along the entire length of the cochlea. The hair cells synapse with the neurons of the auditory nerve which, in turn, sends impulses via an auditory relay station in the thalamus to the auditory cortex, which is located in the temporal lobe.

TABLE 5.3 Decibel Scaling of Common Sounds

Level in Decibels (db)	Common Sounds	Threshold Levels
140	Jet fighter taking off at approximately 25 metres from plane	Potential damage to auditory system
130	Boiler shop	
120	Rock band	Human pain threshold
110	Trumpet automobile horn at approximately one metre	
100	Crosscut saw at position of operator	
90	Train whistle at 150 metres	Hearing damage with prolonged exposure
80		
70	Inside automobile in city	
60	Downtown city street (Toronto)	
50	Restaurant	
40	Classroom	
30	Hospital room	
20	Recording studio	Threshold of hearing (young men)
10		
0		Minimum threshold of hearing

The decibel scale relates a physical quantity—sound intensity—to the human perception of that quantity—sound loudness. It is a logarithmic scale—that is, each increment of 10 db represents a tenfold increase in loudness. The table indicates the decibel ranges of some common sounds as well as thresholds for hearing, hearing damage, and pain. Prolonged exposure at 150 db causes death in laboratory rats.

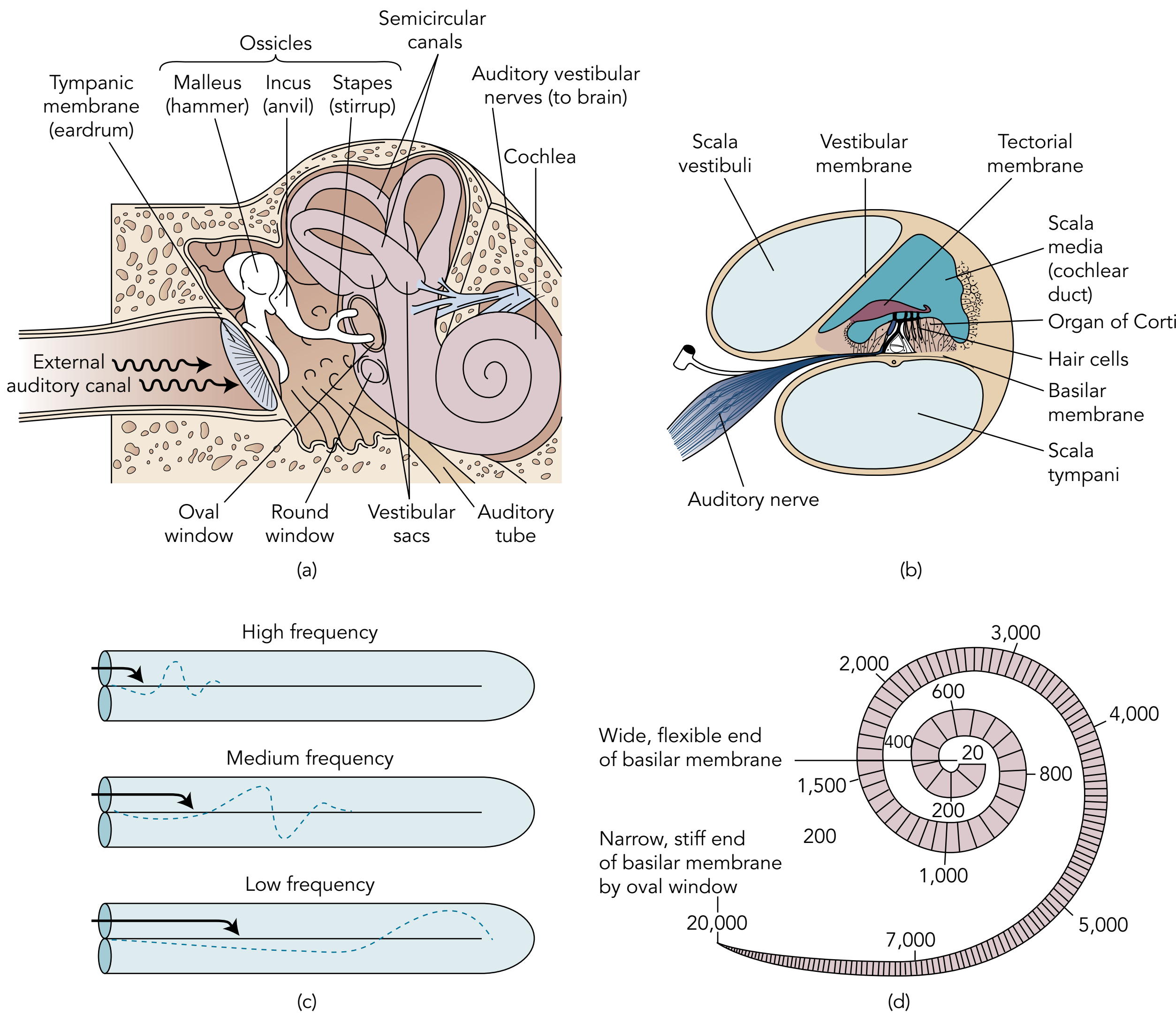


FIGURE 5.18

A cross-section of the ear (a) shows the structures that transmit sound waves from the auditory canal to the cochlea. There sound waves are translated into fluid waves that stimulate hair cells in the organ of Corti (b). The resulting nerve impulses reach the brain via the auditory nerve. The semicircular and vestibular sacs of the inner ear contain sense organs for equilibrium. In (c), the fluid waves created by different sound frequencies are shown, and (d) shows the frequencies that maximally stimulate different areas of the basilar membrane. High-frequency waves peak quickly and stimulate the membrane close to the oval window.

When sound waves strike the eardrum, pressure created at the oval window by the hammer, anvil, and stirrup of the middle ear sets the fluid inside the cochlea into motion. The fluid waves that result vibrate the basilar membrane and the membrane above it, causing a bending of the hair cells in the organ of Corti (Figure 5.18b). This bending of the hair cells triggers a release of neurotransmitter substance into the synaptic space between the hair cells and the neurons of the auditory nerve, resulting in nerve impulses that are sent to the brain. Within the auditory cortex, located in the temporal lobe, are feature detector neurons that respond to specific kinds of auditory input, much as occurs in the visual system (Goldstein, 1998).

Coding of Pitch and Loudness

The auditory system transforms the sensory qualities of loudness and pitch into the language of nerve impulses. In the case of loudness, high-amplitude sound waves cause the hair cells to bend more and release more neurotransmitter substance at the point where they synapse with auditory nerve cells, resulting in a higher rate of firing within the auditory nerve. In addition, certain receptor neurons have higher thresholds than others, so that they will fire only when considerable bending of the hair cells occurs in response to an intense sound. Thus loudness is coded in terms of both the rate of firing in the axons of the auditory nerve and in terms of which specific hair cells are sending messages (Carney, 2002).

The coding of pitch also involves two different processes, one for frequencies below about 1,000 Hz (approximately the midpoint of the piano keyboard) and another for higher frequencies. Historically, as in the case of colour vision, two competing theories were advanced to account for pitch perception. According to the **frequency theory** of pitch perception, nerve impulses sent to the brain match the frequency of the sound wave. Thus a 30 Hz (cycles per second) sound wave from a piano should send 30 volleys of nerve impulses per second to the brain. Unfortunately, frequency theory encounters a major problem. Because neurons are limited in their rate of firing, individual impulses or volleys of impulses fired by groups of neurons cannot produce high enough frequencies of firing to match sound wave frequencies above 1,000 Hz. How then do we perceive higher frequencies, such as a 4,000 Hz note from the same piano?

?

21. Describe the frequency and place theories of pitch perception. In what sense are both theories correct?

Experiments conducted by Georg von Bekesy (1957) uncovered a second mechanism for coding pitch and earned him the 1961 Nobel Prize. Bekesy cut tiny holes in the cochleas of guinea pigs and human cadavers and observed through a microscope what happened inside the fluid-filled cochlea when he stimulated the eardrum with tones of varying frequencies. He found that high-frequency sounds produced an abrupt wave that peaked close to the oval window, whereas lower-frequency vibrations produced a slower fluid wave that peaked farther down the cochlear canal (Figure 5.18c). Bekesy's observations supported a **place theory** of pitch perception, suggesting that the specific point in the cochlea where the fluid wave peaks and most strongly bends the hair cells serves as a frequency coding cue (Figure 5.18d). Later it was found that, similar to the manner in which the retina is "mapped" onto the visual cortex, the auditory cortex has a tonal frequency "map" that corresponds to specific areas of the cochlea. By analyzing the specific location of the cochlea from which auditory nerve impulses are being received, the brain can code pitches such as our 4,000 Hz piano note (Carney, 2002).

Thus, like trichromatic and opponent-process theories of colour vision, which were once thought to contradict each other, frequency and place theories of pitch transduction have both proved to be applicable in their own ways. At low frequencies, frequency theory holds true; at higher frequencies, place theory provides the mechanism for coding the pitch of a sound.

Sound Localization

?

22. How does the structure of the auditory system permit humans to localize sounds? What sensory information is used by the brain in localization?

Have you ever wondered why you have two ears, one located on each side of your head? As is usually the case in nature's designs, there is a good reason. Our very survival may depend upon our ability to locate objects that emit sounds. The two ears play a crucial role in *sound localization.* The nervous system uses information concerning the time and intensity differences of sounds arriving at the two ears to locate the source of sounds in space (Luck & Vecera, 2002).

Sounds arrive first and loudest at the ear closest to the sound. When the source of the sound is directly in front of us, the sound wave reaches both ears at the same time and at the same intensity, so the source is perceived as being straight ahead. Our binaural (two-eared) ability to localize sounds is amazingly sensitive. For example, a sound 3 degrees to the right arrives at the right ear only 300 millionths of a second before it arrives at the left ear, and yet we can tell which direction the sound is coming from (Yin & Kuwada, 1984). But, as Figure 5.19 shows, there is always room for improvement.

FIGURE 5.19

This device, used in the late 1800s by sailors to increase their ability to locate sounds while navigating in thick fog, assisted in two ways. First, because the two ear receptors were much larger than human ears, they could capture more sound waves. More importantly, the wide spacing between the receptors increased the time difference between the sound's arrival at the two human ears, thus increasing directional sensitivity.

Nature's design often bests even human ingenuity. For example, the barn owl comes equipped with ears that are exquisitely tailored for pinpoint localization of its prey during night hunting. Its right ear is directed slightly upward, its left ear slightly downward. This allows it to localize sounds precisely in both the vertical and horizontal planes, and thereby to zero in on its prey with deadly accuracy.

Hearing Loss

If you had to make the unwelcome choice of being blind or being deaf, which impairment would you choose? When asked this question, most of our students say that they would rather be deaf. Yet hearing loss can have more devastating social consequences than blindness does (Fletcher, 1995). Helen Keller, who was both blind and deaf, considered deafness to be more socially debilitating. She wrote, "Blindness cuts people off from things. Deafness cuts people off from people."

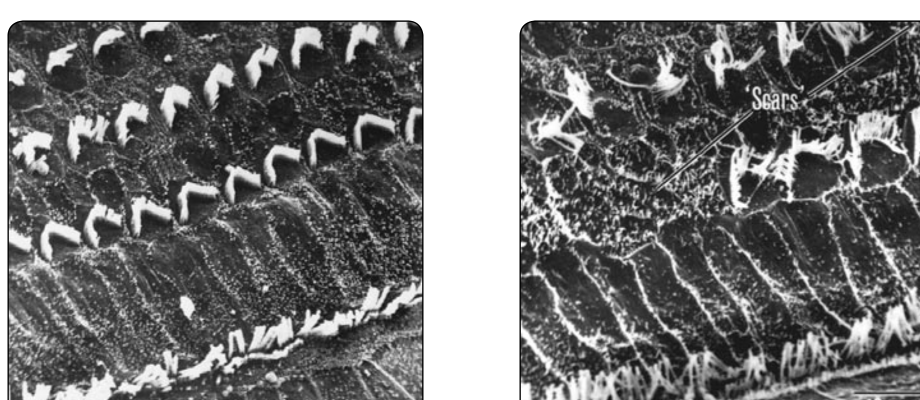
In Canada alone, almost three million people (approximately 10% of the population) suffer from some form of hearing loss. On a North American basis, the figure is closer to 23 million. Of these, 90 percent were born with normal hearing (Fletcher, 1995). They suffer from two major types of hearing loss. **Conduction deafness** is caused by problems involving the mechanical system that transmits sound waves to the cochlea. For example, a punctured eardrum or a loss of function in the tiny bones of the middle ear can reduce the ear's capacity to transmit vibrations. Use of a hearing aid, which amplifies the sounds entering the ear, may correct many cases of conduction deafness.

?

23. What are the two varieties of deafness, and how do they differ in their physical bases and in possible treatment?

Nerve deafness is an entirely different matter. It is caused by damaged receptors within the inner ear or damage to the auditory nerve itself, and it cannot be helped by a hearing aid. Although aging and disease can produce nerve deafness, exposure to loud sounds is a leading cause of nerve deafness. Repeated exposure to loud sounds of a particular frequency (as might be produced by a machine in a factory) eventually can cause workers to lose hair cells at a particular point on the basilar membrane, thereby causing hearing loss for that frequency.

Extremely loud music can take a serious toll on young people's hearing (West & Evans, 1990). Figure 5.20 shows the devastating results of a guinea pig's exposure to a sound level approximating that of loud rock music heard through earphones. As Table 5.3 shows, even brief exposure to sounds exceeding 140 db can cause irreversible damage to the transducers in the middle and inner ears, and so can more continuous sounds at lower decibel levels. In 1986, the music at a rock concert conducted by The Who reached 120 db at a distance approximately 50 metres from the speakers. This earned The Who a place in the *Guinness Book of Records* for the all-time loudest concert, but inflicted severe and permanent damage to many of the concert's spectators (Troufexis, 1990). The Who's guitarist, Pete Townshend,



(a) (b)

FIGURE 5.20

Exposure to loud sounds can destroy auditory receptors in the inner ear. These pictures, taken through an electron microscope, show the hair cells of a guinea pig before (a) and after (b) exposure to 24 hours of noise comparable to that of a loud rock concert.

Micrographs by Robert E. Preston, courtesy of Professor J. E. Hawkins, Kresge Hearing Research Institute, University of Michigan.

eventually suffered severe hearing loss from this prolonged noise exposure. The Canadian Hearing Society recommends that you protect your hearing by listening to music at safe levels (i.e., below 85 db). On a standard portable CD player, a volume setting of four or five will generate this level of intensity.

Although hearing aids can do little to remedy such problems, measures can be taken to prevent damage in people who are exposed to hazardous noise in the workplace (e.g., the use of noise-dampening ear protectors or noise-cancelling headphones).

24. Describe the sensory principles that are applied to create sensory prosthetics for visually and hearing impaired people.

RESEARCH FRONTIERS

Sensory Prosthetics: "Eyes" for the Blind, "Ears" for the Hearing Impaired

Millions of people suffer from blindness and deafness, living in sightless or soundless worlds. Psychological research on the workings of the sensory systems, coupled with technical advances in bioengineering, is being used to produce *sensory prosthetic devices.* These devices produce sensory input that can substitute, to some extent, for what cannot be provided by the normal sensory receptors.

One device, known as a Sonicguide, provides new "eyes" by applying principles of auditory localization (Kay, 1982). The Sonicguide works on the same principle as echolocation, the sensory tool used by bats to navigate in total darkness. The headset contains a transmitter that emits high-frequency sound waves beyond the range of human hearing. These waves bounce back from objects in the environment and are transformed by the Sonicguide into sounds that can be heard through the earphones. Different sound qualities match specific features of external objects, and the wearer must learn to interpret the sonic messages. For example, the sound's pitch tells the person how far away the object is; a low pitch signals a nearby object and the pitch becomes higher with increasing distance. The loudness of the sound tells how large the object is, and the clarity of the sound (ranging from a staticlike sound to a clear tone) signals the texture of the object, from very rough to very smooth. Finally, the auditory localization principle described earlier tells the person where the object is located in the environment by means of differences in the intensity of the sounds that arrive at the two ears.

In the first laboratory tests of the Sonicguide, psychologists Stuart Aitken and T. G. R. Bower (1982) used the apparatus with six blind babies who ranged in age from 5 to 16 months. In his first Sonicguide session with the youngest baby, Bower swung an object on a string until it lightly tapped the baby's nose. After only two presentations, the baby rotated both eyes inward toward his nose as the object approached, and outward as the object swung away. On the seventh trial, the baby reached out with his hand and blocked the object before it reached his face. The blind infant also began to follow the object with his eyes and head when it was moved on a right-left plane in front of him.

Aitken and Bower reported that within hours or days, the older babies using the Sonicguide could reach for objects, walk or crawl through doorways, and listen to the movement of their hands and arms as they moved them about. They also suggested that reaching for objects, recognizing favourite toys, and reaching out to be picked up when mother (but not someone else) approached seemed to occur on the same developmental timetable as in sighted children. They concluded that blind infants can extract the same information from sonic cues as sighted babies do from visual cues, and that this was particularly effective for the young infants. Subsequent long-term longitudinal studies of infants and children by University of Western Ontario researcher Keith Humphrey and his co-workers (Humphrey, Dodwell, Muir, & Humphrey, 1988) and others failed to confirm that infants would immediately use the Sonicguide. In fact, young infants required lengthy training sessions before using the aid effectively to reach and walk. By contrast, 10-year-olds rapidly learned to find large objects handed to them and to navigate through specially constructed obstacle courses (i.e., child mazes) and crowded school corridors; some even played hide-and-seek. The Sonicguide is now being used by visually impaired children in schools and other natural settings in the U.S.A. (e.g., Hill et al., 1995).

The Seeing Tongue

Paul Bach-y-Rita, professor of rehabilitative medicine and biomedical engineering at the University of Wisconsin Medical School, has developed a tactile tongue-based, electrical input sensor as a substitute for visual input (Bach-y-Rita, 2004). The tongue seems an unlikely substitute for the eye, hidden as it is in the dark recess of the mouth. Yet in many ways it may be the second-best organ for providing detailed input, for it is

–*Continued*

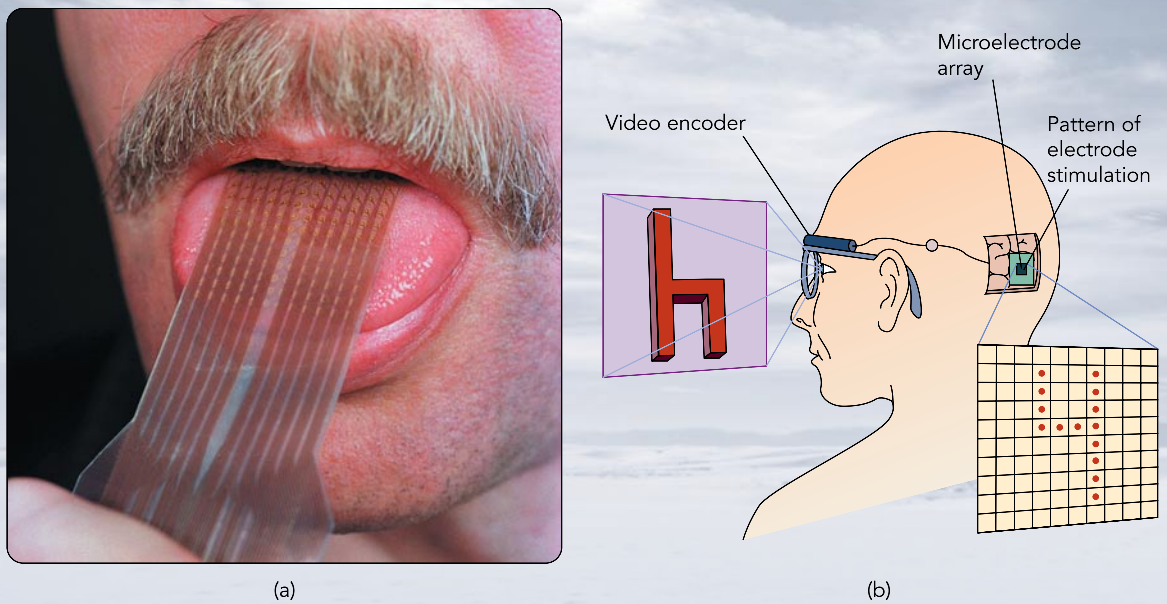


FIGURE 5.21

Two approaches to providing artificial vision for the blind. (a) Bach-y-Rita's device converts digitized stimuli from a camera to a matrix of electrical impulses to route spatial information through the tongue to the brain. (b) Tiny electrodes implanted into individual neurons in the visual cortex produce patterns of phosphenes that correspond to the visual scene observed through the video camera and encoder. Note how the cortical image is reversed as in normal visual input.

densely packed with tactile receptors, thus allowing the transmission of high-resolution data. Moreover, its moist surface is a good conducting medium for electricity, meaning that minimum voltage is required to stimulate the receptors.

The researchers have built an experimental prototype of a device that eventually will be small enough to be invisibly attached directly to the teeth. The current stimulator, shown in Figure 5.21a, receives digital data from a camera and provides patterns of stimulation to the tongue through a 144-electrode array. The array can transmit shapes that correspond to the main features of the visual stimulus. Initial trials with blindfolded sighted and blind people show that with about 9 hours of training, users can "read" the letters of a Snellen eye chart with an acuity of 20/430, a modest but noteworthy beginning (Simpaio et al., 2001). Kupers & Ptito (2004) have further demonstrated that congenitally blind subjects who were trained for a week with the tongue sensor were able to perform a visual discrimination task. In addition, PET scans revealed increased activity in the visual cortex when using the device. Apparently, cross-modal plasticity was still possible in the brains of these individuals who had been blind since birth. With continued development, a miniature camera in an eyeglass will transmit wireless data to a more densely packed electrode array attached to a dental retainer. Bach-y-Rita believes the device also might have both military and civilian applications. For example, it could help soldiers locate objects in pitch-black environments, such as caves, where night-vision devices are useless; it could also aid firefighters as they search smoke-filled buildings for people to rescue.

A different approach to a visual prosthesis is being perfected at the University of Utah, where researchers have developed a device to stimulate the visual cortex directly (Normann, 1995). When cells in the visual cortex are stimulated electrically, discrete flashes of light called *phosphenes* are experienced by both sighted and blind people. Because sensory neurons in the visual cortex are arranged in a manner that corresponds to the organization of the retina, a specific pattern of stimulation applied to individual neurons in the cortex can form a phosphene pattern that conforms to the shapes of letters or objects. The detail or acuity of the pattern depends on the area of the visual cortex that is stimulated (the portion receiving input from the densely packed fovea produces greatest acuity) and on the number of stimulating electrodes in the array.

Building on this approach, researchers have developed the device shown in Figure 5.21b. The Utah Intracortical Electrode Array consists of a silicon strip containing thousands of tiny stimulating electrodes that penetrate directly into individual neurons in the visual cortex, where they can stimulate phosphene patterns. Eventually, a tiny television camera mounted in specially designed eyeglasses will provide visual information to a microcomputer that will analyze the scene and then send the appropriate patterns of electrical stimulation through the implanted electrodes to produce corresponding phosphene patterns in the visual cortex. The researchers already have shown that sighted participants who wore darkened goggles that produce phosphenelike patterns of light flashes can learn quickly to navigate through complex environments and are able to read text at about two-thirds their normal rate (Normann et al., 1996, 1998). Blind people who had the stimulating electrodes implanted in their visual cortex have also been able to learn a kind of "cortical Braille" for reading purposes. Although still experimental, a commercially available intracortical prosthetic device should be available in the near future (Normann et al., 1998).

The hearing impaired also have been assisted by the development of prosthetic devices. Many have been helped by the *cochlear implant,* a device that can restore hearing in people suffering from nerve deafness. The cochlear implant does not amplify sound like a conventional hearing aid, since people with nerve deafness cannot be helped by mere sound amplification. Instead, the device sorts out useful sounds and converts them into electrical impulses, bypassing the disabled hair cells in the cochlea and stimulating the auditory nerve directly. With a cochlear implant, patients can hear everyday sounds such as sirens, and many of them can understand speech (Meyer et al., 1998; Parkinson et al., 1998). Nonetheless, sounds tend to be muffled, and people who expect currently developed cochlear implants to restore normal hearing invariably are disappointed. Improved speech perception is negatively correlated with age at implementation (e.g., Wu & Yang, 2003); thus, it is important to treat congenitally deaf children as early as possible.

Sensory prosthetics illustrate the ways in which knowledge about sensory phenomena such as phosphenes, the organization of the visual cortex, auditory localization, and the place theory of frequency coding can provide the information needed to take advantage of new technological advances. Yet, even with all our present ingenuity, prosthetic devices are not substitutes for our normal sensory systems, a fact that should increase our appreciation for what nature has given us.

Taste and Smell: The Chemical Senses

?

25. Describe the stimuli and the receptors involved in gustation and olfaction. Why do researchers sometimes refer to a "common chemical sense"?

Gustation (taste) and **olfaction** (smell) are chemical senses because their receptors are sensitive to chemical molecules rather than to some form of energy. These senses are so intertwined that some scientists refer to a "common chemical sense" (Beauchamp & Bartoshuk, 1997). Enjoying a good meal usually depends on the simultaneous activity of taste and odour receptors, as becomes apparent when we have a stuffy nose and our food tastes bland. People who lose their sense of smell typically believe they have lost their sense of taste as well (Bartoshuk, 1993).

Gustation: The Sense of Taste

People who fancy themselves gourmets are frequently surprised to learn that their sense of taste responds to only four qualities: sweet, sour, salty, and bitter. Every other taste experience combines these qualities and those of other senses, such as smell, temperature, and touch. For example, part of the "taste" of popcorn includes its texture, its crunchiness, and its odour.

Taste buds are chemical receptors concentrated along the edges and back surface of the tongue. Humans have about 9,000 taste buds, each consisting of several receptor cells arranged like the segments of an orange (Figure 5.22). A small number of receptors also are found in the roof and back of the mouth, so that even people without a tongue can taste substances. Hairlike structures project from the top of each cell into the taste pore, an opening to the outside surface of the tongue. When a substance is taken into the mouth, it interacts with saliva to form a chemical solution that flows into the taste pore and stimulates the receptor cells. A "taste" results from complex patterns of neural activity produced by the four types of taste receptors (Bartoshuk, 1998; Halpern, 2002).

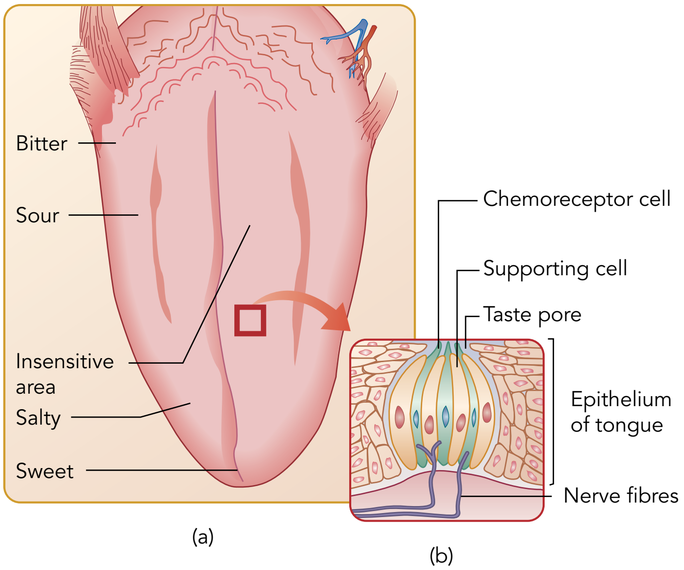


FIGURE 5.22

The receptors for taste are specialized cells located in the tongue's taste buds. The tongue's 9,000 taste buds are grouped in different areas according to the taste sensation they produce. The centre of the tongue is relatively insensitive to the chemical molecules that constitute gustatory stimuli.

The sense of taste not only provides us with pleasure, but also has adaptive significance in discriminating between nutrients and toxins (Scott, 1992). Our response to some taste qualities is innate. For example, newborn infants respond positively to sugar water placed on the tongue and negatively to bitter substances such as quinine (Davidson & Fox, 1988). Many poisonous substances in nature have bitter tastes, so this emotional response seems to be "hardwired" into our physiology (Hoebel, 1997). In nature, sweet substances are more likely to occur in nutritious foods. Unfortunately, many humans now live in an environment different from the food-scarce environment in which preferences for sweet substances may have evolved (Scott & Giza, 1993). As a result, people in affluent countries overconsume sweet foods that are good for us only in small quantities.

Olfaction: The Sense of Smell

Humans are visually oriented creatures, but the sense of smell (olfaction) is of great importance for many species. Bloodhounds, for example, have poor eyesight, but an exquisitely developed olfactory sense that is about two million times more sensitive than ours (Thomas, 1974). A bloodhound can detect a person's scent in a footprint that is four days old, something no human could do. Yet people who are deprived of other senses often develop a highly sensitive olfactory sense. Helen Keller, though blind and deaf, exhibited a remarkable ability to "smell" her environment. With uncanny accuracy, she could tell when a storm was brewing by detecting subtle odour changes in the air. She could also identify people (even those who bathed regularly and did not wear perfumes or colognes) by their distinctive odours (Keller, 1955).

The receptors for smell are long cells that project through the lining of the upper part of the nasal cavity and into the mucous membrane. Humans have about 40 million olfactory receptors, dogs about 1 billion. Unfortunately, our ability to discriminate between different odours is not well understood. The most popular current theory is that olfactory receptors recognize diverse odours individually rather than by mixing the activity of a smaller number of basic receptors, as occurs in taste (Bartoshuk & Beauchamp, 1994). Olfactory receptors have receptor structures that resemble neurotransmitter binding sites on neurons. Any of the thousands of potential odour molecules can lock into sites that are tailored to fit them (Buck & Axel, 1991; Pernollet, Sanz, & Briand, 2006).

The social and sexual behaviour of animals is more strongly regulated by olfaction than is human behaviour (Alcock, 2006). For example, most of us find other ways to mark our territories, such as by erecting fences or spreading belongings over the table we are using in the library. Nonetheless, like animals, humans have special receptors in the nose that send impulses to a separate olfactory area in the brain that connects with brain structures involved in social and reproductive behaviour. Some researchers believe that **pheromones**, chemical signals found in natural body scents, may affect human behaviour in subtle ways (Bartoshuk & Beauchamp, 1994; Monti-Bloch & Grosser, 1991; Rako & Friebely, 2004). One interesting but puzzling observation, known as **menstrual synchrony**, is the tendency of women who live together or are close friends to become more similar in their menstrual cycles. Psychologist Martha McClintock (1971) tested 135 university women and found that, during the course of an academic year, roommates moved from a mean of 8.5 days apart in their periods to 4.9 days apart. Another study of 51 women who worked together showed that close friends had menstrual onsets averaging 3.5 to 4.3 days apart, whereas those who were not close friends had onsets that averaged 8 to 9 days apart (Weller et al., 1999). Are pheromones responsible for synchrony? In experiments conducted at the Monell Chemical Senses Center in Philadelphia, 10 women with

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26. What is menstrual synchrony, and what evidence is there that pheromones are involved?

regular cycles were daubed under the nose every few days with underarm secretions collected from other women. After three months, the participants' cycles began to coincide with the sweat donors' cycles. A control group of women who were daubed with an alcohol solution rather than sweat showed no menstrual synchrony with a partner (Preti et al., 1986). In other studies, however, menstrual synchrony was not found for cohabitating lesbian couples or for Bedouin women who spent most of their time together, indicating that prolonged and very intensive contact may not be conducive to menstrual synchrony (Weller & Weller, 1997, 1998).

As anyone who has owned a dog or cat in heat could attest, odours strongly affect the sexual attractiveness of animals. On the other hand, there is no solid evidence to justify the recent rise in commercial sales of "pheromone substances" to humans who wish to become sexually irresistible. At this point, we would conclude that a good personality is a better bet than a good pheromone.

The Skin and Body Senses

The skin and body senses include the senses of touch, kinesthesis (muscle movement), and equilibrium. The last two are called body senses because they inform us of the body's position and movement. They tell us, for example, if we are running or standing still, lying down, or sitting up.

The Tactile Senses

Touch is important to us in many ways. Sensitivity to extreme temperatures and pain enables us to avoid external danger and alerts us to disorders within our bodies. Tactile sensations are also a source of many of life's pleasures, including sexual orgasm. A lack of tactile contact with a caretaking adult retards physical, social, and emotional development (Harlow, 1958), and physically massaging newborn babies enhances their development (Cigales et al., 1997; Field et al., 1996; Canfield, 2006).

?

27. What four tactile sensations are humans sensitive to? How are these sensations localized, and how are phantom limb sensations produced?

Humans are sensitive to at least four tactile sensations: pressure (touch), pain, warmth, and cold. These sensations are conveyed by receptors in the skin and in our internal organs. Mixtures of these four sensations form the basis for all other common skin sensations, such as itch.

Considering the importance of our skin senses, surprisingly little is known about how they work. The skin, a multi-layered elastic structure that covers 90 cm^2 and weighs between 2.7 and 4.5 kilograms, is the largest organ in our body. It contains a variety of receptor structures, but their role in specific sensations is less clear than for the other senses. Many sensations probably depend upon specific patterns of activity in the various receptors (Goldstein, 2002). We do know that primary receptors for pain and temperature are *free nerve endings,* simple nerve cells beneath the skin's surface that resemble the bare branches of a tree in winter (Gracely et al., 2002). Nerve fibres situated at the base of hair follicles are receptors for touch and light pressure (Heller & Schiff, 1991).

The brain can locate sensations because skin receptors send their messages to the point in the somatosensory cortex that corresponds to the area of the body where the receptor is located. The amount of cortex devoted to each area of the body is related to that part's sensitivity. Our fingers, lips, and tongue are well represented, accounting for their extreme sensitivity to stimulation.

Sometimes the brain "locates" sensations that cannot possibly be present. This occurs in the puzzling *phantom limb* phenomenon, in which amputees experience vivid sensations coming from the missing limb (Warga, 1987). Apparently, an irritation of the nerves that used to originate in the limb fools the brain into interpret-

FIGURE 5.23

Kinesthesis and the vestibular sense are especially well developed in some people, and essential for performing feats like this one.

ing the resulting nerve impulses as real sensations. Joel Katz and Ronald Melzack (1990) studied 68 amputees who insisted that they experienced pain from the amputated limb that was as vivid and "real" as any pain they had ever experienced. This pain was not merely a recollection of what pain used to feel like in the phantom limb; it was actually experienced in the present. The phantom limb phenomenon can be quite maddening: Imagine having an intense itch that you never can scratch, or an ache you cannot rub. When amputees are fitted with prosthetic limbs and begin using them, phantom pain tends to disappear (Gracely et al., 2002).

The Body Senses

We would be totally unable to coordinate our body movements were it not for the sense of **kinesthesis**, which provides us with feedback about our muscles' and joints' positions and movements. The receptors are nerve endings in the muscles, tendons, and joints. The information this sense gives us is the basis for making coordinated movements. Cooperating with kinesthesis is the **vestibular sense**, the sense of body orientation or equilibrium (Figure 5.23). The vestibular receptors are located in the *vestibular apparatus* of the inner ear (see Figure 5.18). One part of the equilibrium system consists of three *semicircular canals,* which contain the receptors for head movement. Each canal lies in a different plane: left/right, backward/forward, or up/down. These canals are filled with fluid and lined with hairlike cells that function as receptors. When the head moves, the fluid in the appropriate canal shifts, stimulating the hair cells and sending messages to the brain. The semicircular canals respond only to acceleration and deceleration; when a constant speed is reached (no matter how high), the fluid and the hair cells return to their normal resting state. That's why takeoffs and landings give a sense of movement, whereas flying at 800 km/h on a cruising airliner does not. Located at the base of the semicircular canals, the *vestibular sacs* also contain hair cells that respond to the position of the body and tell us whether we are upright or tilted at an angle. These structures constitute the second part of the body-sense system.

In Review

- *Sound waves, the stimuli for audition, have two characteristics: frequency, measured in terms of cycles per second or hertz (Hz), and amplitude, measured in terms of decibels (db). Frequency is related to pitch, amplitude to loudness. The receptors for hearing are hair cells in the organ of Corti of the inner ear.*
- *Loudness is coded in terms of the number and types of auditory nerve fibres that fire. Pitch is coded in two ways. Low-frequency tones are coded in terms of corresponding numbers of nerve impulses in individual receptors or by volleys of impulses from a number of receptors. Frequencies above 4,000 Hz are coded according to the region of the basilar membrane that is displaced most by the fluid wave in the cochlear canal.*
- *Hearing loss may result from conduction deafness, produced by problems involving the structures of the inner ear that transmit vibrations to the cochlea, or from nerve deafness, in which the receptors of the inner ear or the auditory nerve are damaged.*
- *Principles derived from the study of sensory processes have been applied in developing sensory prosthetics for the blind and the hearing impaired. Examples include the Sonicguide, a device that provides visual information through tactile stimulation of the tongue, direct electrical stimulation of the visual cortex, and cochlear inplants.*
- *The receptors for taste and smell respond to chemical molecules. Taste buds are responsive to four basic qualities: sweet, sour, salty, and bitter. The receptors for smell (olfaction) are long cells in the upper nasal cavity. Natural body odours produced by pheromones appear to account for a menstrual synchrony that sometimes occurs among women who are in frequent contact.*
- *The skin and body senses include touch, kinesthesis, and equilibrium. Receptors in the skin and body tissues are sensitive to touch, pain, warmth, and cold. Kinesthesis functions by means of nerve endings in the muscles, tendons, and joints. The sense organs for equilibrium are in the vestibular apparatus of the inner ear.*

PERCEPTION: THE CREATION OF EXPERIENCE

Sensory systems provide the raw materials from which experiences are formed. Our sense organs do not select what we will be aware of or how we will experience it; they merely transmit as much information as they can through our nervous system. Yet our experiences are not simply a one-to-one reflection of what is "out there." Different people may experience the same sensory information in radically different ways, because perception is an active, creative process in which raw sensory data are organized and given meaning.

To create our perceptions, the brain carries out two different kinds of processing functions (Figure 5.24). In **bottom-up processing**, the system takes in individual elements of the stimulus and then combines them into a unified perception. Your visual system operates in a bottom-up fashion as you read; its feature detectors analyze the elements in each letter of every word, then recombine them into your visual perception of the letters and words. In **top-down processing**, sensory information is interpreted in the light of existing knowledge, concepts, ideas, and expectations. Top-down processing is occurring as you interpret the words and sentences constructed by the bottom-up process. Here you make use of "higher-order" knowledge, including what you have learned about the meaning of words and sentence construction. Indeed, a given sentence may even convey a different personal meaning to you than to another person if you relate its content to some unique personal experience. Top-down processing accounts for many psychological influences on perception, such as the roles played by our motives, expectations, previous experiences, and cultural learning.

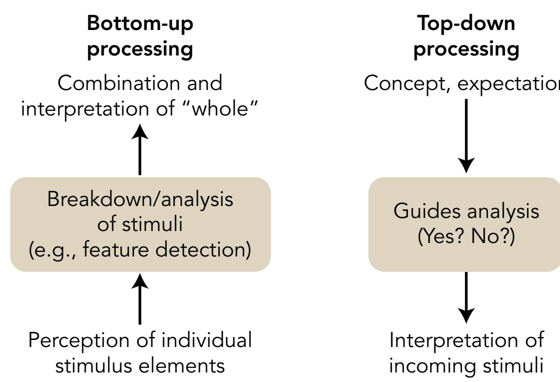


FIGURE 5.24

Bottom-up perceptual processing builds from an analysis of individual stimulus features to a unified perception. Top-down processing begins with a perceptual whole, such as an expectation or an image of an object, and then determines the degree of "fit" with the stimulus features.

Perception Is Selective: The Role of Attention

As you read these words, 100 million sensory messages may be clamouring for your attention. Only a few of these messages register in awareness; the rest you perceive either dimly or not at all. But you can shift your attention to one of those "unregistered" stimuli at any time. (For example, how does the big toe of your right foot feel right now?) Attention, then, involves two processes of selection: (1) focusing on certain stimuli, and (2) filtering out other incoming information (Luck & Vecera, 2002).

These processes have been studied experimentally through a technique called **shadowing**. Participants wear earphones and listen simultaneously to two messages, one sent through each earphone. They are asked to repeat (or "shadow") one of the messages word for word as they listen. Most participants can do this quite successfully, but only at the cost of not remembering what the other message was about. Shadowing experiments demonstrate that we *cannot* attend completely to more than one thing at a time. But we can shift our attention rapidly back and forth between the two messages, drawing on our general knowledge to fill in the gaps (Bonnel & Hafter, 1998; Sperling, 1984).

28. Differentiate between bottom-up and top-down processing of sensory information.

29. What two complementary processes occur in attention?

30. Describe the results of shadowing experiments in relation to attentional capabilities.

Environmental and Personal Factors in Attention

Attention is strongly affected by both the nature of the stimulus and by personal factors. Stimulus characteristics that attract our attention include intensity, novelty, movement, contrast, and repetition. Advertisers use these properties in their commercials and packaging (Figure 5.25).

31. What stimulus and personal characteristics influence attention?

Internal factors, such as our motives and interests, act as powerful filters and influence which stimuli in our environment we will notice. For example, when

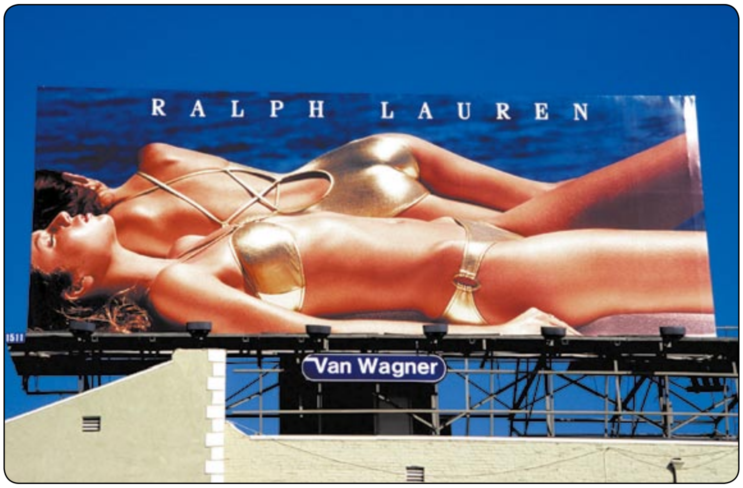


FIGURE 5.25

Advertisers are adept at using attention-attracting stimulus characteristics in their advertisements. Personal characteristics are also important. What kinds of individuals do you suppose would be most attentive to this ad?

we are hungry, we are especially sensitive to food-related cues. A botanist walking through a park is especially attentive to the plants; a landscape architect attends primarily to the layout of the park.

People are especially attentive to stimuli that might represent a threat to their well-being, a tendency that clearly would have biological survival value (Bargh, 1984; Izard, 1989). Christine and Ranald Hansen (1988) presented slides showing groups of nine people. In half of the pictures, all of the people looked either angry or happy. In the other half, there was one discrepant face, either an angry face in a happy crowd or a happy face in an angry crowd. Participants were asked to judge as quickly as possible whether there was a discrepant face in the crowd, then press "yes" or "no" buttons attached to electrical timers. The dependent variable was the length of time required to make this judgment, measured in milliseconds (thousandths of a second). The results, summarized in Figure 5.26, showed that participants were much faster at detecting a single angry face in an otherwise happy crowd than at finding a happy face in an angry crowd. It was as if the angry face, which the experimenters assumed to have threat value, "jumped out" of the crowd when the stimuli were scanned. Swedish psychologist Ulf Dimberg (1997) believes that humans are biologically programmed to detect threatening faces, and he has shown via high-speed photography that emotional facial responses to such stimuli occur in observers within one-third of a second. Attentional processes are thus based both on innate biological factors and on past experiences that make certain stimuli important or meaningful to us.

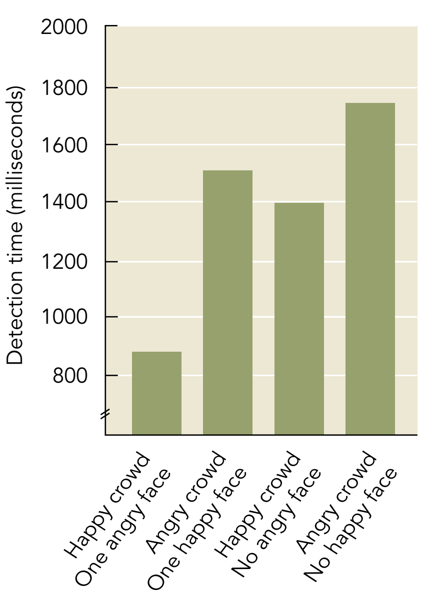


FIGURE 5.26

Perceptual vigilance to threatening stimuli is shown in the finding that people required less time to detect an angry face in a happy crowd than to detect a happy face in an angry crowd or to determine if there was any discrepant face in a happy or an angry crowd.

Data from Hansen & Hansen, 1988.

Perceptions Have Organization and Structure

Have you ever stopped to wonder why we perceive the visual world as being composed of distinct objects? After all, the information sent by the retina reflects nothing but an array of varying intensities and frequencies of light energy. The light rays reflected from different parts of a single object have no more natural "belongingness" to one another than those coming from two different objects. Yet we perceive scenes as involving separate objects, such as trees, buildings, and people. These perceptions must be a product of an organization imposed by our nervous system. This top-down process of perceptual organization occurs so automatically that we take it for granted. But Dr. Richard, a prominent psychologist who suffered brain damage in an accident, no longer does.

> There was nothing wrong with his eyes, yet the input he received from them was not put together correctly. Dr. Richard reported that if he saw a person, he sometimes would perceive the separate parts of the person as not belonging together in a single body. But if all the parts moved in the same direction, Dr. Richard then saw them as one complete person. At other times, he would perceive people in crowds wearing the same colour clothes as "going together" rather than as separate people. He also had difficulty putting sights and sounds together. Sometimes, the movement of the lips did not correspond to the sounds he heard, as if he were watching a badly dubbed foreign movie. Dr. Richard's experience of his environment was thus disjointed and fragmented. . . . (Sacks, 1986, p. 76)

Synaesthesia, in which stimuli in one sensory modality give rise to perceptions in other modalities, is an even more radical departure from ordinary perceptual experience. What, then, are the processes by which sensory nonsense becomes perceptual sense?

Gestalt Principles of Perceptual Organization

Early in the twentieth century, psychologists from the German school of Gestalt psychology set out to discover how we organize the separate parts of our perceptual field into a unified and meaningful whole. *Gestalt* is the German term for "pattern," "shape," or "form." Gestalt theorists were early champions of top-down processing, arguing that the wholes we perceive are often more than (and frequently different from) the sum of their parts.

32. How does our tendency to separate figure and ground contribute to perception?

The Gestalt theorists emphasized the importance of **figure-ground relations**. We tend to organize stimuli into a central or foreground figure and a background. In vision, the central figure is usually in front of or on top of what we perceive as background. It has a distinct shape and is more striking in our perceptions and memory than the background. We perceive borders or contours wherever there is a distinct change in the colour or brightness of a visual scene, but we interpret these contours as part of the figure rather than background. Likewise, instrumental music is heard as a melody (figure) surrounded by other chords or harmonies (ground).

Separating figure from ground can be a challenging task (Figure 5.27), yet our perceptual systems usually are equal to the task. At times, however, what's figure and what's ground is not completely obvious, and the same stimulus may give rise to two different perceptions. Consider Figure 5.28, for example. If you examine it for a while, two alternating but equally plausible perceptions will emerge, one based on the inner portion and the other formed by the two outer portions. When the alternative perception (figure) occurs, what was previously the figure becomes the background.

In addition to figure-ground relations, the Gestalt psychologists were interested in how separate stimuli come to be perceived as parts of larger wholes. They suggested that people group and interpret stimuli in accordance with four **Gestalt laws of perceptual organization**: similarity, proximity, closure, and continuity. These organizing principles are illustrated in Figure 5.29.

What was your perception of Figure 5.29a? Did you perceive 15 unrelated dots, or did you view the stimulus as two triangles formed by different-sized dots? If you saw triangles, your perception obeyed the Gestalt *law of similarity,* which says that when parts of a configuration are perceived as similar, they will be perceived as belonging together. The *law of proximity* says that elements that are near one another are likely to be perceived as part of the same configuration. Thus most people perceive Figure 5.29b as three sets of lines rather than as six separate lines. Illustrated in Figure 5.29c is the *law of closure,* which states that people tend to close the open edges of a figure or fill in gaps in an incomplete figure, so that their identification of the form (in this case, a circle) is more complete than what is actually there. Finally, the *law of continuity* holds that people link individual elements together so that they form a continuous line or pattern that makes sense. Thus Figure 5.29d is far more likely to be seen as combining components

FIGURE 5.27

Figure-ground relations are important in perceptual organization. Here the artist Bev Doolittle has created great similarity between figure and ground in this representation of natural camouflage, yet enough figural cues remain to permit most people to detect the ponies.

Source: Pintos, Bev Doolittle, 1979. The Greenwich Workshop, Trumbull, Conn.

FIGURE 5.28

This reversible figure illustrates alternating figure-ground relations. It can be seen as a vase or as two people facing each other. Whichever percept exists at the moment is seen as figure against background.

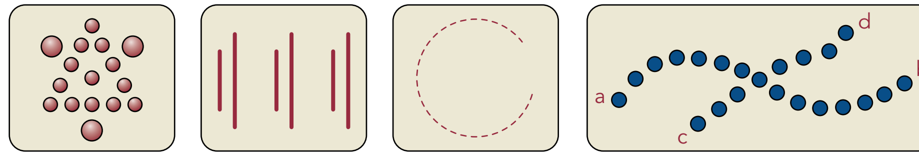


FIGURE 5.29

Among the Gestalt principles for perceptual organization are the laws of similarity (a), proximity (b), closure (c), and continuity (d). Each principle causes us to organize stimuli into "wholes" that are greater than the sum of their parts.

(ab and cd) than (ad and cb), which have poor continuity. Or consider Fraser's spiral, shown in Figure 5.30, which is not really a spiral at all! (To demonstrate, trace one of the circles with a pencil.) We perceive the concentric circles as a spiral because, to our nervous system, a spiral gives better continuity between individual elements than does a set of circles. The spiral is created by us, not by the stimulus.

Perception Involves Hypothesis Testing

"Recognizing" a stimulus implies that we have a **perceptual schema**—a mental representation or image—to compare it with. Our schemas contain the critical features of objects, events, and other perceptual phenomena (Wade & Swanston, 2001). They allow us to classify and identify sensory input in a top-down fashion.

Imagine, for example, that a person approaches you and calls out your name. Who is this person? If the stimuli match your inner representation of your best friend's appearance and voice closely enough, you identify the person as your friend (McAdams & Drake, 2002). Many political cartoonists have an uncanny ability to capture the most noteworthy facial features of famous people, so that we can easily recognize the person represented by even the simplest line sketch.

Perception is, in this sense, an attempt to make sense of stimulus input, to search for the "best" interpretation of sensory information we can arrive at, based on our knowledge and experience. Likening the process to the scientific enterprise described in Chapter 2, Richard L. Gregory (1966) suggested that each of our perceptions is essentially a hypothesis about the nature of the object or, more generally, the meaning of the sensory information. The perceptual system actively searches its gigantic library of internal schemas for the interpretation that best fits the sensory data.

An example of how effortlessly our perceptual systems build up descriptions or hypotheses that best fit the available evidence is found in the comic strips created by Gustave Verbeek in the early 1900s. The Sunday *New York Herald* told Verbeek that his comic strip had to be restricted to six panels. Verbeek wanted 12 panels, so he ingeniously created 12-panel cartoons in only six panels by drawing pictures like that shown in Figure 5.31a. The reader viewed the first six panels, then turned the newspaper upside down. Try this yourself, and you will find that a bird story becomes a fish story! The point is that you do not simply see an upside-down bird, even though the physical stimuli remain exactly the same. You see a radically different picture because the new stimulus closely matches another of your perceptual schemas.

In some instances, sensory information fits two different internal representations, and there is not enough information to permanently rule out one of them in favour of the other. For example, examine the Necker cube, shown in Figure 5.31b.

?

33. Define and give examples of the four Gestalt laws of perceptual organization.

FIGURE 5.30

Fraser's spiral illustrates the Gestalt law of continuity. If you follow any part of the "spiral" with your finger, you will find that it is not really a spiral at all, but a series of concentric circles. The "spiral" is created by your nervous system because that perception is more consistent with continuity of the individual elements.

If you stare at the cube for a while, you will find that it changes before your eyes as your nervous system "tries out" a new perceptual hypothesis.

34. In what sense is perception a kind of hypothesis testing? What is the role of perceptual schemas in this process?

Perception Is Influenced by Expectations: Perceptual Sets

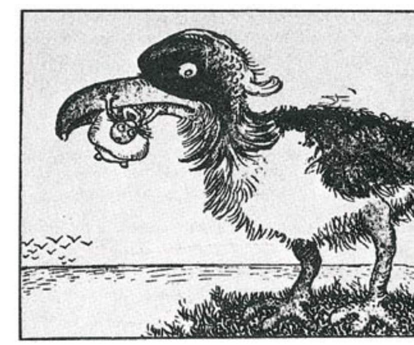
On July 3, 1988, the warship USS Vincennes was engaged in a pitched battle with several speedy Iranian gunboats. Suddenly, the *Vincennes*'s advanced radar system detected an aircraft taking off from a military/civilian airfield in Iran and heading straight toward the American vessel. Radar operators identified the plane as an Iranian F-14 fighter, known to carry lethal air-to-surface missiles used earlier in a damaging attack on another U.S. warship. Repeated requests to the plane to identify itself yielded no response. The plane was now only 16 kilometres from the ship and, according to the crewmen watching on radar, descending toward the *Vincennes* on an attack course. A final warning evoked no response, and the *Vincennes*'s captain gave the command to fire on the plane. Two surface-to-air missiles streaked into the sky. Moments later, all that remained of the plane was a shower of flaming debris.

The jubilation and relief of the *Vincennes*'s crew was short-lived. Soon the awful truth was known: The plane they had shot down was not an attacking F-14 warplane. Instead, it was a commercial airliner carrying 290 passengers, all of whom died when the aircraft was destroyed. Moreover, videotape recordings of the electronic information that the crew had used to identify the plane and its flight pattern showed conclusively that the aircraft was not an F-14 and that it had actually been climbing rather than descending toward the ship.

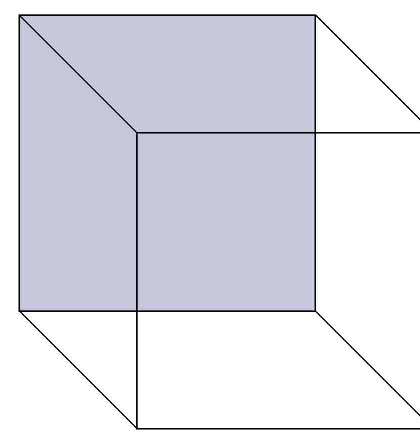
How could such a tragic error have been made by a well-trained and experienced crew with access to the world's most sophisticated radar equipment? At a Congressional hearing on the incident, several prominent perception researchers reconstructed the psychological environment that could have caused the radar operators' eyes to "lie."

Clearly, the situation was stressful and dangerous. The *Vincennes* was already under attack by Iranian gunboats, and other attacks could be expected. It was easy for the radar operators, observing a plane taking off from a military field and heading toward the ship, to interpret this as the possible prelude to an air attack. The *Vincennes*'s crew was determined to avoid the fate of the other American warship, producing a high level of vigilance to any stimuli that suggested an impending attack. Fear and expectation thus created a psychological context within which the sensory input from the computer system was interpreted in a top-down fashion. The perception that the aircraft was a warplane and that it was descending toward the ship fit the crew's expectations and fears, and it became the "reality" that they experienced. They had a **perceptual set**—a readiness to perceive stimuli in a particular way. Sometimes believing is seeing.

Perceptual sets influence our social perceptions as well, as psychologist Harold Kelly (1950) demonstrated the day he invited a guest lecturer into his class. Half of the students in the class were given a set of introductory notes that described the guest as "industrious, critical, practical, determined and a rather *cold* person" (italics ours). The other half were given notes that described the visitor as "industrious, critical, practical, determined and a rather *warm* person." After the class, the students rated the guest lecturer and his presentation. Those who received the *cold* description interacted very little with him and later rated the guest lecturer as unhappy and irritable during the lecture. But those who got the *warm* description rated him as happy and good natured during the lecture, and they took part



(a)



(b)

FIGURE 5.31

Two examples of how the same stimulus can give rise to different perceptions are found in the comic strips of Gustave Verbeek (a) and the Necker cube (b). To produce the reversals, turn the comic strip panel upside down and stare at the cube. The front of the cube will suddenly become the back, and it will appear that the cube is being viewed from a different angle.

35. What is a perceptual set? What factors can create such sets? How did the *Vincennes* incident illustrate this concept? How is it involved in perceiving people?

actively in the class discussion. They also rated his presentation more favourably. All of the students had seen and heard the *same lecturer,* or had they? It seems they perceived what they expected to, as did the football spectators in the classic study by Hastrof and Cantril discussed in Chapter 1.

Stimuli Are Recognizable under Changing Conditions: Perceptual Constancies

36. What are the nature and adaptive value of perceptual constancies?

When a door swings open, it casts a different image on our retina, but we still perceive it as a door. Our perceptual hypothesis remains the same. Were it not for **perceptual constancies** that allow us to recognize familiar stimuli under varying conditions, we would have literally to rediscover what something is each time it appeared under different conditions. Thus you can recognize a tune even if it is played in a different octave, as long as the relations among its notes are maintained. You can detect the flavour of a particular spice even when it occurs in foods having very different tastes.

In vision, several constancies are important. *Shape constancy* allows us to recognize people and other objects from many different angles, as in the case of the swinging door. Perhaps you have had the experience of sitting up front and off to one side of the screen in a crowded movie theatre. At first, the picture probably looked distorted, but after a while your visual system corrected for the distortion, and objects on the screen looked normal again.

Because of *brightness constancy*, the relative brightness of objects remains the same under different conditions of illumination, such as full sunlight and shade. Brightness constancy occurs because the ratio of light intensity between an object and its surroundings usually is constant. The actual brightness of the light that illuminates the objects does not matter, as long as the same light intensity illuminates both an object and its surroundings.

When we take off in an airplane, we know that the cars on the highway below are not shrinking and becoming the size of ants. *Size constancy* is the perception that the size of objects remains relatively constant even though images on our retina change in size with variations in distance. Thus a man who is judged to be 180 centimetres tall when standing two metres away is not perceived to be 90 centimetres tall at a distance of four metres, even though the size of his image on the retina is reduced to half its original size (Figure 5.32).

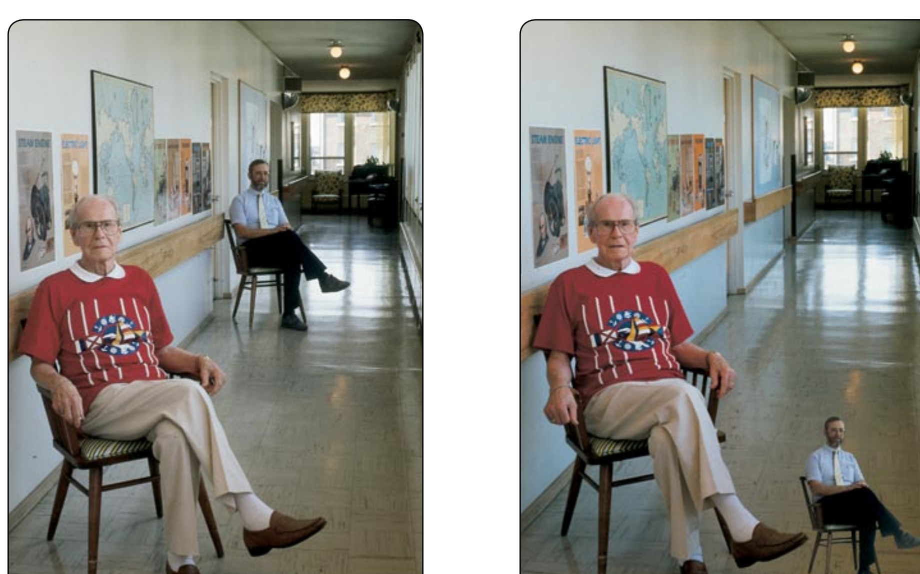


FIGURE 5.32

Size constancy based on distance cues causes us to perceive the person in the background as being of normal size. When the same stimulus is seen in the absence of the distance cues, size constancy breaks down.

In Review

- Perception involves both bottom-up processing, in which individual stimulus fragments are combined into a perception, and top-down processing, in which existing knowledge and perceptual schemas are applied to interpret stimuli.
- Attention is an active process in which we focus on certain stimuli while blocking out other stimuli. We cannot attend completely to more than one thing at a time, but we are capable of rapid attentional shifts. Attentional processes are affected by the nature of the stimulus and by personal factors such as motives and interests. The perceptual system appears to be especially vigilant to stimuli that denote threat or danger.
- The Gestalt psychologists identified a number of principles of perceptual organization, including figure-ground relations and the laws of similarity, proximity, closure, and continuity. R. L. Gregory suggested that perception is essentially a hypothesis about what a stimulus is, based on previous experience and the nature of the stimulus.
- Perceptual sets involve a readiness to perceive stimuli in certain ways, based on our expectations, assumptions, motivations, and current emotional state.
- Perceptual constancies allow us to recognize familiar stimuli under changing conditions. In the visual realm, there are three constancies: shape, brightness, and size.

PERCEPTION OF DEPTH, DISTANCE, AND MOVEMENT

The ability to adapt to a spatial world requires that we make fine distinctions involving distances and the movement of objects within the environment. Humans are capable of great precision in making such judgments. Consider, for example, the perceptual task faced by a batter in the sport of baseball (Figure 5.33). A fastball thrown by a pitcher at 90 mph from 18 metres will reach the batter who is trying to hit it in about 42/100 of a second. A curveball thrown at 80 mph will reach the hitting zone in 47/100 of a second, a difference of only 5/100 of a second (but a world of difference for timing and hitting the pitch). Within the first two metres of a ball's flight from the pitcher's hand (an interval of about 25/1,000 of a second), the batter must correctly judge the speed, type, and location of the pitch. If any of the judgments is in error, the hitter will be unable to hit a fair ball (Adair, 1990). The perceptual demands of such a task are imposing indeed (as are the salaries earned by those who can perform this task consistently). How does the visual perception system make such judgments?

FIGURE 5.33

The demands faced by a batter in judging the speed, distance, and movements of a pitched baseball within thousandths of a second underscore the capabilities of the visual perceptual system.

Depth and Distance Perception

One of the more intriguing aspects of visual perception is our ability to perceive depth. The retina receives information in only two dimensions (length and width), but the brain translates these cues into three-dimensional perceptions. It does this by using both **monocular cues** (which require only one eye) and **binocular cues** (which require both eyes).

Monocular Depth Cues

37. Identify eight monocular cues for distance and depth.

Judging the relative distances of objects is one important key to perceiving depth. Because artists paint their portraits on a flat canvas, they depend upon a variety of monocular cues to create perceptions of depth in their pictures. One such cue is patterns of *light and shadow*. The Dutch artist M. C. Escher skilfully used light and shadow to create the three-dimensional effect shown in Figure 5.34. The depth effect is as powerful if you close one eye as it is when you use both. Another, *linear perspective*, refers to the perception that parallel lines converge or angle toward one another as they recede into the distance. Thus, if you look down railroad tracks,

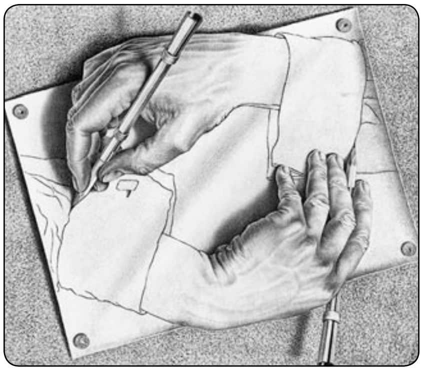


FIGURE 5.34

Patterns of light and shadow can serve as monocular depth cues, as shown in Drawing Hands by M. C. Escher.

they appear to angle toward one another with increased distance, and we use this as a depth cue. The same occurs with the edges of a highway or the sides of an elevator shaft. *Interposition,* in which objects closer to us may cut off part of our view of more distant objects, provides another cue for distance and depth.

An object's *height in the horizontal plane* provides another source of information. For example, a ship eight kilometres offshore appears in a higher plane and closer to the horizon than does one that is only one kilometre from shore. *Texture* is a fifth cue, because the texture or grain of an object appears finer as distance increases. Likewise, *clarity* can be an important cue for judging distance; we can see nearby hills more clearly than ones that are far away, especially on hazy days. *Relative size* is yet another basis for distance judgments. If we see two objects that we know to be of similar size, then the one that looks smaller will be judged to be farther away. A final monocular cue is *motion parallax,* which tells us that if we are moving, nearby objects appear to move faster in the opposite direction than do faraway ones. All of these cues provide us with information that we can use to make judgments about distance and, therefore, about depth.

The artist Raphael Sanzio was a master at using monocular depth and distance cues. *The School of Athens,* shown in Figure 5.35, illustrates seven of the monocular cues described above.

FIGURE 5.35

The School of Athens, *by Raphael Sanzio, illustrates seven monocular depth cues. (1) Linear perspective is produced by the converging lines of the corridor in the background. (2) The arches and the people in the background are smaller than those in front (relative size). (3) The back of the floor is in a higher horizontal plane than the foreground. (4, 5) The objects in the background are less detailed than the closer ones (texture and clarity). (6) Light and shadow are used to create depth. (7) The arches and people in the front of the painting cut off parts of the corridor behind them (interposition).*

Binocular Disparity

The most dramatic perceptions of depth arise with binocular depth cues, which require the use of both eyes. For an interesting binocular effect, hold your two index fingers about 15 centimetres in front of your eyes with their tips about two and a half centimetres apart. Focus on your fingers first, then focus beyond them across the room. The two different views will produce a "third" finger between the other two. This "finger sausage" will disappear if you close either eye.

Many of us are familiar with the delightful depth experiences provided by View Master slides and 3-D movies watched through special glasses. These devices make use of the principle of **binocular disparity**, in which each eye sees a slightly different image. Within the brain, the visual input from the two eyes is analyzed by feature detectors that are attuned to depth (Howard, 2002; Livingstone & Hubel, 1994). Some of the feature detectors respond only to stimuli that are either in front of or behind the point we are fixing our gaze upon. The responses of these depth-sensitive neurons are integrated to produce our perception of depth (Goldstein, 2002).

A second binocular distance cue, **convergence**, is produced by feedback from the muscles that turn your eyes inward to view a near object. You can experience this cue by holding a finger about 30 centimetres in front of your face, then moving it slowly toward you. Messages sent to your brain by the eye muscles provide it with a depth cue.

Perception of Movement

The perception of movement is a complex process that requires the brain to integrate information from several different senses. Try this demonstration: Hold your pen in front of your face. Now, while holding your head still, move the pen back and forth. You will perceive the pen moving. Now hold the pen still and move your head back and forth at the same rate of speed. In both cases, the image of the pen moved across your retina in about the same way. But when you moved your head, your brain took into account input from your kinesthetic and vestibular systems and "concluded" that you were moving but the pen was not.

The primary cue for perceiving motion is the movement of the stimulus across the retina. Under optimal conditions, a retinal image need move only about one-fifth the diameter of a single cone for us to detect movement (Nakayama & Tyler, 1981). The relative movement of an object against a structured background is also a movement cue (Gibson, 1979). For example, if you fixate on a bird in flight, the relative motion of the bird against its background is a strong cue for perceiving speed of movement.

The illusion of smooth motion can be produced if we arrange for the sequential appearance of two or more stimuli. Gestalt psychologist Max Wertheimer (1912) demonstrated this in his studies of **stroboscopic movement**, illusory movement produced when a light is briefly flashed in darkness and then, a few milliseconds later, another light is flashed nearby. If the timing is just right, the first light seems to move from one place to the other in a manner indistinguishable from real movement.

Stroboscopic movement (termed the *phi phenomenon* by Wertheimer) has been used commercially in numerous ways. For example, we have all seen the strings of successively illuminated lights on theatre marquees that seem to move endlessly around the border or that spell out messages in a "moving" script. Stroboscopic movement is also the principle behind motion pictures, which consist of a series of still photographs, or frames, that are projected onto a screen in rapid succession with dark intervals in between (Figure 5.36). The rate at which the frames are projected is critical to our perception of smooth movement. Early movies, such as the "silent" films of the 1920s, projected the "stills" at only 16 frames per second, and the movements appeared fast and jerky. Today the usual speed is 24 frames per second, which more accurately produces an illusion of smooth movement.

?
38. Describe two binocular cues.

?
39. What is the primary cue for motion perception? How is stroboscopic movement used in motion pictures and television?

FIGURE 5.36

Stroboscopic movement is produced in moving pictures as a series of still photographs projected at a rate of 24 per second.

ILLUSIONS: FALSE PERCEPTUAL HYPOTHESES

Our knowledge of perceptual schemas, hypotheses, sets, and constancies allows us to understand some interesting perceptual experiences known as illusions. **Illusions** are compelling but incorrect perceptions. They can be understood as erroneous perceptual hypotheses about the nature of the stimulus. Illusions are not only intriguing and sometimes delightful visual experiences, but they also provide important information about how our perceptual processes work under normal conditions.

?
40. In what sense is an illusion a false perceptual hypothesis? In what ways are constancies and context involved in producing visual illusions?

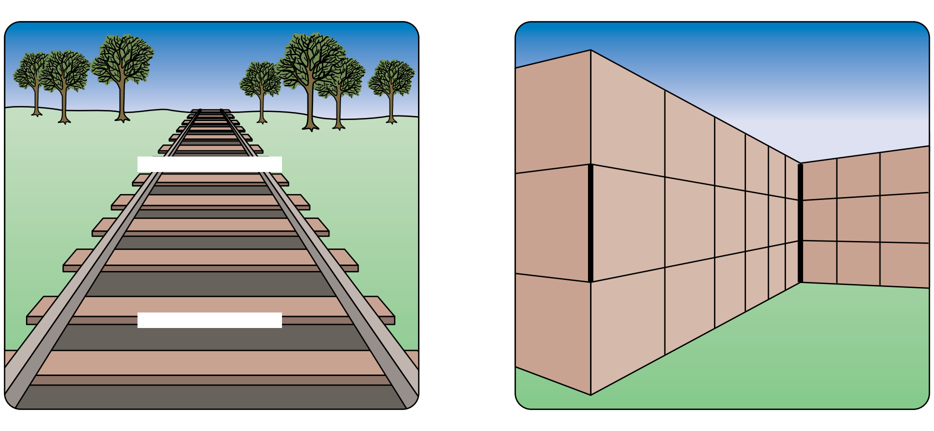
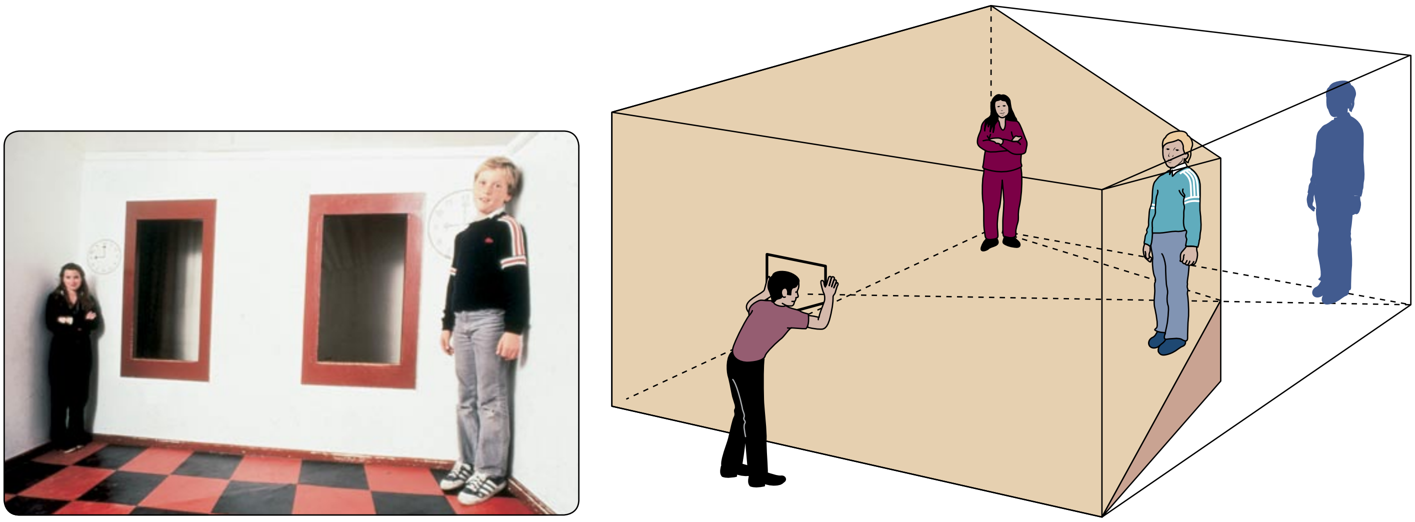


FIGURE 5.37

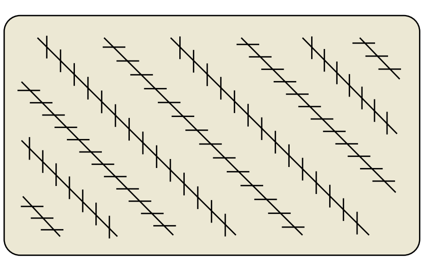
The Ponzo illusion. Which lines in (a) and (b) are longer? Measure them and see. The distance cues provided by the converging railroad tracks and walls affect size perception and disrupt size constancy.



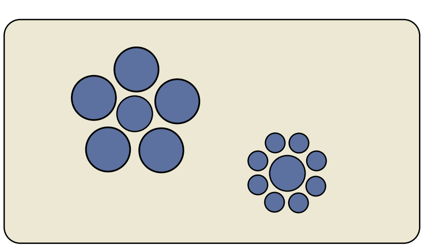
(a) (b)

FIGURE 5.38

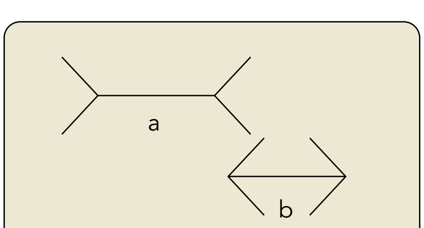
The Ames Room (a) produces a striking size perception because it is designed to appear rectangular. However, as (b) shows, the room is actually trapezoidal in shape, and the figure on the left is actually much farther away from the viewer than the one on the right, making it appear smaller.



The long lines are actually parallel, but the small lines make them appear crooked.



Which inner circle is larger? Check and see.



The Müller-Lyer illusion. Which line, a or b, is longer? Compare them with a ruler.

FIGURE 5.39

Context-produced geometric illusions.

Ironically, most visual illusions can be attributed to perceptual constancies that ordinarily help us to perceive more accurately (Frisby, 1980). For example, size constancy results in part from our ability to use distance cues to judge the size of objects. But distance cues sometimes may fool us. In the Ponzo illusion, shown in Figure 5.37, the depth cues of linear perspective (the tracks converging) and height in the horizontal plane provide distance cues that make the upper bar appear farther away than the lower bar. Because it seems farther away, the perceptual system concludes that the bar in the background must be larger than the bar in the foreground, despite the fact that the two bars cast retinal images of the same size. The same occurs in the vertical arrangement seen in Figure 5.37b.

Distance cues can be manipulated to create other size illusions. One occurs in a room constructed by Adelbert Ames. Viewed through a peephole with one eye, the scene presents a startling size reversal (Figure 5.38a). Our perceptual system assumes that the room has a normal rectangular shape because, in fact, most rooms do. Monocular depth cues do not allow us to see that, in reality, the left corner of the room is twice as far away as the right corner (Figure 5.38b). As a result, size constancy breaks down, and we base our judgment of size on the sizes of the retinal images cast by the two people.

The study of perceptual constancies shows that our perceptual hypotheses are strongly influenced by the *context*, or surroundings, in which a stimulus occurs. Figure 5.39 shows some examples of how context can produce illusory perceptions.

Some of the most intriguing perceptual distortions are produced when monocular depth cues are manipulated to produce a figure or scene whose individual parts make sense, but whose overall organization is "impossible" in terms of our existing perceptual schemas. Figure 5.40 shows three impossible figures. In each case, our brains extract information about depth from the individual features of the objects, but when this information is put together and matched with our existing schemas, the percept that results simply doesn't make sense. The "devil's tuning fork," for example (Figure 5.40c), could not exist in our universe. It is a two-dimensional image containing paradoxical depth cues. Your brain, however, automatically interprets it as a three-dimensional object and matches it with its internal schema

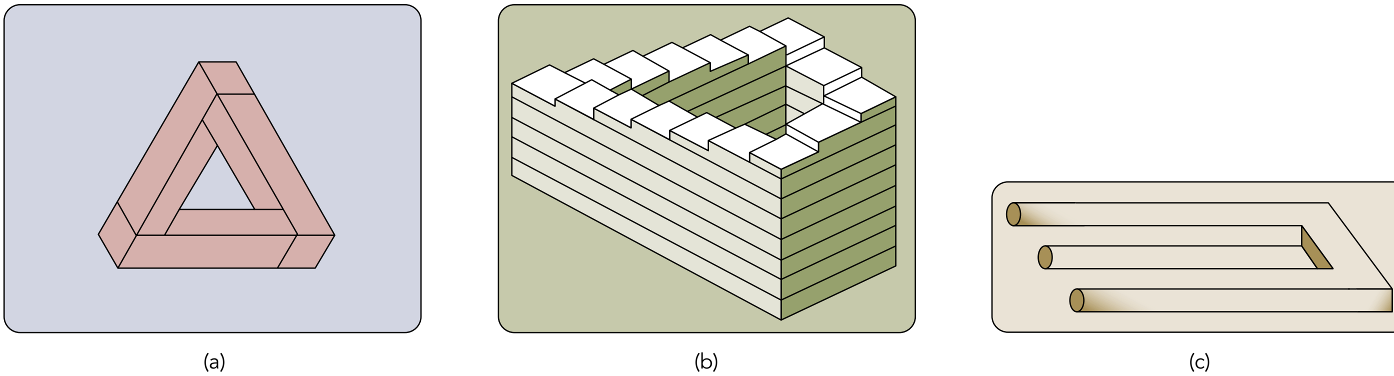


FIGURE 5.40

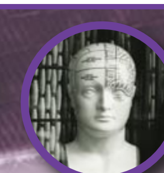
Monocular depth cues are cleverly manipulated to produce an impossible triangle, a never-ending staircase, and the "devil's tuning fork."

of a fork, a bad fit indeed. The never-ending staircase (Figure 5.40b) provides another compelling example of an impossible scene that seems perfectly reasonable when we focus only on its individual elements.

Illusions are not only personally and scientifically interesting, but they can have important real-life implications. Our *Psychological Applications* box describes one scientist's search for an illusion having life-and-death implications.

PSYCHOLOGICAL APPLICATIONS

Stalking a Deadly Illusion



Background

When the Boeing Company introduced the 727 jet airliner in the mid-1960s, it was the latest word in aviation technology. The plane performed well in test flights, but four fatal crashes soon after it was placed in service raised fears that there might be some fatal flaw in its design.

The first accident occurred as a 727 made its approach to Chicago over Lake Michigan on a clear night. The plane plunged into the lake 30 kilometres offshore. About a month later, another 727 glided in over the Ohio River to land in Cincinnati. Unaccountably, it struck the ground about two and a quarter metres below the runway elevation and burst into flames. The third accident occurred as an aircraft approached Salt Lake City over dark land. The lights of the city twinkled in the distance, but the plane made too rapid a descent and crashed short of the runway. Months later, a Japanese airliner approached Tokyo at night. The flight ended tragically as the plane, its landing gear not yet lowered, struck the waters of Tokyo Bay 10 kilometres from the runway.

Analysis of these four accidents, as well as others, suggested a common pattern. All occurred at night under clear weather conditions, so that the pilots were operating under visual flight rules rather than performing instrument landings. In each instance, the plane was approaching city lights over dark areas of water or land. In all cases, the lights in the background sloped upward to varying degrees. Finally, all of the planes crashed short of the runway. These observations led a Boeing psychologist, Conrad L. Kraft, to suspect that the cause of the crashes might be pilot error based on some sort of visual illusion.

Method

To test this possibility, Boeing engineers constructed an apparatus to simulate night landings (Figure 5.41). It consisted of a cockpit and a miniature lighted "city" named Nightertown. The city moved toward the cockpit on computer-controlled rollers, and it could be tilted to simulate various terrain slopes. The pilot could control simulated air speed and the rate of climb and descent, and the Nightertown scene was controlled by the pilot's responses just as a true visual scene would be.

The participants were 12 experienced Boeing flight instructors who made virtual reality "landings" at Nightertown under systematically varied conditions created by the computerized simulator. All of their landings were visual landings in order to test whether a visual illusion was occurring. Every

–*Continued*

FIGURE 5.41

Conrad Kraft, a Boeing psychologist, created an apparatus to study how visual cues can affect the simulated landings of airline pilots. Pilots approached Nightertown in a simulated cockpit. The computer-controlled city could be tilted to reproduce the illusion thought to be responsible for fatal air crashes.

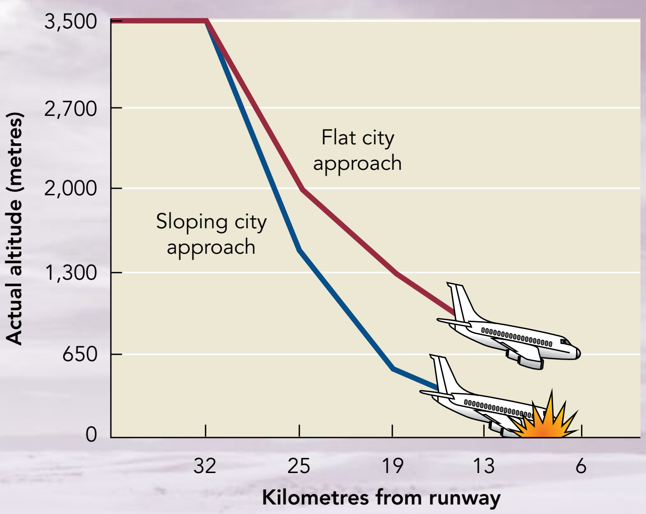


FIGURE 5.42

The illusion caused by upward-sloping city lights caused even highly experienced pilots to overestimate their altitude, and 11 of the 12 flight instructors "crashed" short of the runway. When the lights were flat, all the pilots made perfect approaches.

Data from Kraft, 1978.

aspect of their approach and the manner in which they controlled the aircraft was measured precisely.

Results

The landings made by the flight instructors were nearly flawless until Kraft duplicated the conditions of the fatal crashes by having the pilots approach an upward-sloping distant city over a dark area. When this occurred, the pilots were unable to detect the upward slope, assumed that the background city was flat, and consistently overestimated their altitude. On a normal landing, the preferred altitude at 7.25 kilometres from the runway is about 378 metres. As Figure 5.42 shows, the pilots approached at about this altitude when the simulated city was in a flat position. But when it was sloped upward, 11 of the 12 experienced pilot instructors crashed about 7.25 kilometres short of the runway.

Critical Analysis

This study shows the value of being able to study behaviour under highly controlled conditions and with precise measurements. By simulating the conditions under which the fatal crashes had occurred, Kraft identified the visual illusion that was the source of pilot error. He showed that the perceptual hypotheses of the flight instructors, like those of the pilots involved in the real crashes, were tragically incorrect. It would have been ironic if one of the finest jetliners ever built had been removed from service because of presumed mechanical defects while other less capable aircraft remained in service.

Kraft's research not only saved the 727 from months, and perhaps years, of needless mechanical analysis but, more importantly, it identified a potentially deadly illusion and the precise conditions under which it occurred. On the basis of Kraft's findings, Boeing recommended that pilots attend carefully to their instruments when landing at night, even under perfect weather conditions. Today commercial airline pilots are required to make instrument landings not only at night, but also during the day.

Source: Conrad L. Kraft (1978). A psychophysical contribution to air safety: Simulator studies of illusions in night visual approaches. In H. L. Pick, Jr., H. W. Leibowitz, J. E. Singer, A. Steinschneider, & H. W. Stevenson (Eds.), *Psychology: From research to practice.* New York: Plenum.

In Review

- *Monocular cues to judge distance include linear perspective, relative size, height in the horizontal plane, texture, and clarity. These distance cues also help us judge depth. Depth perception also occurs throughthe monocular cues of light and shadow patterns, interposition, and motion parallax.*

- *Binocular disparity occurs as slightly different images are viewed by each eye and acted on by feature detectors for depth. Convergence of the eyes provides a second binocular cue.*
- *The basis for perception of movement is absolute movement of a stimulus across the retina or relative movement of an object in relation to its background. Stroboscopic movement is illusory.*
- *Illusions are erroneous perceptions. They may be regarded as incorrect perceptual hypotheses. Perceptual constancies help produce a variety of context-produced illusions.*

EXPERIENCE, CRITICAL PERIODS, AND PERCEPTUAL DEVELOPMENT

Development of sensory and perceptual systems results from the interplay of biological and experiential factors. Genes program biological development, but this development is also influenced by environmental experiences. For example, if you were to be blinded in an accident and later learned to read Braille, the area of the somatosensory cortex that is devoted to the fingertips would enlarge over time as it "borrowed" other neurons to increase its sensitivity (Pool, 1994). By the time they are old enough to crawl, children placed on a *visual cliff* formed by a glass-covered table that suddenly drops off beneath the glass ordinarily will not venture "over the edge" (Figure 5.43). This aversion may result from the interaction of innate depth perception abilities and previous experience (Gibson & Walk, 1960).

FIGURE 5.43

Eleanor Gibson and Richard Walk constructed this "visual cliff" with a glass-covered drop-off to determine whether crawling infants and newborn animals can perceive depth. Even when coaxed by their mothers, infants refuse to venture onto the glass over the cliff. Newborn animals also avoid the cliff.

What might a lifetime of experience in a limited environment do to perceptual abilities that seem innate? The Ba Mbuti pygmies, who live in the rain forests of central Africa, spend their lives in a closed-in green world of densely packed trees without open spaces. The anthropologist C. M. Turnbull (1961) once brought a man named Kenge out of the forest to the edge of a vast plain. A herd of buffalo grazed in the distance. To Turnbull's surprise, Kenge remarked that he had never seen insects of that kind. When told that they were buffalo, not insects, he was deeply offended and felt that Turnbull was insulting his intelligence. To prove his point, Turnbull drove Kenge in his jeep toward the animals. Kenge's eyes widened in amazement as the "insects" grew into buffalo before his eyes. To explain his perceptual experience to himself, he concluded that witchcraft was being used to fool him. Kenge's misperception occurred as a failure in size constancy. Having lived in an environment without open spaces, he had no experience in judging the size of objects at great distances.

As noted earlier, when light passes through the lens of the eye, the image projected on the retina is reversed, so that right is left and up is down. What would happen if you were to wear a special set of glasses that undid this natural reversal of the visual image and created a world like that in Figure 5.44? In 1896, perception researcher George Stratton did just that, possibly becoming the first human ever to have a right-side-up image on his retina while standing upright. Reversing how nature and a lifetime of experience had fashioned his perceptual system at first disoriented Stratton. The ground and his feet were now "up" and he had to put on his hat from the bottom up. He had to reach to his left to touch something he saw on his right. Stratton suffered from nausea and couldn't eat or get around for several days. Gradually, however, he adapted to his inverted world, and by the end of eight days, he was able successfully to reach for objects and walk around. Years later,

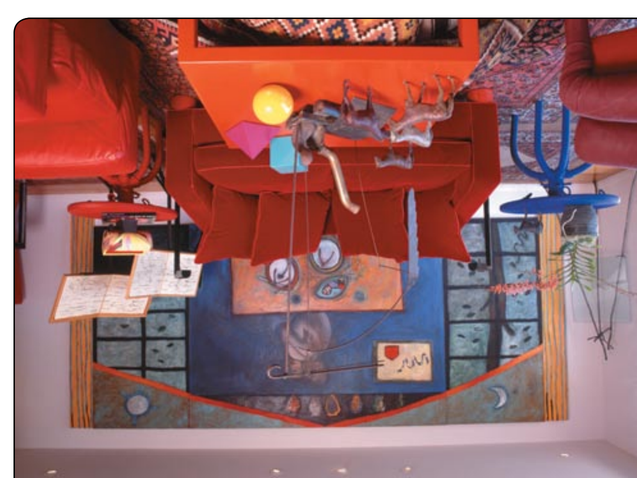


FIGURE 5.44

Inverted vision would create a world that looks like this. Adaptation to such a world is possible, but challenging.

people who wore inverting lenses for longer periods of time did the same. Some were able to ski down mountain slopes or ride motorcycles while wearing the lenses, even though their visual world remained "upside down" and never became normal for them. When they removed the inverting lenses, they initially had some problems, but soon readapted to the normal visual world (Dolezal, 1982).

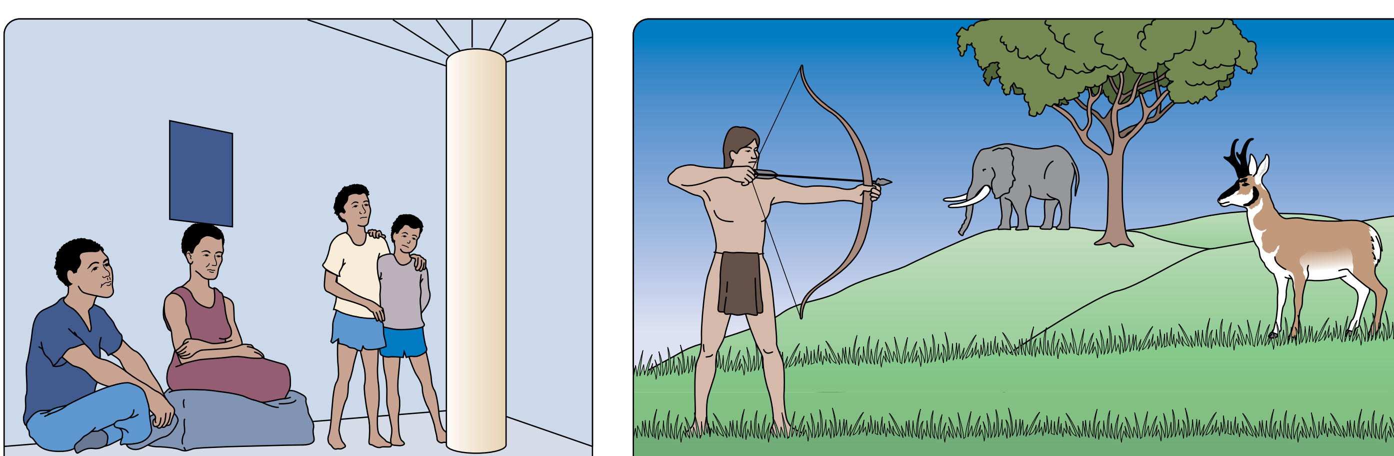
Cross-Cultural Research on Perception

41. What evidence is there that cultural factors can influence picture interpretations, constancies, and susceptibility to illusions?

As far as we know, humans normally come into the world with the same perceptual abilities. However, from that point, the culture one grows up in helps determine the kinds of perceptual learning experiences people have. Cross-cultural research can help identify which aspects of perception occur in all people, regardless of their culture, as well as perceptual differences that result from cultural experiences (Deregowski & Kinnear, 1997). Athough there are far more perceptual similarities than differences in the peoples of the world, the differences that do exist show us that perception can indeed be influenced by experience.

Consider the perception of a picture, which depends on both the nature of the picture and characteristics of the perceiver. In Figure 5.45a, what is the object above the woman's head? Most North Americans and Europeans reply instantly, "A window." They also tend to see the family sitting inside a dwelling. But when the same picture was shown to East Africans, nearly all perceived the object as a basket or box that the woman is balancing on her head. To them, the family is also outside, sitting under a tree (Gregory & Gombrich, 1973). These interpretations are more consistent with their cultural experiences.

In our earlier discussion of monocular depth cues, we used paintings such as those in Figure 5.35 to illustrate monocular depth perception. In Western culture, we have constant exposure to two-dimensional pictures that our perceptual system effortlessly turns into three-dimensional perceptions. Do people who grow up in cultures in which they are not exposed to pictures have the same perceptions? When presented with the picture in Figure 5.45b and asked which animal the hunter was about to shoot, tribal African people answered that he was about to kill the "baby elephant." They did not use the monocular cues that cause Westerners to



(a) (b)

FIGURE 5.45

(a) What is the object above the woman's head? East Africans had a far different answer than did North Americans. (b) Cultural differences also occurred when people were asked which animal the archer was about to shoot.

(a) Adapted from Gregory & Gombrich, 1973; (b) Adapted from Hudson, 1960.

perceive the man as hunting the antelope and to view the elephant as an adult animal in the distance (Hudson, 1960).

Illusions occur when one of our common perceptual hypotheses is in error. Earlier, we showed you the Müller-Lyer illusion (see Figure 5.39) in which a line appears longer when the V-shaped lines at its ends radiate outward than when they face inward. Westerners are very susceptible to this illusion. They have learned that in their "carpentered" environment, which has many corners and square shapes, inward-facing lines occur when corners are closer, outward-facing lines when they are farther away (Figure 5.46). But when people from other cultures who live in more rounded environments are shown the Müller-Lyer stimuli, they are more likely to correctly perceive the lines as equal in length (Segall et al., 1966). They do not fall prey to a perceptual hypothesis that normally is correct in an environment like ours that is filled with sharp corners, but is wrong when applied to the lines in the Müller-Lyer illusion (Deregowski & Kinnear, 1997).

Cultural learning affects perceptions in other modalities as well. Our perceptions of tastes, odours, and textures are strongly influenced by our cultural experiences. A taste that might produce nausea in one culture may be considered delicious in another. The taste and gritty texture experienced as you chew a large raw insect or the rubbery texture of a fish eye may appeal far less to you than it would to a person from a culture in which that is a staple food.

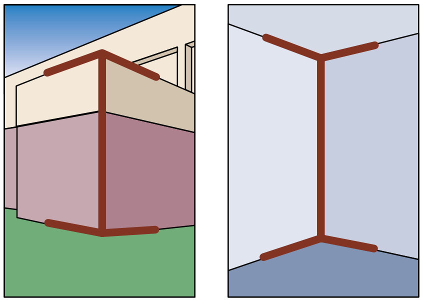


FIGURE 5.46

Perceptual experiences within our "carpentered" environment makes us susceptible to the Müller-Lyer illusion, which appears here in vertical form. Again, the vertical lines are the same physical length.

?

42. How do animal studies of restricted stimulation and human studies of restored vision illustrate the important role of critical periods for perceptual development?

RESEARCH FOUNDATIONS

Critical Periods: The Role of Early Experience

Background

Our discussion of cultural factors in perception suggests that experience is critical to the development of perceptual abilities. For some aspects of perception, there are also **critical periods** during which certain kinds of experiences must occur if perceptual abilities and the brain mechanisms that underlie them are to develop normally. If the critical period passes without the experience occurring, it is too late to undo the deficit that results. How can we find out what the critical period is? Under normal circumstances, young organisms experience the environment into which they are born. Thus, we must arrange for the environmental experience to be absent. This is the basic methodology behind a **deprivation experiment**, such as the one by Blakemore and Cooper (1970) described below.

Method

Recall that the visual cortex has feature detectors composed of neurons that respond only to lines at particular angles. What would happen if newborn animals grew up in a world in which they saw some angles, but not others? British researchers Colin Blakemore and Grahame Cooper (1970) created such a world for newborn kittens. At birth, the kittens were housed in a dark room. At about two weeks of age, the kittens spent five hours each day in specially designed round chambers that had either high contrast vertical or horizontal stripes on the walls. Figure 5.47a shows one of the kittens in a vertically striped chamber. A special collar prevented the kittens from seeing their own bodies while they were in the chamber, guaranteeing that they saw nothing but the stripes. At five months of age, the kittens were no longer exposed to the vertical or horizontal environment. Instead, they spent several hours each week in a well-lit furnished room. The remainder of the time was spent in the dark.

Results

The kittens quickly adapted to this "normal" environment and could easily navigate around the room. However, the kittens seemed to be "blind" to orientations that were perpendicular to the stripes in the special chambers. For example, a kitten raised in the horizontal environment would walk into vertical table legs. The cat would visually track a pencil held in a horizontal position, but showed no interest when the pencil was rotated to vertical. Blakemore and Cooper then proceeded to record from feature detector cells in the visual cortex using bars of light at various orientations as the stimuli. The results for animals raised in the vertical environment are shown in Figure 5.47b. As you can see, these kittens had no cells that fired in response to horizontal stimuli, resulting in visual impairment. As you might expect, the animals raised in the horizontally striped environment showed the opposite effects. They had no feature detectors for ver-

–*Continued*

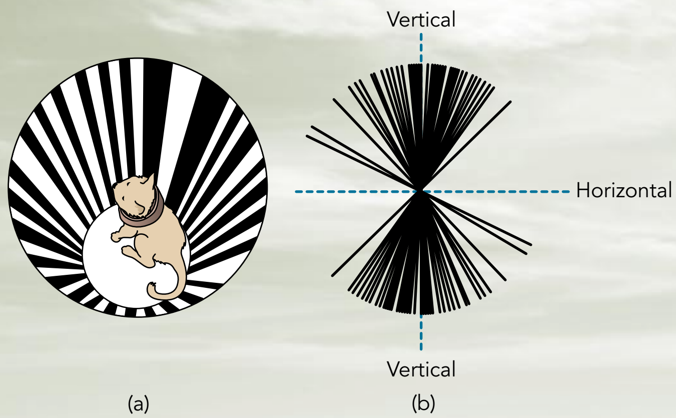


FIGURE 5.47

Kittens raised in a vertically striped chamber such as the one shown in (a) lacked cortical cells that fire in response to horizontal stimuli. The perceptual "holes" are easily seen in (b), which shows the orientation angles that resulted in evoked potentials from feature detectors.

Adapted from Blakemore & Cooper, 1970.

tical stimuli. Thus, the cortical neurons of both groups of kittens developed in accordance with the stimulus features of their environment. Blakemore and Cooper note that almost every cell examined showed this orientation specificity—there were no large areas of inactive cortex. The cells had adapted to their new environment rather than simply degenerating.

Critical Discussion

The type of cortical change found by Blakemore and Cooper seems to be permanent. Using behavioural tests, Muir and Mitchell (1975) have demonstrated that kittens raised in a vertically striped chamber were able to discriminate vertical test patterns as well as kittens raised in a normal environment. However, their ability to "see" horizontal patterns was quite diminished, and showed no improvement whatsoever even after 30 months of exposure to a normal environment. Other cells in the cortex were not able to compensate for the loss.

Should we expect similar findings in humans? Daphne Maurer and her colleagues (e.g., Maurer & Lewis, 2001) have studied a number of children at the Hospital for Sick Children in Toronto who were born with cataracts and, consequently, were deprived of normal visual input. Upon surgical correction, these children were tested for visual acuity (the ability to distinguish patterns, gratings, or letters at various distances). Maurer found that upon correction, visual acuity of the children is about the same as that of newborns. Acuity does improve over time, but some effects of the early deprivation linger (e.g., sensitivity to fine detail). Apparently, the cortices of the children were influenced by the degraded visual input and the cells simply cannot function in the normal way. Maurer notes that the critical period for visual acuity in humans seems to be from about birth until 10 years of age. A child born with cataracts that were not corrected before age 10 would show serious deficiencies in visual acuity.

Some perceptual abilities are influenced more than others by restricted stimulation. For example, monkeys, chimpanzees, and kittens have been raised in an environment devoid of shapes. Such animals distinguish differences in size, brightness, and colour almost as well as normally reared animals do. On the other hand, for the rest of their lives they perform poorly on more complex tasks, such as distinguishing different types of objects and geometric shapes (Riesen, 1965).

Restored Sensory Capacity

Suppose it had been possible to restore Helen Keller's vision when she reached adulthood. What would she have seen? Could she have perceived visually the things that she had learned to identify through her other senses?

Unfortunately, it was not possible to provide Helen Keller with the miracle of restored vision. However, scientists have studied the experiences of other visually impaired people who acquired the ability to see later in life. For example, people born with cataracts grow up in a visual world without form. The clouded lenses of their eyes permit them to perceive light, but not patterns or shapes. One such person was Virgil, who had been almost totally blind since childhood. He read Braille, enjoyed listening to sports on the radio and conversing with other people, and had adjusted quite well to his disability. At the urging of his fiancée, Virgil agreed to undergo surgery to remove his thick cataracts. The day after the surgery, his bandages were removed. Neurologist Oliver Sacks recounts what happened next.

> There was light, there was colour, all mixed up, meaningless, a blur. Then out of the blur came a voice that said, "Well?" Then, and only then . . . did he finally realize that this chaos of light and shadow was a face—and, indeed, the face of his surgeon. . . . His retina and optic nerve were active, transmitting impulses, but his brain could make no sense of them. (Sacks, 1993, p. 62)

Virgil never was able to adjust to his new visual world. He had to touch objects in order to identify them. He had to be led through his own house and quickly would become disoriented if he deviated from his path. Eventually, Virgil lost his sight once again. This time, however, he regarded his blindness as a gift, a release from a sighted world that had become bewildering to him.

Virgil's experiences are characteristic of people who have their vision restored later in life. A German physician, von Senden (1960), compiled data on patients born with cataracts who were tested soon after their cataracts were surgically removed in adulthood. These people were immediately able to perceive figure-ground relations, to scan objects visually, and to follow moving targets with their eyes, indicating that such abilities are innate. However, they could not visually identify objects, such as eating utensils, that were familiar through touch, nor were they able to distinguish simple geometric figures without counting the corners or tracing the figures with their fingers.

After several weeks of training, the patients were able to identify simple objects by sight, but their perceptual constancies were very poor. Often they were unable to recognize the same shape in another colour, even though they could discriminate between colours. Years later, some patients could identify only a few of the faces of people they knew well. Many also had great difficulty judging distances. Apparently, no amount of subsequent experience could make up for their lack of visual experience during the critical period of childhood.

All of these lines of evidence—cross-cultural perceptual differences, animal studies involving visual deprivation, and observations of congenitally impaired people whose vision has been restored—suggest that biological and experiential factors interact in complex ways. Some of our perceptual abilities are at least partially present at birth, but experience plays an important role in their normal development. How innate and experiential factors interact promises to be a continued focus of perception research. Thus perception is very much a biopsychological process whose mysteries are best explored by examining them from biological, psychological, and environmental levels of analysis (see Figure 5.48).

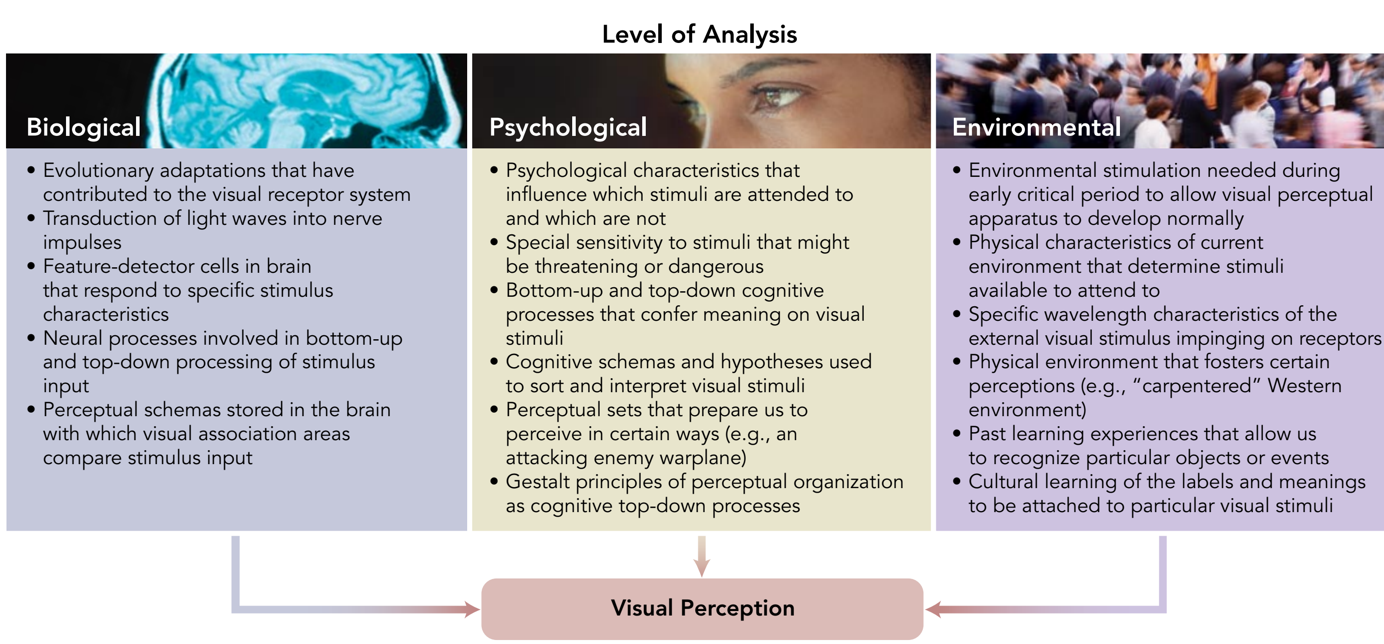


FIGURE 5.48

Understanding Behaviour: biological, psychological, and environmental factors in visual perception.

In Review

- *Perceptual development involves both physical maturation and learning. Some perceptual abilities are innate or develop shortly after birth, whereas others require particular experiences early in life in order to develop.*
- *Cultural factors can influence certain aspects of perception, including picture perception and susceptibility to illusions. However, many aspects of perception seem constant across cultures.*
- *Visual deprivation studies, manipulation of visual input, and studies of restored vision have shown that the normal biological development of the perceptual system depends on certain sensory experiences at early periods of development.*

GAINING DIRECTION

What are the issues?

The opening scenario describes Moncton's "Magnetic Hill." At first it seems that the phenomenon cannot possibly be true. How can cars roll uphill? However, if you've ever visited the site or watched a bus roll uphill on video (check out the link below), you become intrigued. How can this be happening? We know that there are no magnetic or supernatural forces involved, so what gives rise to this perception? There must be something about the geography of the hill or the way we see it that "misleads" our perceptual experience. What are the factors that help us to perceive "up" from "down"? Are these cues available at Magnetic Hill? This scenario deals with image processing, Gestalt rules, and one of the most basic questions regarding perception—how do we construct reality from sensory experience?

http://www.travelvideo.tv/videos/newbrunswick/magnetichillvideo.html

What do we need to know?

How do we separate figure from ground?
What are the Gestalt rules of perception?
How do we perceive depth?
Can our expectations drive perceptual experience?
Can we be "fooled" by erroneous cues in the environment?

Where can you find the information necessary to answer these questions?

A number of the chapter icons point to perceptual processes that influence how we see the world. We need to understand how we construct perception and then locate objects within this perceptual world. So-called magnetic or gravity hills are the result of an optical illusion. Typically, the hill is located in a wooded area where the horizon is obscured. Without access to the horizon, we have to use other cues to determine the lay of the land. Are the trees straight or angled? Does the shading suggest a hill or a valley? What does our sense of balance tell us? As we combine this information, it is likely that we come to believe that we are at the bottom of a hill when, in fact, we are standing at the top of the rise. Thus, a vehicle appears to roll uphill when it actually is rolling downhill. If you were to look at the water in the creek at the side of the road, you would see that it appears to run uphill as well, suggesting that the slope is not as you perceive it.

KEY TERMS AND CONCEPTS*

absolute threshold (171)
amplitude (184)
basilar membrane (185)
binocular cues (201)
binocular disparity (202)
bipolar cells (178)
bottom-up processing (195)
cochlea (185)
conduction deafness (188)
cones (178)
convergence (202)
critical periods (209)
dark adaptation (179)
decibels (db) (184)
decision criterion (172)
deprivation experiment (209)
difference threshold (174)
dual-process theory (181)
feature detectors (183)
figure-ground relations (197)
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frequency theory (187)
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visual acuity (178)
visual association cortex (183)
Weber's law (174)

*Each term has been boldfaced in the text on the page indicated in parentheses.

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For additional resources and interactive quizzing, visit the book's Online Learning Centre at **www.mcgrawhill.ca/olc/passer**.