CHAPTER

12

Sensory Reception

Chapter Concepts

12.1 Sensory Receptors and Sensation

- Sensory reception occurs at the senses. Sensation and perception occur in the brain.
- Various sensory receptors detect information in the internal and external environments.

12.2 Photoreception

- The human eye is similar to a camera. It contains a lens that focusses light, a pupil that lets in light, and a dark interior that contains light receptors.
- The retina contains rods and cones. Rods function in dim light and produce black and white images. Cones function in bright light and produce colour images.

12.3 Mechanoreception and Chemoreception

- The outer ear and middle ear transmit the energy of sound waves to the inner ear.
- The inner ear contains mechanoreceptors for hearing and balance.
- Tastes are detected by chemoreceptors in the taste buds of the tongue. Smells are detected by chemoreceptors in the nose.
- The skin contains receptors for light touch, pressure, pain, heat, and cold.

The woman meditating is trying to ignore all sights, sounds, and other sensory input from the outside world. It is a difficult task. Some people prefer the experience of relaxing inside a sensory deprivation tank for an hour or so. Many people find this experience relaxing for a short period of time—usually about an hour or so. If the brain is deprived of sensory information for an extended period of time, however, extreme anxiety, hallucinations, depression, memory loss, and antisocial behaviour can result. People who are in solitary confinement sometimes experience these effects, as do people who are confined to bed in hospital isolation wards. Why does sensory deprivation confuse the brain and upset homeostasis in the body? As you will discover in this chapter, the senses function together to allow the human body to detect and adjust to changes in the body and in the external environment.

Launch Lab

Sense It

When one or more of the senses are inhibited, the brain's perception of the environment can change. Identifying even familiar objects can become difficult. In this activity, you will try to identify familiar objects while one or more of your senses is inhibited.

Safety Precautions

- Do not bring food meant for consumption into the laboratory.
- Do not taste any sample (you will use only the senses of touch and smell in this exercise).
- Before the exercise begins, alert your teacher to any allergies you have.

Materials

- new earplugs
- blindfold
- samples of unidentified but familiar objects supplied by your teacher

Procedure

1. Work with a partner. One partner will be the tester, and the other partner will be the subject.
2. The subject will use earplugs and a blindfold to block the senses of hearing and sight.
3. The tester will acquire samples of the unknowns provided by the teacher.
4. Now, with the subject gently pinching his or her nose shut to block the sense of smell, the tester will provide the first sample for the subject to hold.
5. The subject should use the sense of touch to identify the unknown sample, and then the subject should use the sense of smell if the sample remains unknown. The tester should record how and if the subject is able to identify the sample.
6. Repeat steps 4 and 5 using the other samples. Then switch roles, and repeat the activity with another set of samples.

Analysis

1. Which samples were the most difficult to identify? Which samples were the easiest to identify?
2. Which senses would you normally use to identify the samples?
3. You probably found it easier to identify the samples using a number of senses, rather than only one. Which senses would you use to
   a) check if milk is sour
   b) remove stones from a bag of dry lentils
   c) stand on one leg without falling over
4. Explain why integration is important for interpreting sensory information.

SECTION 12.1

Sensory Receptors and Sensation

Section Outcomes

In this section, you will
- **explain** the difference between sensory reception, sensation, and perception
- **describe** the process of sensory adaptation
- **distinguish** among the major sensory receptors in the human body

Key Terms

sensory receptors
sensation
perception
sensory adaptation
photoreceptors
chemoreceptors
mechanoreceptors
thermoreceptors

Figure 12.1 What information would your senses detect if you were standing in this scene? How would this information help your body maintain homeostasis?

Imagine yourself in the fairgrounds shown in Figure 12.1. What sensory information would your nervous system be gathering? What would you see, hear, and smell? What foods would you taste? How would a light breeze feel on your skin? Your senses of sight, hearing, taste, smell, and touch keep you informed about the world around you, and allow your body to respond to your external environment. Internal sensors, such as those that regulate blood pH, blood pressure, and blood volume, also help your body maintain homeostasis.

The senses transmit sensory information, in the form of electrochemical impulses, to the brain. Different forms of energy stimulate the **sensory receptors**—the nerve endings and cells that detect sensory information. The sensory receptors then initiate neural impulses. **Sensation** occurs when the neural impulses arrive at the cerebral cortex. For example, your face may detect the warmth of a beam of sunlight. When the brain receives and processes this information, you will feel, or experience, the sensation of warmth on your cheek. The resulting sensation depends on the area of the brain that has interpreted this information.

Neural impulses that begin in the optic nerve are sent to the visual areas of the cerebral cortex, and we see objects (Figure 12.2). Neural impulses that begin in the auditory nerve of the ear are sent to the area of the brain that perceives sound, and we hear sounds. Each person's unique **perception** results from how the cerebral cortex interprets the meaning of the sensory information.

1. Compare sensory reception and sensation. Provide an example of each.
2. Each type of sensory receptor functions by initiating neural impulses. How is the brain able to convert sensory information into perception?

Sensory Adaptation

A massive amount of sensory information, coming from many neural pathways, bombards the brain every second. Sometimes, the brain can filter out

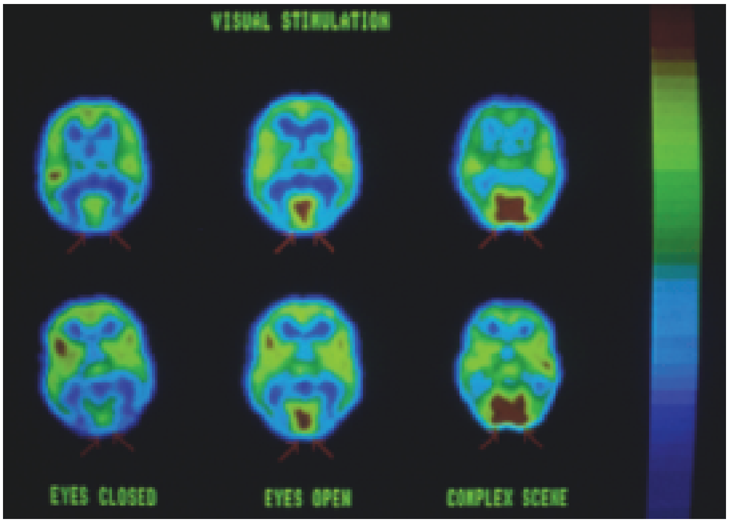

Figure 12.2 A PET scan of the human brain showing brain activity in a volunteer at different stages of stimulation. The orange-red colour indicates that the brain is active and perception is taking place. In the last two columns, the visual area at the back of the brain is activated and the perception of sight is occurring. In the first column, the subject's eyes are closed. Thus neural information is not getting from the senses to the brain, and there is no perception of sight.

redundant, insignificant information. This process is called **sensory adaptation**. For example, sensory adaptation has occurred when you no longer notice the ticking of a clock or feel the clothes on your skin. When the senses detect a significant change in external or internal conditions, the body readjusts (Figure 12.3).

In order to process sensory information quickly, the brain *parallels* or splits up this input to various areas of the brain—a form of neural multi-tasking. Sometimes the sensory information does not get reintegrated precisely, and what we sense is not necessarily what we perceive. This effect can be demonstrated with optical illusions, which scientists use to try to understand how the brain perceives sensory information. Use the illusions in Figure 12.4 on page 408 to determine the difference between the sensory information received and what your brain actually perceives.

3. Describe an example of sensory adaptation, and explain why it occurs.

4. What happens during integration that causes people to perceive optical illusions?

Sensory Receptors

Sensory receptors are specialized cells or neuron endings that detect specific stimuli. Human sensory receptors can

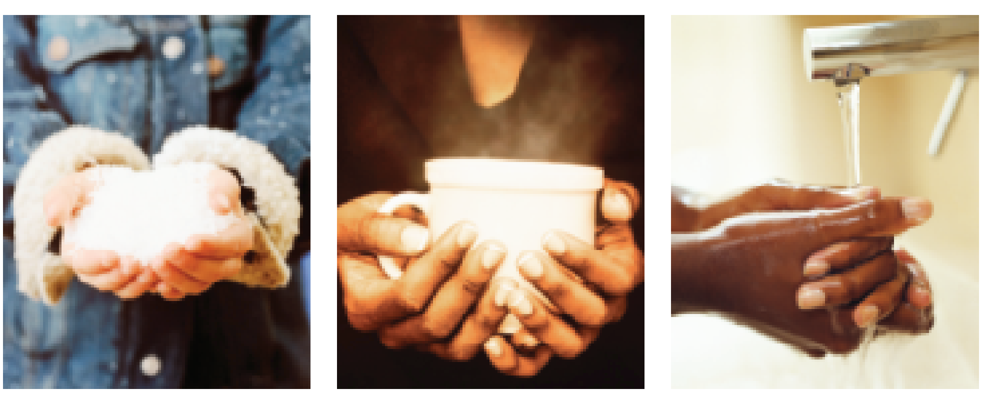

Figure 12.3 When you wash your hands in tepid water after being outside in the cold, the water may feel very hot. In contrast, you may perceive the tepid water as chilly after holding a warm cup of tea. You can duplicate this phenomenon by placing your right hand in a cup of warm water and your left hand in a cup of cold water for 1 min. Then put both hands in room-temperature water. What has happened to your perception of temperature, and why?

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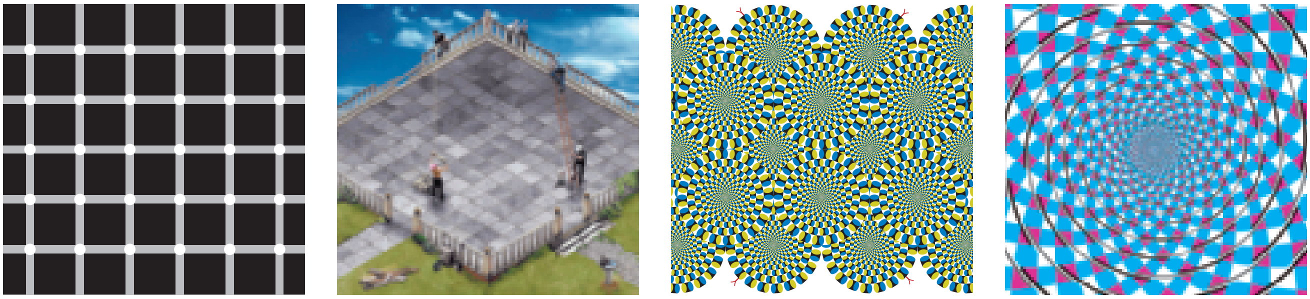
FYI

Can an octopus experience pain and suffering? Most likely, say neuroscientists, which is why these common research animals need to be treated humanely and given behavioural enrichment. Support for this idea has come from experiments conducted by octopus expert Jennifer Mather, professor of psychology at the University of Lethbridge, and Roland Andersen of the Seattle Aquarium. The researchers gave empty plastic pill bottles to eight octopuses, who played with the pill bottles. This was the first time play had been observed in invertebrates.



A Herman's Grid. When you look at the centre of the large square, the dots in the middle should look white, and the dots you see out of the corners of your eye should look black.

B The Impossible Terrace, by D. MacDonald. Is down up, or is up down?

C Kitaoka's Rotating Snakes. Look at these circles from off centre. Do you think they are actually spinning?

D Fraser's Spiral. Try to follow the spiral into the centre.

Figure 12.4 These diagrams produce various optical illusions.

be classified into four categories: photoreceptors, chemoreceptors, mechanoreceptors, and thermoreceptors (Table 12.1). Each type of receptor is able to transduce, or convert, one form of energy from a specific stimulus into electrochemical energy, which can be processed by the nervous system.

Light energy stimulates **photoreceptors**. Our eyes contain photoreceptors, called rods and cones, that absorb light and allow us to sense different levels of light and shades of colour. **Chemoreceptors** are stimulated by certain chemicals. The tongue contains taste buds that detect various particles in the food we eat. The nose has olfactory cells that detect odours in the air. Other chemoreceptors detect changes in the internal environment. For example, chemoreceptors in the carotid arteries and aorta detect blood pH. **Mechanoreceptors** respond to mechanical forces from some form of pressure. For example, hair cells in the inner ear (hearing sensors) are activated when sound waves cause parts of the inner ear to vibrate. Other hair cells in the inner ear (sensors for balance) are stimulated when they bend, thus providing information about body and head position. Proprioceptors in and near the muscles also provide information about body position, as well as movement. There are various mechanoreceptors in the skin, which allow the body to detect light touch, pressure, and even pain. **Thermoreceptors** in the skin detect heat and cold.

Damage to particular sensory receptors such as photoreceptors can result in loss of the associated sense, even if the rest of the sense organ and nervous system are fully functional. Hundreds of thousands of Canadians have lost their sight due to eye injuries or degenerative eye disorders, such as retinitis pigmentosa and age-related degeneration of the photoreceptors. A newly developed artificial eye, however, offers hope to these people. The artificial eye includes a digital video camera that is mounted on glasses. The camera captures images and sends them to a small computer on a belt worn by a person who is visually impaired. The images are processed and sent to several electrodes that are implanted in the visual cortex, thus bypassing the damaged light receptors in the eye. The electrodes directly stimulate the brain, producing a pattern of bright

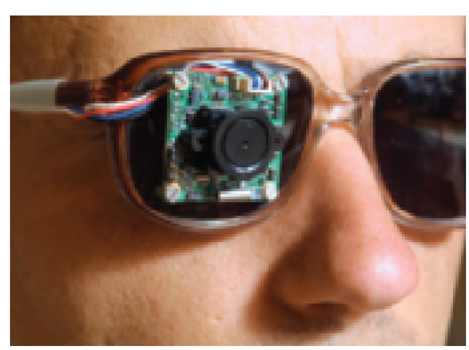


Figure 12.5 The artificial eye sends electrical impulses that directly stimulate the visual cortex of the brain. This man became blind in an accident over 20 years ago. He can now distinguish large letters and several objects, and he has even driven a car around a parking lot.

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Web Link
Retinitis pigmentosa includes several inherited diseases that cause the photoreceptor cells (rods and cones) in the retina to degenerate and die. Dr. Paul Schnetkamp at the University of Calgary is one of the scientists studying this disorder, which affects an estimated 50 000 Canadians. What is the current state of understanding and treatment of retinitis pigmentosa?

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Table 12.1 Major Sensory Receptors in the Human Body

Category and type of receptor	Examples of receptor	Stimulus
Photoreceptors		
vision	rods and cones in the eye	visible light
Chemoreceptors		
taste	taste buds on the tongue	food particles in saliva
smell	olfactory receptors in the nose	odour molecules
internal senses	osmoreceptors in the hypothalamus	low blood volume
	receptors in the carotid artery and aorta	blood pH
Mechanoreceptors		
touch/pressure/pain	receptors in the skin	mechanical pressure
hearing	hair cells in the inner ear	sound waves
balance	hair cells in the inner ear	fluid movement
body position	proprioceptors in the muscles and tendons, and at the joints	muscle contraction, stretching, and movement
Thermoreceptors		
temperature	heat and cold receptors in the skin	change in radiant energy

spots that the visual cortex perceives as a crude image. Currently, the resolution of this device is poor—about five pixels per square centimetre—but it allows users to distinguish objects with high contrast. Researchers predict that future developments will improve the device enough to restore vision completely, or perhaps to enhance vision beyond natural human capabilities.

Q5 Identify five major senses and their corresponding sensory receptors.

Q6 List three types of internal sensory receptors and their functions.

Section 12.1 Summary

- The senses are the human brain's connection to the outside world.
- Sensation is initiated in the senses through sensory reception, but sensation and perception take place in the brain.
- Everyone's perception of the world is unique.
- Sensory receptors convert different forms of energy into electrochemical energy, which the nervous system can interpret.

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Web Link

What would happen if your optic and auditory nerves were switched? How would you perceive a flash of lightening or crash of thunder? Researchers at the University of Waterloo in Ontario, Canada, are studying what happens when senses blend, a condition called synesthesia. Visit the Web Links page to find out what some people with synesthesia experience.

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Section 12.1 Review

1. State the form of energy that stimulates

a) thermoreceptors **b)** photoreceptors

2. What types of sensory receptors are stimulated in someone who is performing a complicated yoga pose?

3. Crime-scene investigators are often frustrated by different eyewitness accounts of the same crime. With your knowledge of sensation and perception, explain how different people's perceptions of the same sensory information can be different.

4. When you put on your new winter boots one morning, you cannot help noticing how different they feel from your summer shoes. By the time you reach school, however, you have forgotten about your boots. Why does your perception of the way your boots feel change?

5. Describe, in general terms, what happens in the nervous system when someone receives a large amount of significant sensory information, such as when viewing an optical illusion.

SECTION 12.2

Photoreception

Section Outcomes

In this section, you will
- **describe** the principal structures of the human eye and their functions
- **observe** the principal features of the mammalian eye and **perform** experiments that demonstrate the functions of the human eye
- **describe** several eye disorders and treatments

Key Terms

sclera
cornea
choroid
iris
pupil
adaptation
retina
rods
cones
optic nerve
aqueous humour
glaucoma
vitreous humour
lens
accommodation
cataracts
astigmatism
myopia
hyperopia
fovea centralis
colour blindness
blind spot

BiologyFile

Web Link
Some Canadian companies are using biometrics technology to verify that you are who you say you are. What is biometrics, and what advantages and disadvantages are associated with it?

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Figure 12.6 The human sense of sight can tell us more about the world than any other sense can. How does the human eye detect the colour, contrast, depth, and three-dimensional shapes of this landscape?

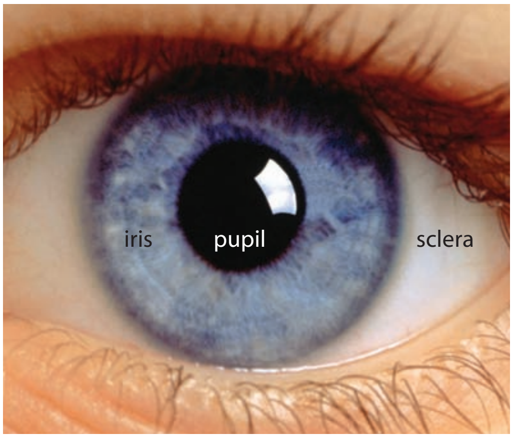
Scientists estimate that, in sighted people (people who can see), vision supplies 80 to 90 percent of the important sensory information reaching the brain. The incredible variety of colours and shapes and the range of distance depicted in the landscape shown in Figure 12.6 would be difficult to conceive of without the sense of sight. How does the human eye carry out its varied functions?

The human eye is essentially a fluid-filled hollow ball, about 2.5 cm in diameter. It focusses incoming light energy on the photoreceptors of the retina. As shown in Figure 12.7, the eye has three layers: external, intermediate, and internal. The external layer of the eye is a white, tough, and fibrous protective layer called the **sclera**. Light enters the eye through the **cornea**, the transparent part of the sclera at the front of the eye.

The intermediate layer of the eye is called the **choroid**. The choroid absorbs stray light rays that are not detected by the photoreceptors. As well, the choroid contains blood vessels that nourish the eye. Toward the front, the choroid forms the doughnut-shaped, coloured **iris**, which contains a central dark **pupil**. Like fingerprints, the pattern of colour in the iris is unique to each person. Thus, an iris scan could potentially be used for personal identification.

The iris allows light to enter the inner eye through the pupil. As shown in Figure 12.8, the iris adjusts the size of the pupil based on the light conditions—a process called **adaptation**. You can observe adaptation in your own eyes by turning off the lights for 1 min and holding a mirror in front of your face. When you turn the lights back on, you can see your pupils shrink, which allows less light to enter your eyes.

Behind the iris, the choroid thickens and forms the ciliary muscle. The ciliary muscle attaches to the lens, which focusses images on the retina. The **retina** is the internal layer of the eye. It is a thin layer of tissue that contains the photoreceptors—the rods and cones. The **rods** are sensitive to light intensity (level of brightness), and the **cones** are sensitive to different colours. The cones are packed most densely at the back of the eye in an area called the fovea centralis. The rods and cones send sensory impulses to the brain via the **optic nerve**.



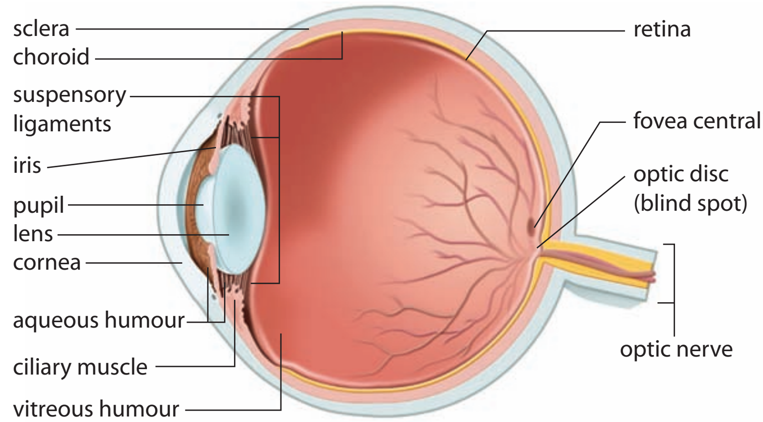


Figure 12.7 The anatomy of the human eye

If there were no fluid inside the eyeball, it would lose its shape, like an empty water balloon. The lens, which is attached to the ciliary muscles by suspensory ligaments, divides the eye into two chambers. The anterior chamber is in front of the lens, and the posterior chamber is behind the lens. In the anterior chamber, a clear, watery fluid called the **aqueous humour** maintains the shape of the cornea and provides oxygen and nutrients for the surrounding cells, including those of the lens and cornea. A small amount of aqueous humour is produced every day and drained by small ducts. If these ducts become plugged, pressure can build up in the eye, causing the delicate blood vessels in the eye to rupture. The cells of the eye then deteriorate, due to a lack of oxygen and nutrients. This results in **glaucoma**, which leads to blindness if untreated.

The posterior chamber, which is surrounded by the retina, contains a clear, jelly-like fluid called the **vitreous humour**. The vitreous humour also helps to maintain the shape of the eyeball, and it supports the surrounding cells.

The structures of the human eye, and their functions, are summarized in Table 12.2.

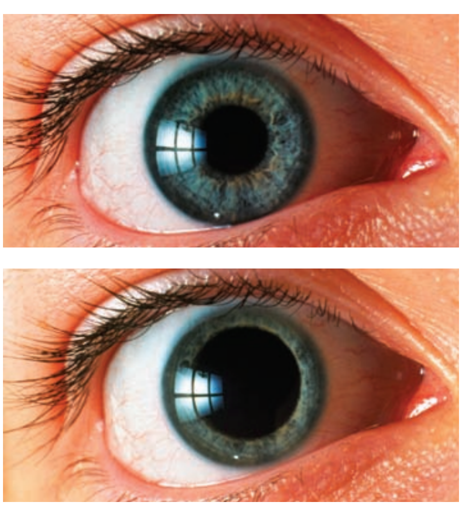


Figure 12.8 Light adaptation in the eye. In bright light, the iris constricts, which shrinks the pupil to let in less light. In dim light, the iris dilates, which widens the pupil and lets in more light.

Table 12.2 The Principal Structures of the Human Eye and Their Functions

Structure	Function
External layer (Sclera)	
sides and back of sclera	protects and supports the eyeball
cornea	bends light rays into the eye
Intermediate layer (Choroid)	
sides and back of choroid	absorbs scattered light and contains blood vessels
iris	regulates the amount of light that enters the eye
pupil	is the opening for light to enter the inner eye
ciliary muscles	changes the shape of the lens in order to focus
Internal layer (Retina)	
rods	photoreceptors that are sensitive to dim light
cones	photoreceptors that are sensitive to different wavelengths of light (colour vision)
fovea centralis	contains a high density of cones, and provides acute vision
Other	
lens	focusses light rays onto the fovea centralis
humours	support the eyeball, with the pressure of the fluids they contain
optic nerve	transmits sensory information to the brain

> 7 Draw a cross section of an eye in your notebook. Identify the key structures and their functions.
>
> 8 How do the eyes adjust to changing light intensities? Name this process.
>
> 9 How does glaucoma occur, and how can it cause blindness?

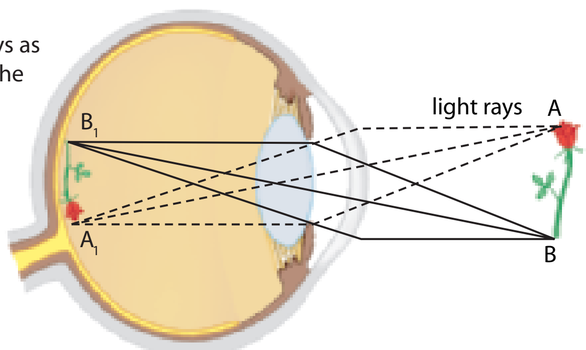
Focussing

How do eyeglasses and contact lenses help people see? How do the lenses in cameras and microscopes work? If you could closely examine any artificial lens, you would find that light rays bend as they pass through the lens. In other words, the lens focusses the light in a particular direction. The lens of the eye focusses incoming light in a similar way. Eyeglasses and contact lenses make up for imperfections in the eyes that prevent them from focussing clearly.

Figure 12.9 shows what happens when the eye brings an image into focus. Light rays are bent as they pass through the rigid cornea, flexible lens, and fluid humours. Notice that, compared with the object being viewed, the image fixed on the fovea centralis of the retina is smaller, upside down, and reversed from left to right.

Because the **lens** is flexible, it can change shape. This allows for finer focus when viewing objects, whether they are nearby or far away. As shown in Figure 12.10, if an object is far away, the ciliary muscles relax and the suspensory ligaments become taut, causing the lens to flatten. If an object is nearby, the ciliary muscles contract and the suspensory ligaments relax, causing the lens to become more rounded. Similarly, a nondigital camera focusses by changing the distance between the lens and the film. The ability of the lens to change shape in order to focus images clearly on the retina is a reflex called **accommodation**. If you read your textbook up close for an extended period of time, the ongoing contraction of your ciliary muscles will likely cause muscle fatigue, which you will experience as eyestrain.

Figure 12.9 What happens to light rays as they pass through the cornea and lens?



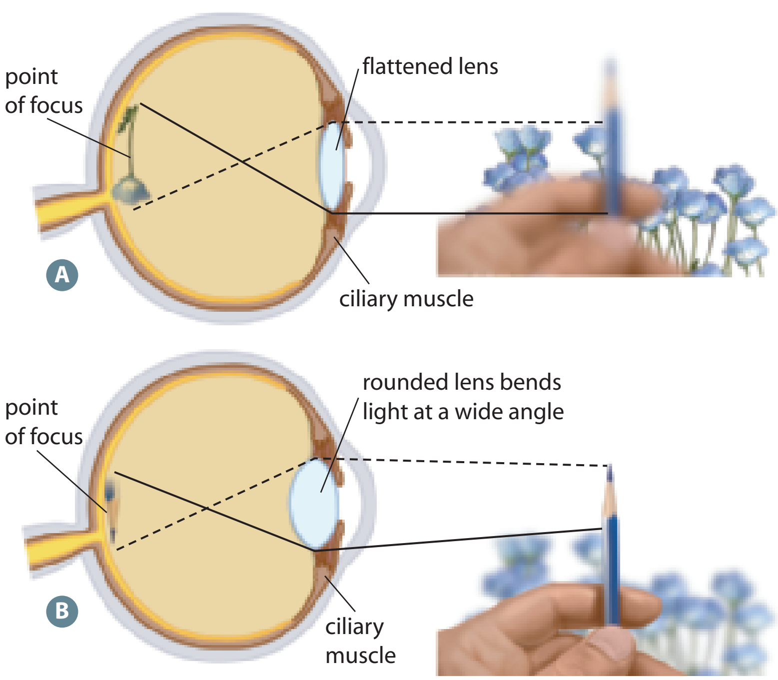
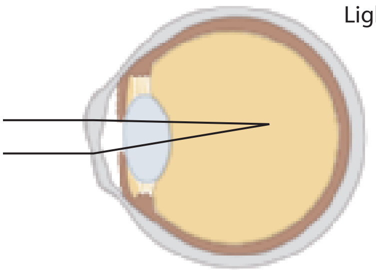


Figure 12.10 Accommodation. **(A)** What happens to the shape of the lens when the eye is focussed on a distant object? **(B)** What happens when the eye is focussed on a nearby object? Note that the ability of the lens to bend light is exaggerated in this diagram. In reality, the cornea also bends light.

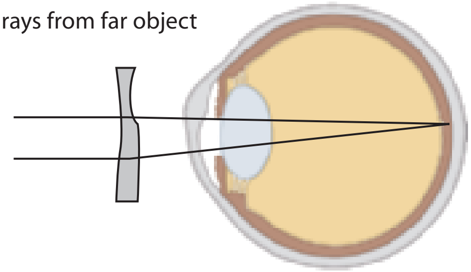
Conditions Affecting the Cornea and Lens

As the lens ages, its protein structure can start to degenerate, making it opaque and preventing light from passing through it. This condition can cause grey-white spots, called **cataracts**, on the lens. To prevent cataracts from impairing vision, the lens can sometimes be surgically replaced.

Inherited conditions that affect the eye's ability to focus light directly



A The off-centre bending of light rays by an uneven cornea



B Unevenly ground glasses or contact lenses can correct for astigmatism

C A test for astigmatism. If any of the dark lines in the diagram seem darker than the others, you could have an asymmetrical cornea

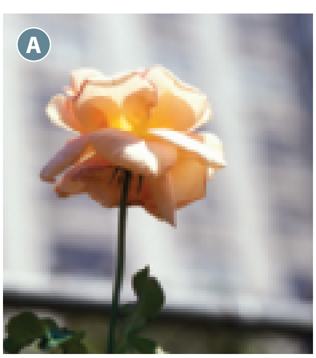
Figure 12.11 Astigmatism and how it can be corrected

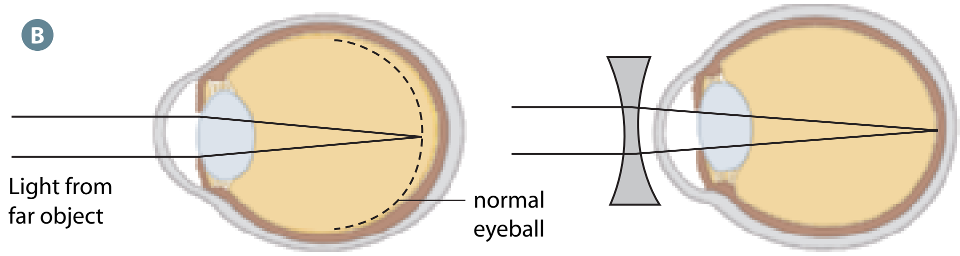
on the fovea centralis are common. **Astigmatism**, for example, is due to an uneven curvature of part of the cornea. Because the cornea is asymmetrical, it cannot bend light rays so that they meet at the correct focal point (Figure 12.11). As a result, vision is blurred.

When young, most people can clearly see a size 20 letter on an eye chart from a distance of 20 feet (about 6.1 m). This is referred to as 20/20 vision. People who have no difficulty seeing close objects but cannot see a size 20 letter from 20 feet are nearsighted. They have a condition called **myopia**. As shown in Figure 12.12, the eyeball of people with myopia is elongated, so the focussed light falls *in front* of the retina instead of on the photoreceptors. To see distant objects, nearsighted people can wear concave lenses, which diverge incoming light rays so that the image falls directly on the retina. An alternative to wearing corrective lenses is corrective laser surgery. In this procedure, an ophthalmologist (eye doctor) uses a laser to cut and reshape the cornea so that it will focus light onto the retina.

Another common condition is **hyperopia**. People with this condition are farsighted, which means they can see clearly from 20 feet, but cannot focus on nearby objects because the eyeball is too short. The light rays do not meet before they reach the retina, so the image is focussed *behind* the retina. Convex lenses can correct hyperopia by bending light rays at a sharper angle.

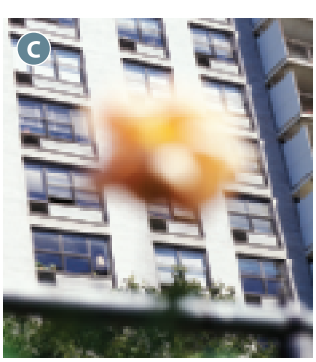
Figure 12.12 **(A)** Image seen by someone who is nearsighted. Which object is most in focus? **(B)** Myopia. Where does the image fall in the eye? **(C)** Image seen by someone who is farsighted. **(D)** Hyperopia. Where does the image fall?

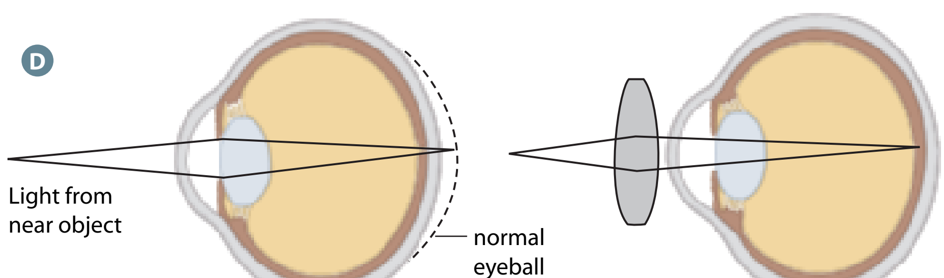




Long eyeball; rays focus in front of the retina when viewing distant objects

Concave lens allows subject to see distant objects





Short eyeball; rays focus behind the retina when viewing close objects

Convex lens allows subject to see close objects

BiologyFile

FYI

There are about 150 000 cones per square millimetre in the fovea centralis of the human retina. In some predatory birds, however, the fovea centralis has over 1 000 000 cones per square millimeter. Thus, a falcon can see a mouse that is 10 cm long from 1.5 km away. The image stays sharp even when the bird dives at over 160 km/h.

10 Describe the functions of the cornea and lens of the eye.

11 What causes astigmatism, myopia, and hyperopia?

12 Compare adaptation with accommodation. Give an example of each.

The Photoreceptors: The Rods and Cones

Vision begins as light is focussed on the light-receiving cells, or photoreceptors. The human retina contains about 125 million rods and 6 million cones, which account for at least 70 percent of all sensory receptors in the human body.

The rods are extremely sensitive to light. In fact, a rod can be stimulated by a single photon of light. The rods do not enable us to distinguish colours, however, just degrees of black and white. This is why it is difficult to detect any colours in a dark room, although you may be able to see the shapes of the furniture. Rods also detect motion and are responsible for peripheral vision. In the human eye, the rods are spread throughout the retina, but are more concentrated in the outside edges.

The cones are the colour-detecting sensors of the eye. They are packed most densely at the **fovea centralis** (see Figure 12.13) at the back and centre of the retina. You may have noticed that your peripheral vision lacks colour. This is due to the central location of the fovea centralis. The cones require relatively intense light to stimulate them. Thus, the structures of the eye must focus light onto the fovea centralis in order to produce a sharp image. In daylight, you can see best (your eyes produce the sharpest image) if you look at an object straight on. In addition to allowing us to see "in colour," the cones allow us to perform high-acuity tasks, such as reading.

There are three types of cones, and each type absorbs a different wavelength of light. The combination of cones that can detect red, blue, and green wavelengths of light allows us to see a range of colours. **Colour blindness** is an inherited condition that occurs more frequently in males than in females. (You will discover why in Unit 7.) Colour blindness is actually colour *deficiency*, because it is caused by a lack or deficiency in particular cones, usually red and green cones. Thus, a red-green colour-blind person may find it difficult or impossible to distinguish between these colours. If you have a full range of colour vision, you should be able to see a number 8 in Figure 12.14. If you have red-green colour blindness, due to a lack of red cones, you will see a number 3.

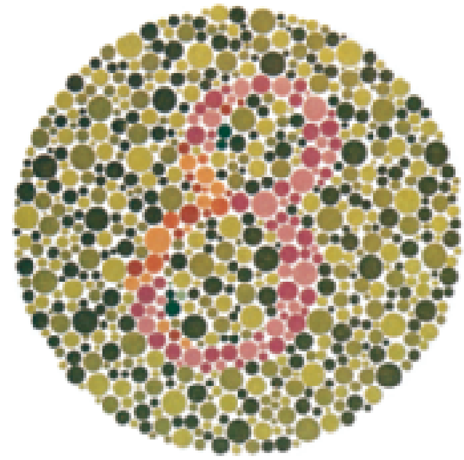
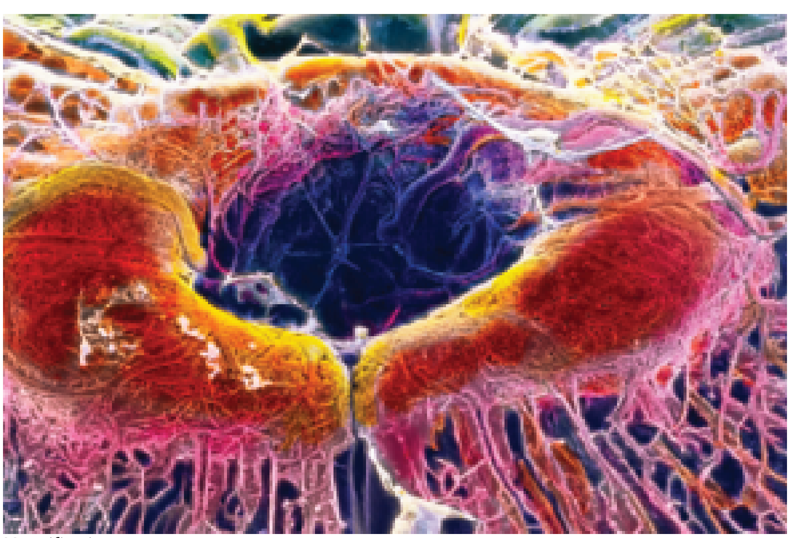


Figure 12.14 Check your colour vision by studying this colour blindness chart. Can you see the number 8?



Magnification: 26.4 ×

Figure 12.13 An electron micrograph of the fovea centralis. The fovea centralis has been called "the most valuable square millimetre in the human body." This part of the eye is densely packed with cones, which detect colours.

How do the photoreceptors relay visual information to the brain? Figure 12.15 shows the structure of the rods and cones. The rods contain a light-absorbing pigment called rhodopsin, which is composed of retinal (a vitamin A derivative) and the protein opsin. In the dark, the rods release an inhibitory neurotransmitter that inhibits nearby nerve cells. When the rods absorb light, however, the rhodopsin splits into retinal and opsin. This triggers a chain reaction that *stops* the release of the inhibitory neurotransmitter, thus *allowing* transmission of a neural impulse to the optic nerve. A similar process occurs in the cones except the pigment is photopsin, which reacts only to certain wavelengths of light.

Figure 12.16 shows the three main layers of neurons in the retina. The layer that is closest to the choroid contains the rods and cones, which synapse with the bipolar cells in the middle layer. When light stimulates the rods and cones, they stop releasing an inhibitory neurotransmitter into the synapse. The bipolar cells then transfer a neural impulse to the ganglion cells, which are in the layer closest to the vitreous humour. The axons of the ganglion cells form the optic nerve. Optic nerve fibres that emerge from the back of the eye transmit visual images to the occipetal lobe of the brain.

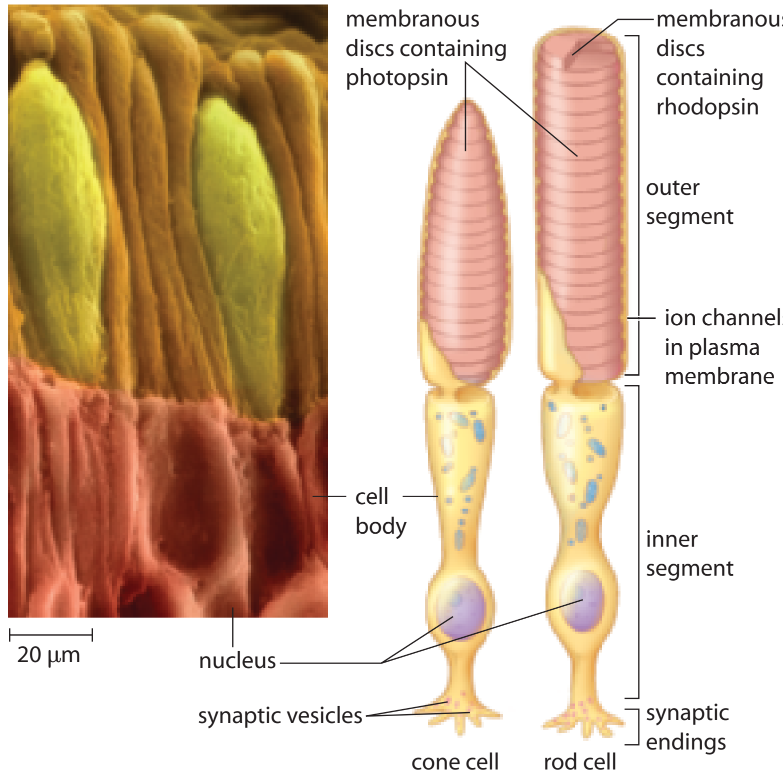


Figure 12.15 The rods and cones of the retina. When light strikes the cells, molecules in the membranous discs change shape. This triggers a cascade of reactions, which allow a nerve impulse to be sent to the optic nerve.

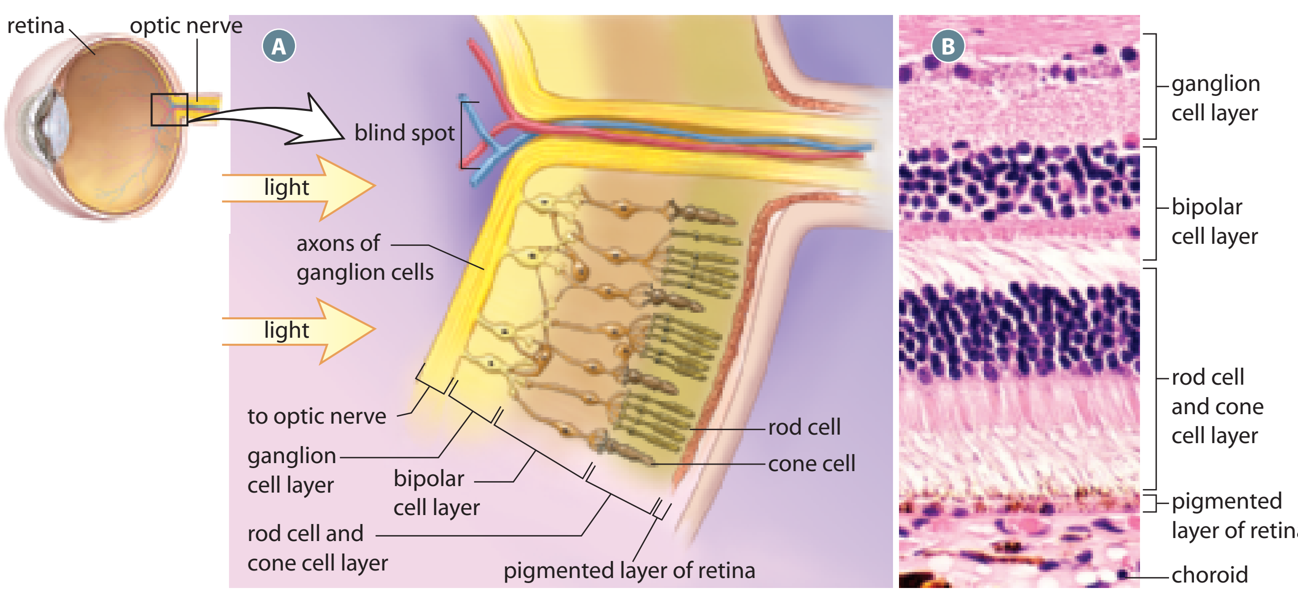


Figure 12.16 **(A)** The organization of the principal cells of the retina. Once stimulated, the rods and cones permit a neural impulse to pass through the bipolar cells to the ganglion cells, which form the optic nerve. **(B)** A light micrograph of the layers of the retina. The outer layer of the retina, called the pigmented layer, does not contain rods or cones. The pigmented layer stores vitamin A and prevents light from scattering in the eye.

Figure 12.17 Can you detect your blind spot? Hold the textbook about 30 cm from your eyes. Close your right eye and look at the black cross with your left eye. Slowly move your left eye toward this figure. The dot on the left will disappear when its image falls on the blind spot in your left eye.

13 Compare the locations and functions of the two photoreceptors found in the eye.

14 What is the direct cause of red-green colour blindness?

15 How does visual information get from the retina to the brain? List the main steps in this process.

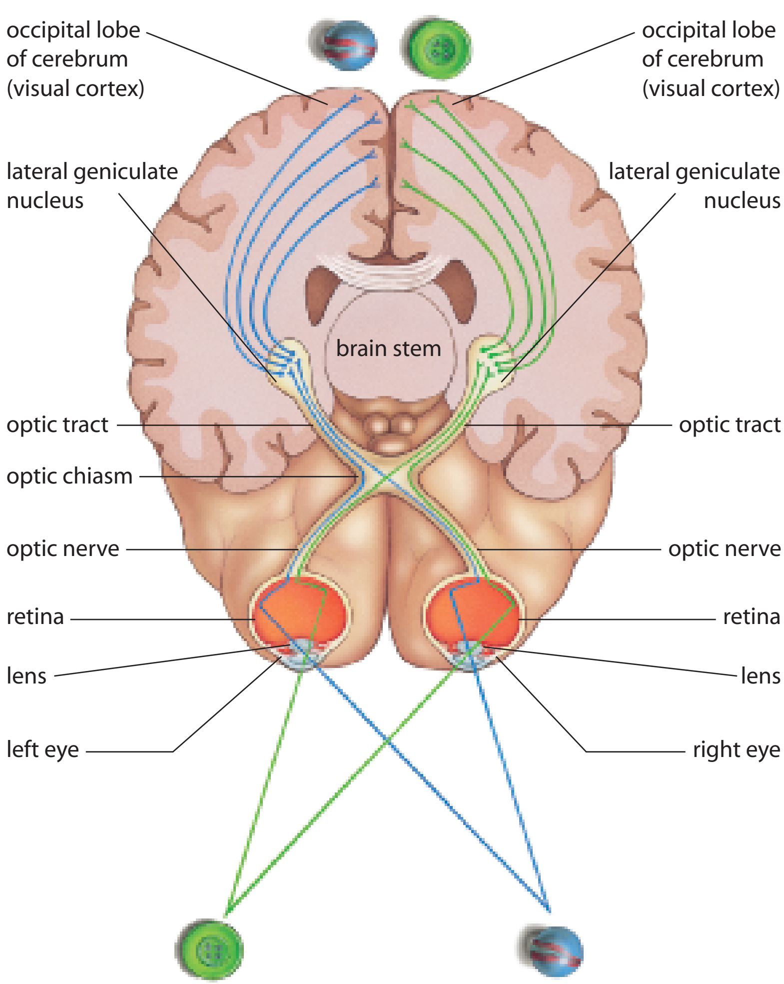


Figure 12.18 The neural pathway of the optic nerve from the retina to the occipital lobe. Data from the right half of each retina go to the right side of the occipital lobe, and data from the left half of each retina go to the left side of the occipital lobe. Integration of the image occurs in the brain.

Visual Interpretation

Figure 12.16 on the previous page shows where the ganglion cells merge to form the optic nerve. This area, called the **blind spot**, does not contain photoreceptors and is therefore incapable of detecting light. Use the illustration in Figure 12.17 to find the blind spot in each of your eyes. Usually you do not notice your blind spots because each eye compensates for the visual information that the other eye misses.

Before the brain can integrate visual information from both eyes, however, the retina must send information to the optic nerve. From there, the information travels to the thalamus and then to the occipital lobe of the cerebral cortex for interpretation (Figure 12.18). The image is split in the occipital lobe because the left optic tract carries information about the right portion of the visual field, and the right optic tract carries information about the left visual field. The eyes look at an object from different positions, so each neuron carries a slightly different view of the information to the brain. In the cerebrum, the various pieces of visual information are processed and integrated, and the image is perceived right-side up. Because humans (and other primates) have forward-facing eyes, we have what is called *binocular vision*. This means we use both eyes to look at and collect visual information about an object. This enables the brain to perceive depth and three-dimensional images.

The various aspects of sight, such as movement, colour, depth, and shape, appear to be handled simultaneously by different areas of the occipital lobe. This speeds up processing, which is important because the brain must constantly receive visual information in order to see.

16 What is the blind spot in the eye?

17 What aspects of vision are integrated in the human brain so that we can see?

INVESTIGATION 12.A

Target Skills

Observing and **describing** the major structures of the mammalian eye

Dissection of an Eye

The human eye and cow eye are very similar in structure and function. In this investigation, you will examine diagrams of a dissected cow eye and dissect a real cow eye to gain a better understanding of how the structures of the eye relate to their functions. As an alternative to doing the dissection, you can use only the diagrams or examine an online dissection of a mammalian eye.

Question

How do the structures of a cow eye relate to their functions?

Safety Precautions

- Handle sharp instruments with care.
- Wash your hands well when you are finished.
- Disinfect the dissection equipment and area with 10 percent bleach solution when you have finished.

Materials

- preserved cow eye
- paper towel
- safety goggles
- 10 percent bleach solution
- apron
- dissecting tray
- dissecting kit

Procedure

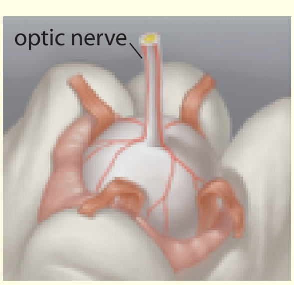
1. Put on safety goggles, gloves, and an apron. Rinse off the cow eye, and place it on the dissecting tray.
2. Examine and locate the fat, muscles, and optic nerve on the back of the eye.
3. Remove as much of the outer fat as possible. Then use the scalpel to cut the eye in half. Cut in a circle, about halfway between the cornea and the optic nerve, as shown in the diagram. Do not put too much pressure on the eye; apply light slicing cuts until you penetrate the eye.
4. Use the diagrams and Figures 12.7 and 12.16, to help you identify the structures of the eye. Examine the posterior (rear) chamber of the eye. Notice the clear, jelly-like vitreous humour, which fills this chamber. Identify the tough, white sclera (external layer), the black choroid (intermediate layer), and the thin retina (internal layer). Follow the converging blood vessels to locate the area where the retina is attached to the back of the eyeball at the blind spot. Identify the fovea centralis in the middle of the retina.
5. Examine the anterior (front) chamber of the eye. Identify the large, central lens, as well as the ciliary muscle and suspensory ligaments attached to it. The aqueous humour is the fluid in the anterior chamber. Identify the iris and the pupil. Identify the cornea.
6. If the lens is not too cloudy, hold it over some typed letters on a scrap piece of paper. What do you observe?
7. Dispose of the cow eye and clean your dissecting tray and work area as instructed by your teacher.

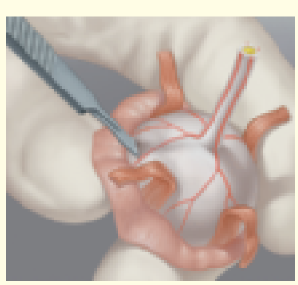
Analysis

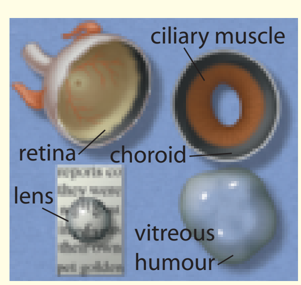
1. Sketch and label the structures of the eye.
2. Create a two-column table in your notebook. Use the following headings: Eye structure, Eye function. Record the structures you labelled in your diagram and their functions.
3. On your diagram, indicate where you would find the rods and cones. What is the function of each structure?

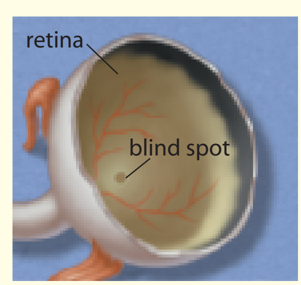
Conclusion

4. Summarize how the structures of the eye direct light onto the fovea centralis.









Preventing Vision Loss

You have already read about two of the most frequent causes of vision loss: glaucoma and cataracts. The leading cause of vision loss involves disorders of the retina. There are different kinds of retinal disorders. In diabetic retinopathy, for example, capillaries to the retina burst, spilling blood into the vitreous fluid between the lens and the retina. Careful regulation of blood glucose levels can help guard against this disorder.

Changes in the consistency of the vitreous fluid may also cause retinal detachment—a condition in which the retina becomes separated from the choroid vessels that supply it with nutrients and oxygen. These changes may be brought on by an inflammatory disorder, advanced diabetes, or an injury or trauma to the eye. Retinal detachment is a medical emergency, because it can cause permanent vision loss. If detected early, the condition may be corrected surgically.

Macular degeneration occurs when the cones are destroyed due to thickened choroid vessels that no longer function as they should. The result is a blurring of, or the development of, a blind spot in central vision. A principal factor in developing macular degeneration is age. The condition is the main cause of severe loss of vision in people of age 60 or older. Cigarette smoking, obesity, and exposure to sunlight are other factors implicated in the condition. There is no cure. However, behaviours that reduce the risk of developing the condition and preventing further vision loss include exercise, not smoking, and a diet rich in green leafy vegetables and fish.

Section 12.2 Summary

- The cornea, lens, and humours focus light on the retina.
- The lens is flexible. Its ability to change shape in order to focus on near or far objects is called accommodation.
- The ability to focus is impaired if the cornea is uneven (causes astigmatism), or if the eyeball is too long (myopia) or too short (hyperopia).
- Each eye has a blind spot, where the optic nerve connects to the eyeball, but each eye compensates for what the other cannot see. Binocular vision also allows us to see in three dimensions.
- The retina contains the photoreceptor cells. The rods function in dim light and produce black and white images. The cones function in bright light and produce colour images.
- Once stimulated, the rods and cones send a neural message to the occipital lobe of the brain, which processes and integrates the information, and then perceives it as an image.

Section 12.2 Review

1. The sclera, choroid, and retina are the three main layers of the eye. Identify the structures associated with each.
2. Suppose that someone you think you recognize is walking toward you. Explain what happens to the lenses of your eyes as this person approaches. What is this reflex called?
3. How do the structures of the eye focus light on the retina? What happens if the light is focussed behind or in front of the retina?
4. Can a person who has a functioning optic nerve still be blind? Explain your answer.
5. As people age, the lenses become less elastic. How would this affect the accommodation reflex? Why might older people often need bifocals (a combination of convex and concave lenses) to correct their vision?
6. Use word processing software to make a three-column table. List the following eye conditions in the first column: glaucoma, cataract, astigmatism, nearsightedness (myopia), farsightedness (hyperopia), macular degeneration. In the other two columns, describe the specific problem that causes each condition and the method of treatment. ICT
7. A significant portion of the human brain is devoted to processing visual information. What does this suggest about how humans are adapted to perceive their surroundings?

SECTION 12.3

Mechanoreception and Chemoreception

Section Outcomes

In this section, you will
- **describe** how the structures of the human ear support the functions of hearing and balance
- **explain** how humans sense their environment through taste, smell, and touch
- **design** and **plan** experiments that demonstrate the structures and sensory functions of the human ear, nose, tongue, and skin
- **explain** how small doses of neurotoxins can be used as painkillers

Key Terms

sound waves
outer ear
pinna
auditory canal
middle ear
tympanum
ossicles
oval window
Eustachian tube
inner ear
cochlea
organ of Corti
basilar membrane
hair cells
tectorial membrane
semicircular canals
rotational equilibrium
gravitational equilibrium
utricle
saccule
otoliths
proprioceptors
taste buds
olfactory cells
olfactory bulb

Figure 12.19 These blind Paralympic athletes are playing goalball, a sport developed in the 1940s specifically for people who are blind or vision-impaired.

Many animals exhibit senses that are beyond human capabilities. Elephants can hear sounds that are too low for us to detect, penguins can see into the ultraviolet range, and many snakes have sensors for infrared energy. Birds, whales, and insects migrate thousands of kilometres using a sense of navigation that humans have yet to understand. Nevertheless, human senses go well beyond vision (Figure 12.19). They include the senses of hearing, taste, touch, and smell, as well as internal senses, such as the sense of balance. This section explores the structures and functions of these vital senses.

Hearing and Balance

Humans spend considerable time talking and listening, and so, when we communicate, hearing is often our most important sense. Our hearing can also warn us of danger. When listening to a favourite tune, it can trigger a strong emotional response. In addition, sense receptors in the muscles and ears provide constant information about the body's orientation in space. This sensory input gives us our sixth sense—our sense of balance, which allows us to move, sit, and stand without falling. The specialized sensory receptor cells for both hearing and balance are mechanoreceptors.

Capturing Sound

Sound causes particles around the source to vibrate and move. The auditory system (sense of hearing) detects these movements as small fluctuations in air pressure, called **sound waves**. You can visualize sound waves as ripples, like the ripples of water that move out from a stone when it is thrown into a pond. At room temperature in air, sound travels at about 1217 km/h. Mechanoreceptors in the inner ear convert the energy of sound waves into the electrochemical energy that the brain perceives as sound.

Three major divisions of the ear—the outer ear, middle ear, and inner ear—collect and direct auditory information to the hearing receptors (Figure 12.20 on page 420). The **outer ear** consists of the pinna and auditory canal. The **pinna** is the outside flap of the ear. It is made of skin and cartilage, shaped in a way that enhances sound vibrations and focusses them into the ear. The **auditory canal**

Biology File

Web Link
Visit an on-line simulation that shows how the inner ear detects different frequencies of sound. Describe what happens in the basilar membrane when you listen to a series of ascending notes played on a piano.

www.albertabiology.ca
WWW

is a tube, 2.5 cm long, that leads to the eardrum in the middle ear. The auditory canal amplifies sound waves, effectively making sounds louder. Hairs, as well as earwax secreted by glands in the auditory canal, prevent dust, insects, bacteria, and other foreign materials from proceeding deeper into the ear. This is one reason why physicians suggest that people do not use swabs to clean out earwax. As well, there is a risk that an object inserted into the ear could damage the auditory canal and eardrum.

The **middle ear** is an air-filled space that is bordered on one side by the **tympanum** (also called the eardrum or tympanic membrane). The tympanum is a round, elastic structure that vibrates in response to sound waves. (The word *tympanum* comes from the Greek word for "drum.") When sound waves push the tympanum, its vibrations are passed on and amplified by the neighbouring **ossicles**: three tiny, interconnected bones in the middle ear. The ossicles are the smallest three bones in the body (Figures 12.20 and 12.21). Each bone acts as a lever for the next, so that a small movement in one results in a larger movement in the next. As a result, the strength of the vibrations is amplified as they pass from the malleus (hammer), to the incus (anvil), and finally to the stapes (stirrup). The stapes concentrates vibrations into the membrane-covered opening in the wall of the inner ear, called the **oval window**. The middle ear can significantly amplify and concentrate vibrations because the tympanum is 15 to 30 times larger than the oval window.

The middle ear is connected to the throat by the thin **Eustachian tube**. This tube allows air pressure to equalize when there is a difference in air pressure within and outside the otherwise contained middle ear. You may have noticed, while driving on a mountain road or travelling in an airplane, that when the external air pressure drops, the higher pressure within the middle ear can feel uncomfortable. Chewing gum or yawning allows air in the Eustachian tube to connect with air in the throat, thus equalizing the pressure and making the ears "pop."

The **inner ear** consists of three interconnecting structures: the semicircular canals, the vestibule, and the cochlea. The semicircular canals and vestibule contain sensors for balance, while the coiled **cochlea** (Latin for "snail") is used for hearing. It is within the structures of the cochlea that the mechanical energy of sound is converted into the electrochemical impulses that are transmitted to the brain. Because the inner ear is fluid-filled, vibrations in the oval window must be converted to pressure waves in the fluid.

Figure 12.21 also shows a cross section of a cochlea. The middle chamber contains the **organ of Corti**, which is the organ of hearing. Along the base of the organ of Corti is the **basilar membrane**, to which sensory mechanoreceptors known as **hair cells** are attached. The hair cells have thin projections called stereocilia, which stick out at the top of the cells (Figure 12.22). The far ends of the stereocilia are embedded within the **tectorial membrane**. When the stapes strikes the oval window, this vibrates the

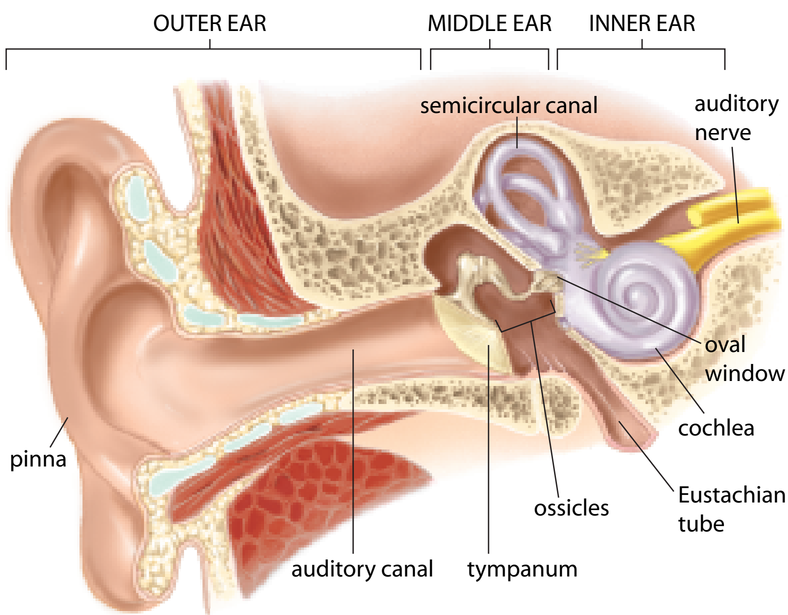


Figure 12.20 The anatomy of the human ear. How are sound waves that arrive at the outer ear amplified as their energy travels to the inner ear?

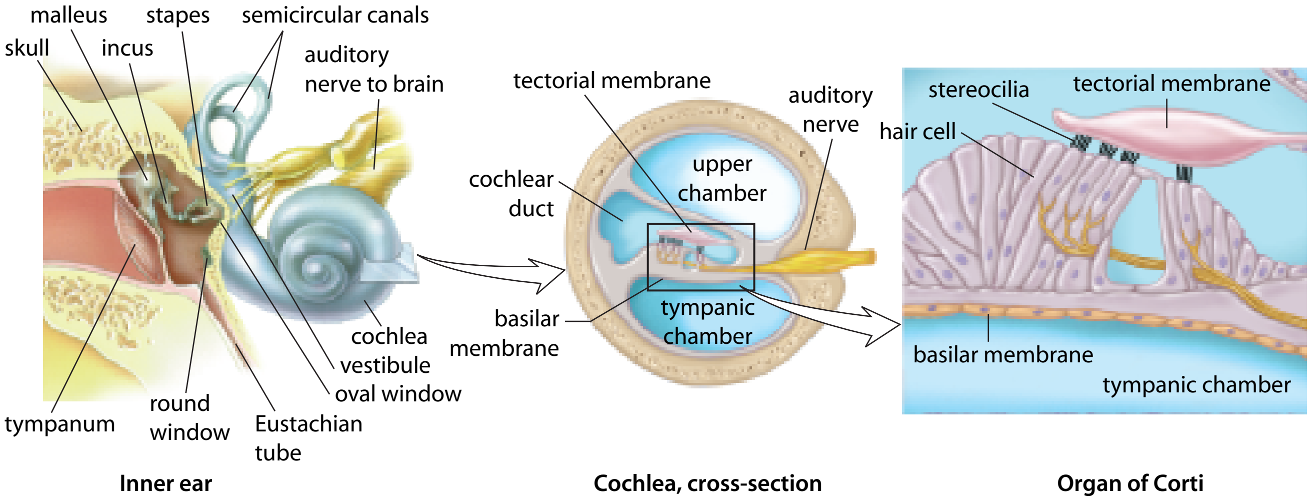


Figure 12.21 The structure of the cochlea. Notice how membranes separate its three fluid-filled chambers, the upper chamber, cochlear duct, and tympanic chamber. Since fluids cannot be compressed, the round window bulges out as pressure waves move through the inside of the cochlea.

window and creates pressure waves in the fluid of the cochlea. The pressure waves make the basilar membrane move up and down, which causes the stereocilia of the hair cells to bend against the tectorial membrane. The hair cells, which synapse with the nerve fibres of the auditory nerve, sense the bending of the stereocilia and relay this message to the nerves. The nerves then send an impulse to the brain.

Q 18 List, in order, the structures of the ear that a sound wave encounters, starting with the outer ear.

Q 19 What happens to the energy of sound waves, which travel through air, after it reaches the tympanum?

Q 20 What is the role of the Eustachian tube?

Frequencies of Sound

The hair cells of the organ of Corti are able to distinguish both the frequency (pitch) and amplitude (intensity) of sound waves. Frequency is the number of waves that pass through a specific point every second. It is measured in hertz (Hz). The frequency of speech usually ranges from 100 to 4000 Hz, although humans can hear sounds that are between 20 and 20 000 Hz. If you could hear below 20 Hz, you would hear the blood moving through your ears! Different areas of the organ of Corti are sensitive to different frequencies. High frequencies, such as the sound of a whistle, most strongly stimulate the hair cells that are closest to the oval window. Low frequencies, such as a low note played by a tuba, most strongly stimulate the hair cells that are farthest from the oval window. In the next investigation, you will test your ability to detect sounds of different frequencies.

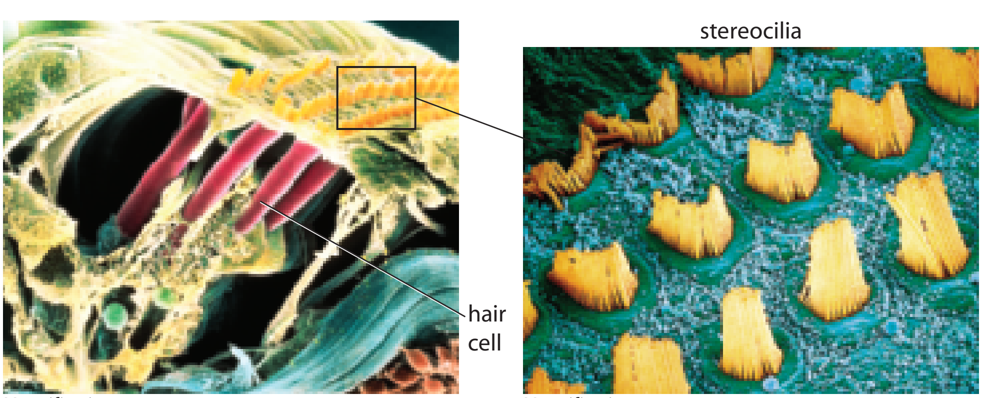


Figure 12.22 Electron micrographs of hair cells and stereocilia from the organ of Corti. What causes the stereocilia to move?

INVESTIGATION 12.B

Target Skills

Performing experiments to measure the ability to discriminate objects visually and to hear a range of sounds

Gathering and **recording** data

Compiling and **displaying** data in an appropriate form

Distinguishing Sights and Sounds

The sensory receptors of the eyes and ears allow the brain to perceive a wide range of sights and sounds. In this investigation, you will determine your ability to discriminate different shades of colour, and you will examine the property of sound known as frequency or pitch.

Question

What range of sights and sounds can you distinguish?

Part 1: Distinguishing Shades of Colour

Hypothesis

Write a hypothesis about which factors might affect your ability to distinguish different shades of a colour.

Materials

- liquid food colouring
- water
- 5 beakers (100 mL) or 5 clear containers of equal size

Procedure

1. Read the procedure, and create a table to record your data.
2. Put an equal amount of water (about 50 mL) into the five beakers (or clear containers).
3. Label the beakers 1 through 5, so that the labels can be concealed. Put 1 drop of food colouring in the first beaker, 2 drops in the second, 3 drops in the third, 4 drops in the fourth, and 5 drops in the fifth. Jiggle the beakers gently to mix the samples.
4. Have someone else change the order of the beakers. Then try to arrange the beakers from darkest to lightest colour. Check your success, and record any mistakes.
5. Repeat step 4 with the five beakers in different lightings: dark room, moderate lighting, and, if possible, bright sunlight. Look straight at the beakers when you observe them.
6. Repeat step 5, but this time look at the beakers from out of the corners of your eyes.
7. Repeat step 4 with the five beakers at several different distances: for example, 1 m, 5 m, 10 m, and 20 m.

Analysis

1. What factors allowed you to discriminate the different shades most easily? Did your observations support or refute your hypothesis? Explain.
2. Compare your results with the results of other students.

Conclusions

3. Name the structures in the eye that are responsible for vision and colour discrimination. Which receptors did you rely on the most in step 5? Which receptors did you rely on the most in steps 6 and 7? Justify your answers by explaining how the different receptors work.

Part 2: Distinguishing Sound Frequencies ICT

Prediction

Predict the range of frequencies that you will be able to hear.

Materials

- device that produces a wide range of sound frequencies, such as a set of tuning forks, a frequency signal generator, a Vernier or Pasco computer program that aids in analyzing different sound frequencies, or an Internet site that provides different tone frequencies
- frequency sensor (optional)

Procedure

1. Make a three-column table in your notebook to record your data for steps 2 and 3. In the first column, list the frequencies that you will generate with your device. In the next column, *predict* whether or not you will be able to detect each frequency. You will use the third column in steps 2 and 3 to record whether or not you can hear each frequency and, if so, to describe what you hear.
2. Set up your test in a quiet location. If you are using a frequency generator, turn it on. If a frequency sensor is available, turn this on too, so you can use it to record the exact frequencies generated.

3. Starting with the lowest frequency, check your ability to hear the sound generated. Then switch to higher frequencies in 1000 Hz increments, until you reach the highest frequency that can be generated. At each increment, fill in your data table.

4. Close your eyes, and have a partner generate a 4000 Hz sound at different locations around your head. Indicate to your partner where the sound is coming from. After the test, check with your partner to see if you were correct. Note the locations that you identified correctly.

Analysis

1. Name the specific structures of the inner ear that allow us to discriminate different frequencies. How did these structures function to allow you to hear sounds of different frequencies?

2. What range of frequencies were you able to hear? Was your prediction correct?

3. Compare your results with other students' results or with data supplied by your teacher. Are there people who can hear frequencies that you cannot, or vice versa? Suggest a reason for this.

Conclusions

4. If you cannot hear certain frequencies within the range of 20 to 20 000 Hz, suggest a reason why. Explain specifically what damage might have occurred in your ears.

5. In step 5, why was it easier to locate the source of a sound when the sound was directly in front of you or behind you, and more difficult to locate the source when the sound came from either side of you?

Extension

6. Research different causes of hearing loss. Contact an audiologist (hearing specialist), and arrange for a visit to learn how hearing tests are performed.

Hearing Loss

Hearing loss generally results from nerve damage (damage to the hair cells, called nerve deafness) or damage to the sound-conduction system of the outer or middle ear (called conduction deafness). Birth defects, ear infections, noise, and aging are common causes of hearing loss.

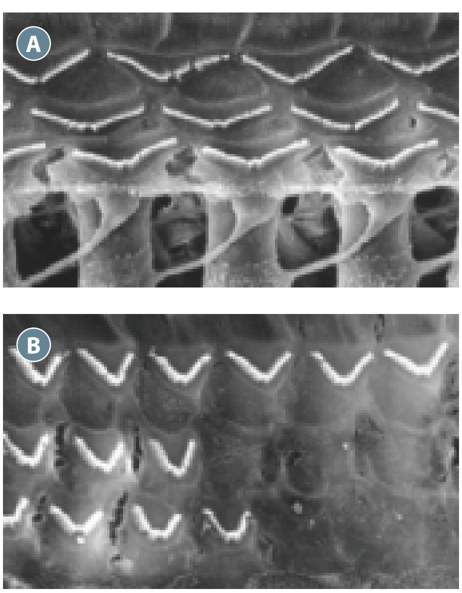


Figure 12.23 Scanning electron micrographs of stereocilia from a mouse ear. **(A)** Healthy stereocilia. **(B)** Stereocilia damaged by brief exposure to a 115 dB noise.

The amplitude of a sound wave is experienced as the intensity or volume of a sound. The louder the noise is, the more pressure that the fluid in the cochlea puts on the hair cells of the basilar membrane. The stereocilia of the hair cells are very delicate, however. Repeated or sustained exposure to loud noise destroys the stereocilia, and the resulting damage is permanent (Figure 12.23). Noise is measured in decibels (dB), and any noise over 80 dB can damage the hair cells. In today's society, people are commonly exposed to a variety of loud and potentially damaging noises (Table 12.3).

Table 12.3 Noises That Affect Hearing

Type of noise	Sound level (dB)	Effect
jet engine or rock concert	over 125	Noise is beyond the threshold of pain. There is a high potential for hearing loss.
boom box, chain saw, or snowmobile	100–125	Regular exposure for short periods of time may cause permanent hearing loss.
farm tractor, lawn mower, or motorcycle	90–100	15 min of exposure may cause hearing loss.
food blender or average city traffic	80–90	Continuous daily exposure for longer than 8 h can cause damage.

Source: United States National Institute of Deafness and Other Communication Disorders, September 2005.

Biology File

FYI

Many animals can hear frequencies of sound that are outside the human range of hearing. Whales communicate regularly in frequencies below 20 Hz. Bats and dogs can detect frequencies well above 20 000 Hz. This explains why humans cannot hear dog whistles.

While hearing aids to amplify sounds can often help people with conduction deafness, nerve deafness is more difficult to treat. In some cases, a device can be implanted in the ear to pick up sounds and directly relay signals to the auditory nerve. As well, researchers are exploring techniques to regenerate damaged or lost hair cells. One technique is to use a virus to insert a gene into the inner ear cells. The gene causes these cells to "sprout" new hair cells. So far, the technique has worked in guinea pigs, but scientists are not yet sure if it will work as a treatment for people with nerve deafness.

Q21 State the parts of the ear that have been damaged in someone with

a) nerve deafness

b) conduction deafness

The Perception of Sound

Sensory neurons in the ear send information through the auditory nerve to the brain stem, thalamus, and ultimately the temporal lobes of the cerebrum for processing. Depending on which sensory neurons are stimulated, the brain can perceive the frequency and amplitude of the sound. Recent research suggests that the source of the sound determines the specific neurons that are stimulated in the temporal lobes. Therefore, the brain can also perceive the location where the sound came from. Next time you hear a sound in front or behind you, imagine a cluster of neurons being stimulated in the corresponding area of your temporal lobes!

Q22 How is the brain able to perceive sounds of higher or lower frequencies and higher or lower amplitudes?

Biology File

Web Link

Describe how a hearing aid and a cochlear implant work, and compare how sounds are perceived with each type of technology.

www.albertabiology.ca

WWW

Balance and Coordination

Three major structures in the inner ear—the semicircular canals, utricle, and saccule—help us stand upright and move without losing our balance (Figure 12.24(A)). Thus, these structures function in our sense of equilibrium. The **semicircular canals** contain mechanoreceptors that detect head and body rotation (**rotational equilibrium**). The semicircular canals are three fluid-filled loops, arranged in three different planes—one for each dimension of space. The base of each semicircular canal ends in a bulge. Inside each bulge, the stereocilia of the hair cells stick into a jelly-like covering called a cupula. When the head rotates, the fluid inside the semicircular canals moves and bends the stereocilia, causing the hair cells to send rotational information to the brain (Figure 12.24(B)). On a fast-spinning midway ride, for example, the rapid circular motion causes the fluid within the semicircular canals to rotate and send information confirming this to the brain. When the ride stops, however, the fluid is still moving. Why might the moving fluid make someone feel dizzy or nauseous?

The balance required while moving the head forward and backward is called **gravitational equilibrium**. Gravitational equilibrium depends on the **utricle** and the **saccule**, which together make up the fluid-filled vestibule of the inner ear (Figure 12.24(A)). Both of these structures contain calcium carbonate granules, called **otoliths**. The otoliths lie in a cupula over a layer of hair cells. When the head dips forward or back, gravity pulls on the otoliths. This puts pressure on some of the hair cells, causing them to send a neural impulse to the brain, indicating the position of the head (Figure 12.24(C)).

Proprioceptors are another type of mechanoreceptor involved in coordination. Proprioceptors are found in muscles, tendons, and joints throughout the body, and they send information about body position to the brain. For

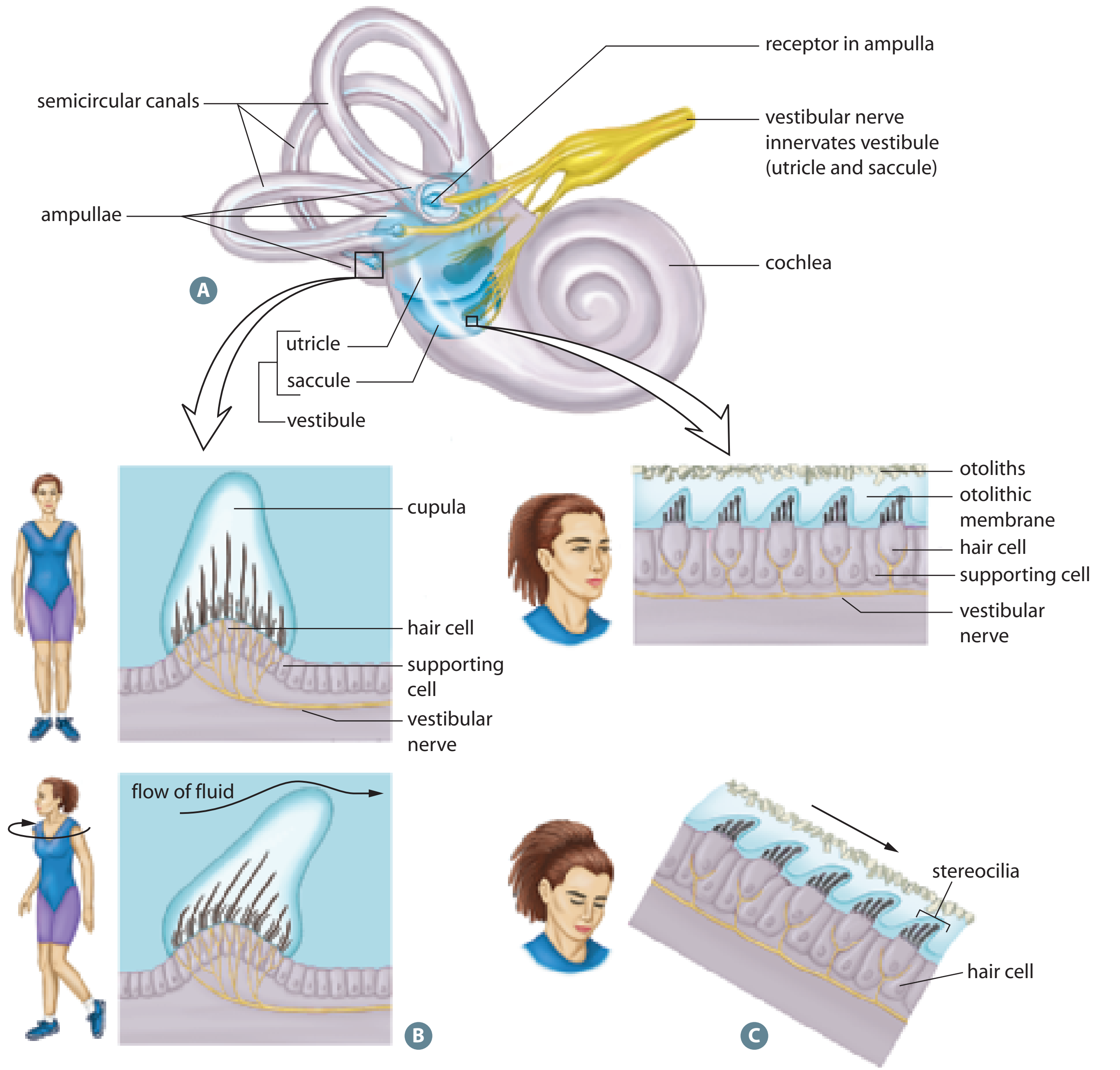


Figure 12.24 (A) The organs of balance: the semicircular canals, utricle, and saccule. Each semicircular canal ends in a bulge called an *ampulla*. **(B)** Rotational equilibrium. Rotating fluid bends the stereocilia in the cupula, and the hair cells send a message through the vestibular nerve to the brain. **(C)** Gravitational equilibrium. The hair cells of the utricle and saccule bend in response to head position.

example, proprioceptors give the brain enough information for you to get dressed in the dark—although they do not ensure that you will put on matching socks!

23 Explain how the structures of the inner ear allow for rotational equilibrium.

24 Explain how the structures of the inner ear allow for gravitational equilibrium.

25 How does the brain perceive that the body is lying down?

Taste

The tongue contains chemoreceptors that allow us to taste substances entering the mouth. The ability to distinguish different tastes probably developed as an adaptation. Animals that avoided harmful substances and instead ate foods that were good for the body survived and reproduced. Poisonous plants, for example, often contain bitter-tasting molecules made of alkaloid compounds.

Most scientists recognize four basic tastes: sour, sweet, salty, and bitter. When we eat, saliva dissolves some of our food. Specific molecules dissolved in the saliva

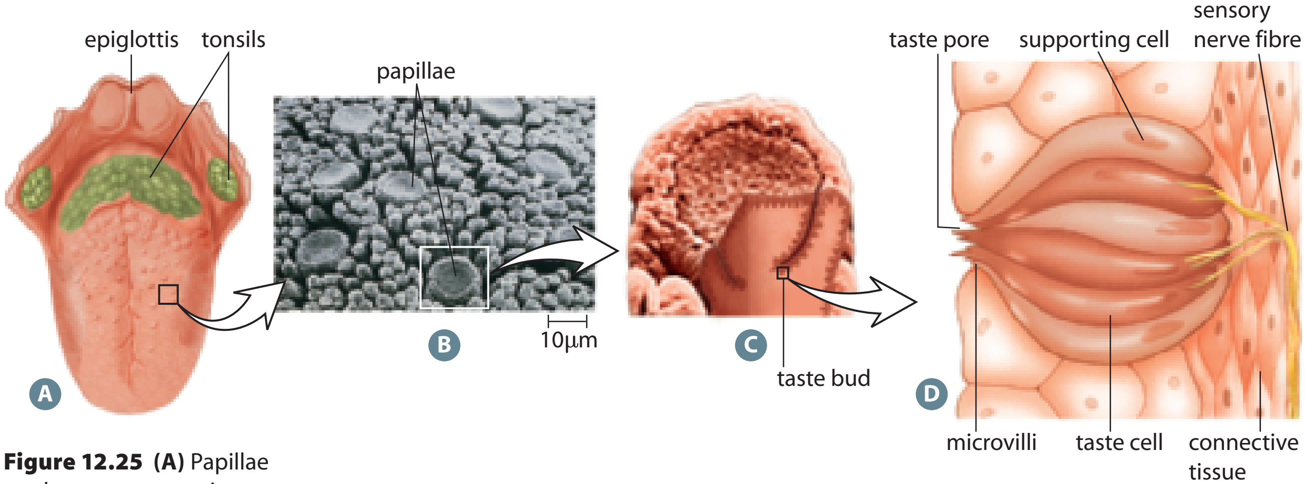


Figure 12.25 (A) Papillae on the tongue contain taste buds that are sensitive to salty, sweet, sour, and bitter molecules. **(B)** Electron micrograph of many papillae. **(C)** Electron micrograph of one papilla. **(D)** Taste cells within the taste buds. The taste buds depolarize in response to particular tastes and generate an action potential that sends a neural impulse to the brain.

are detected by the **taste buds**: the sensory receptors in the bumps (papillae) on the tongue (Figure 12.25). Specific taste cells within the taste buds detect molecules from one of the four basic tastes.

Impulses from the taste buds travel to areas of the brain stem, to the thalamus, and then to the gustatory centre of the parietal lobe, which is responsible for the perception of taste. The combination of taste information sent from different areas of the tongue, as well as from sensory neurons in the nose, allows us to perceive flavours. The salivary glands are connected to the brain stem, which is why they are stimulated whenever we taste, smell, or think about something delicious.

> 26 Describe how taste buds detect taste.

Smell

Scientists estimate that the human sense of smell can distinguish over 10 000 different odours. They think that each of these odours is produced from particles that fit, much like a lock and key, into specific chemoreceptors, called **olfactory cells**, lining the upper nasal cavity (Figure 12.26). When the particles bind to the olfactory cells, ion channels in the cell membrane open. This generates an action potential in the olfactory cells, which are directly linked to the **olfactory bulb** of the brain. From there, the impulse is sent to the emotional centres of the brain (the limbic system) and the frontal lobe, where the perception of odour occurs. Have you noticed that particular odours can instantly conjure up scenes and emotions from the past? Perfume experts create fragrances to evoke certain memories and emotions.

The sense of smell is closely linked to the sense of taste. In fact, someone who is born without a functional olfactory system has no concept of taste, despite having functional taste buds. As much as 80 to 90 percent of what we perceive as taste is actually due to the sense of smell. This is why everything tastes so bland when you have a cold. Molecules from food travel through the nose and the passages in the throat. There, they trigger the chemoreceptors which, in turn, trigger the olfactory sensory neurons. The sense of smell is what lets you experience the complex flavours that you associate with your favourite foods.

Many animals, including humans, release substances, called pheromones, that aid in the recognition and attraction of a mate, sometimes over long distances. These hormone-like chemicals are detected in the nose by a structure called the vomeronasal organ. Recently, scientists determined that the human nose also contains a vomeronasal organ, although people cannot consciously smell pheromones.

BiologyFile

FYI

There is evidence for a fifth basic taste, called *umami*. Umami is described as a savoury taste, characteristic of monosodium glutamate (MSG), and detectable in some meats and cheeses.

> **27** How do the olfactory cells detect odours?
>
> **28** Why might a particular scent evoke a strong emotional response in a person?

Touch

Unlike the mechanoreceptors associated with balance, hearing, taste, and smell, the mechanoreceptors associated with the sense of touch are located all over the body. The skin contains more than four million sensory receptors, but, as you learned in Chapter 11, they are not evenly distributed. Many of them are concentrated in the genitals, fingers, tongue, and lips.

Different receptors in the skin are sensitive to different stimuli, such as light touch, pressure, pain, and high and low temperatures. These receptors gather information and transmit it back through sensory neurons to the brain and spinal cord for processing and a possible reaction (Figure 12.27 on page 429).

Pain is a complicated sense that occurs when specialized sensors or nerve endings in the skin are activated by mechanical pressure or chemical signals. If tissue is damaged, for example, nerve cells called nociceptors release chemicals that trigger pain receptors to send impulses to the brain. Painkillers, such as ibuprofen and Aspirin™, block the release of these chemicals. Everyone is familiar with the sensation of pain. How we experience pain and the effects of different painkillers is highly subjective, however.

How do our senses, such as the ability to feel pain, contribute to homeostasis? Consider this question as you complete Investigation 12.C.

> **29** List the different types of stimuli that sensory receptors in skin can detect.
>
> **30** Where are the greatest concentrations of touch receptors in the body?

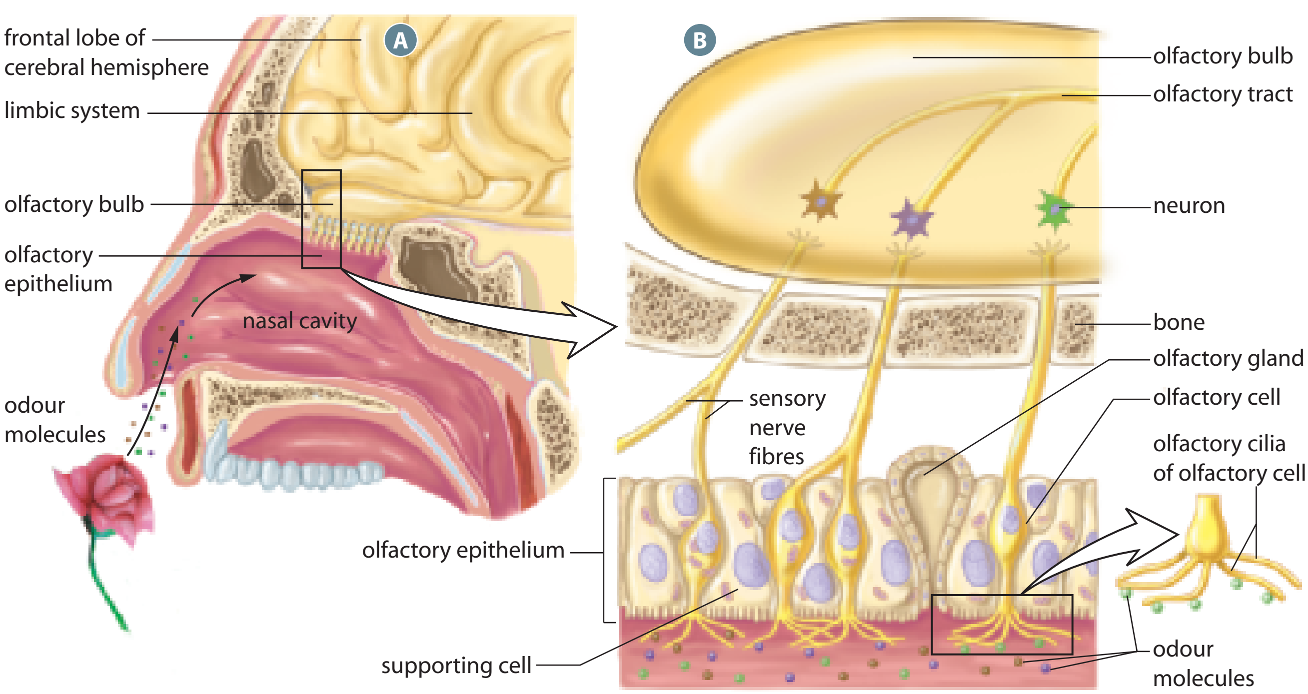
Sensation and Homeostasis

The senses allow us to navigate and experience the world around us. The senses relay information to the nervous system that allows the body to maintain homeostasis. Seeing the bright morning

BiologyFile

Try This
Bend a paper clip into a U-shape with the two ends about 2 mm apart. Close your eyes, and gently push down on the palm of your hand. Then try this on your shoulder. In which location could you distinguish the prongs as separate? What do your results suggest about the number of sensory receptors in the palm of your hand, relative to your shoulder?

Figure 12.26 **(A)** The human olfactory system. Trace how the smell of this rose is detected and then perceived in **(B)**. The cilia of each olfactory cell can bind to only one type of odour molecule (represented here with colour).



INVESTIGATION 12.C

Target Skills

Asking questions about observed relationships

Designing an experiment to investigate various sensory receptors

Analyzing data to show interrelationships between the different senses

Feel, Taste, or Smell: Design Your Own Investigation

How can you determine the range and types of information that each of your senses can detect? Your group will explore one of the topics described below by designing, planning, and conducting an investigation. You will need to show clearly how a specific sense (touch, taste, or smell) can distinguish numerous sensations.

Question

How can you design an investigation to show how a particular sense, or a combination of senses, can distinguish various sensations?

Safety Precautions

- Do not bring food meant for consumption into the laboratory.
- Do not eat or drink anything in the laboratory.

Topic 1: Feel Those Sensations

Design an investigation to distinguish the different sensory receptors found in the skin, including the receptors for touch, pressure, pain, heat, and cold.

Suggested Materials

- 500 mL beaker of hot water (60 °C)
- 500 mL beaker of ice water (0–2 °C)
- non-permanent pen for marking gridlines on the body
- alcohol thermometer
- finishing nails

Topic 2: Tantalize Those Taste Buds

Design an investigation to distinguish the four basic tastes (sweet, salty, sour, and bitter) using the tongue. Also investigate the relationship between smell and taste. **Note:** You must conduct this investigation at home or in the school cafeteria, *not* in the laboratory.

Suggested Materials

- salty water
- lemon juice
- sugary water or candy
- garbage bin
- onion juice or tonic water
- blindfold
- clean toothpicks or cotton swabs

Topic 3: Expose Your Nose

Design an investigation to determine the ability of the olfactory receptors to distinguish various smells.

Suggested Materials

- ginger
- peppermint
- vinegar
- lemon
- pine needles
- perfume
- menthol
- vanilla
- blindfold

Experimental Plan

1. As a group, record the question(s) that you plan to investigate.
2. Write a hypothesis related to your experimental question(s).
3. Using the suggested materials as a starting point, develop a procedure to investigate your topic. List the manipulated, responding, and controlled variables. Note what you can use as a control test or trial (point of reference for your experimental trials).
4. Decide how your group will make the appropriate measurements, how many samples you will use, and whether you will pool your data with other groups' data. Design a table to record your data.
5. After obtaining approval from your teacher for your experimental design, conduct your investigation.

Data and Observations

Record your data. When you have completed your investigation, present your experimental design and results to the rest of the class. Include a diagram that shows the neural pathway from the sensory receptors to the area of the brain where perception occurs.

Analysis

1. Describe any unexpected results. Hypothesize if and how your results would have been different if you had tested a combination of senses.
2. How could you improve your experimental design?

Conclusion

3. How are the sensory receptors organized so that we can distinguish different strengths and types of touch, taste, and smell?

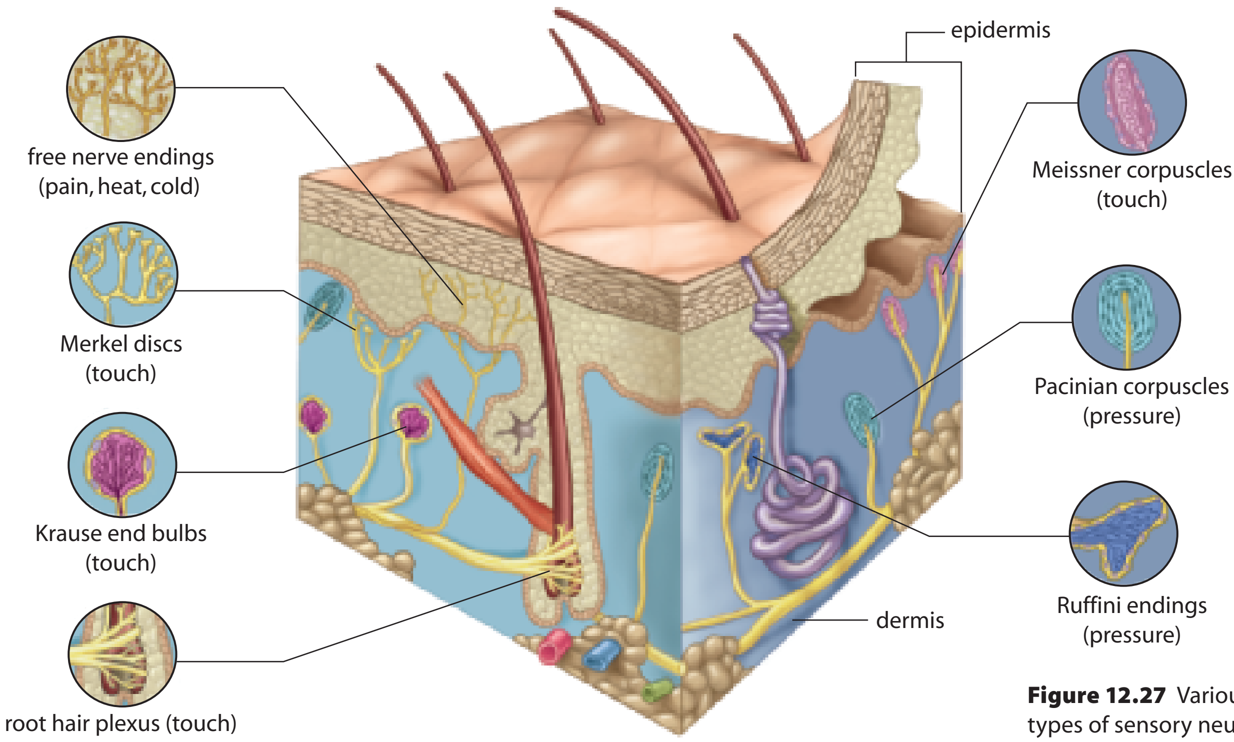


Figure 12.27 Various types of sensory neurons found in the skin

sunlight, for example, tells the body that it is time to wake up. Internal sensors help to prevent you from slipping in the shower. In Chapter 13, you will explore how hormones—chemical messengers in the body—trigger responses to sensations, as well as changes in the body that we do not consciously feel.

Section 12.3 Summary

- The mechanoreceptors for hearing and balance are located in the inner ear.
- The cochlea, semicircular canals, utricle, and saccule all contain hair cells that react to movement.
- The hair cells synapse with nerve fibres, which transmit the sensory information to the nerves. The nerves then send an impulse to the brain.
- Proprioceptors in the muscles, joints, and tendons also inform the brain about the position of body parts.
- Sensory receptors in the tongue (taste buds), nose (olfactory cells), and skin (temperature, pressure, and pain receptors) provide additional information to the brain.

Section 12.3 Review

1. Explain how the structures of the ear amplify sounds.
2. How do the inner ear and brain distinguish the high shriek of a sea gull from the low sound made by a drum? What area of the brain perceives these sounds?
3. Based on your understanding of the inner ear, explain why someone might feel unwell after riding in a fast elevator in a tall building.
4. Suppose that you have been swimming along the bottom of the deep end of a pool. When you surface, you experience discomfort in your ears. Explain why plugging your nose while gently exhaling may help to alleviate the discomfort.
5. Suppose that your aunt works long hours at a newspaper printing press, where she is constantly exposed to sounds over 97 dB. What precautions, if any, would you recommend to her? Explain your answer in terms of the cellular structures of the inner ear.

Pain Relievers or Deadly Neurotoxins?

Phyllobates terribilis

Pain receptors called *nociceptors* are free nerve endings found throughout the skin and internal organs. When tissue injury or chemical messengers stimulate the nociceptors, they transmit information to the brain and we feel pain. Pain may be unpleasant, but it usually serves as a warning to the brain to take action to prevent further injury. However, for millions of Canadians who suffer from the chronic pain of headaches, back pain, muscular-skeletal disorders, fibromyalgia, cancer, or AIDS, pain can be debilitating. To help those with chronic pain, researchers are looking to natural—but deadly—neurotoxins for targeted pain relief.

Poisonous Frogs and Pain

The golden poison arrow frog (*Phyllobates terribilis*) secretes a powerful neurotoxin called batrachotoxin. For centuries, aboriginal peoples of the Columbian rainforests have used batrachotoxin in traditional spiritual rituals and in healing and hunting practices. Before a hunt, arrows are dipped in a blend made from the frog's secretions. When the arrow penetrates the prey's skin, the animal dies swiftly. Batrachotoxin affects the victim's neurons by preventing sodium gates in the neural membrane from closing. The resulting constant stimulation leads to a depletion of neurotransmitters and irreversible depolarization of nerves and muscle cells. Muscles throughout the body, most significantly the heart and diaphragm, remain contracted, which causes rapid paralysis and death.

Researchers are now studying the neurotoxin for its use as a targeted pain medication. Severe pain is commonly treated with morphine, which suppresses the whole central nervous system as it blocks the transmission of pain signals to the brain from the receptors. Morphine also interferes with other parts of the nervous system, causing nausea, sedation, and confusion. In addition, patients can build up a tolerance for the drug that makes progressively higher doses necessary in order for it to work. Very small doses of neurotoxins such as batrachotoxin could, on the other hand, be used to stop impulse transmission in the cell membranes of the pain receptors, without the side effects associated with morphine. Scientists are searching the world's jungles and oceans to find organisms, including plants, snails, fish, bacteria, and amphibians, which contain similar neurotoxins.

Takifugu

Biodiversity: A Medicine Chest

Substances with medicinal potential come from some unlikely sources. For example, coral reefs are home to over 500 species of cone snail (*Conus*), each of which produces a version of the deadly venom called conotoxin, which the snails use to immobilize prey. Conotoxin contains a component that causes muscle paralysis, plus a pain-reducing component, which blocks the acetylcholine receptors on pain transmission neurons. It could potentially be used to control nerve pain caused by surgery, diabetes, cancer, or AIDS.

Puffer fish, or fugu (*Takifugu*), is a popular delicacy in Japan, despite containing the deadly neurotoxin tetrodotoxin. Ingesting even a milligram of tetrodotoxin can be fatal. The toxin appears to work by blocking sodium ion channels in the neurons, which can lead to respiratory paralysis. A Vancouver, British Columbia company produces a purified form of tetrodotoxin called Tectin™, which has shown promise as a pain reliever for some people undergoing cancer treatment. Tetrodotoxin is 3000 times stronger than morphine but in low doses appears to safely inhibit the pain neurons.

• • •

1. Why might some organisms have evolved to contain or secrete potent neurotoxins?
2. The bacterium *Clostridium botulinum* produces botulinum toxin, which can cause fatal food poisoning. Botulinum toxin inhibits the release of acetylcholine, resulting in paralysis. (A by-product, Botox®, is used to paralyze facial muscles and temporarily smooth wrinkles.) Knowing that one of the causes of migraine headaches is the constriction of arteries that bring blood to the brain, why might low doses of botulinum toxin be effective for controlling migraines?
3. What are the advantages of targeted painkillers over those with more general effects?

Chapter 12 SUMMARY

Sensory reception occurs at the senses. Sensation and perception occur in the brain. Various sensory receptors detect information in the internal and external environments. Photoreceptors detect light. Chemoreceptors detect tastes, odours, and internal conditions, such as blood pH and volume. Thermoreceptors detect temperature. Mechanoreceptors function in hearing, balance, and coordination.

The cornea, lens, and humours of the eye direct light on the photoreceptor cells in the retina. Rods function in dim light and produce black and white images. Cones function in bright light and produce colour images. The optic nerve transmits signals from the rods and cones to the occipetal lobe of the cerebral cortex, where images are perceived. The lens can accommodate to focus nearby or distant objects on the retina.

The outer ear transmits sound waves to the middle ear, which makes the tympanum vibrate. This, in turn, makes the bones of the middle ear vibrate. These bones amplify and transmit the vibrations to the oval window in the inner ear. The vibrations in the oval window produce pressure waves in the fluid of the cochlea in the inner ear. The pressure waves are detected by hair cells, which relay electrochemical messages to the brain via the auditory nerve.

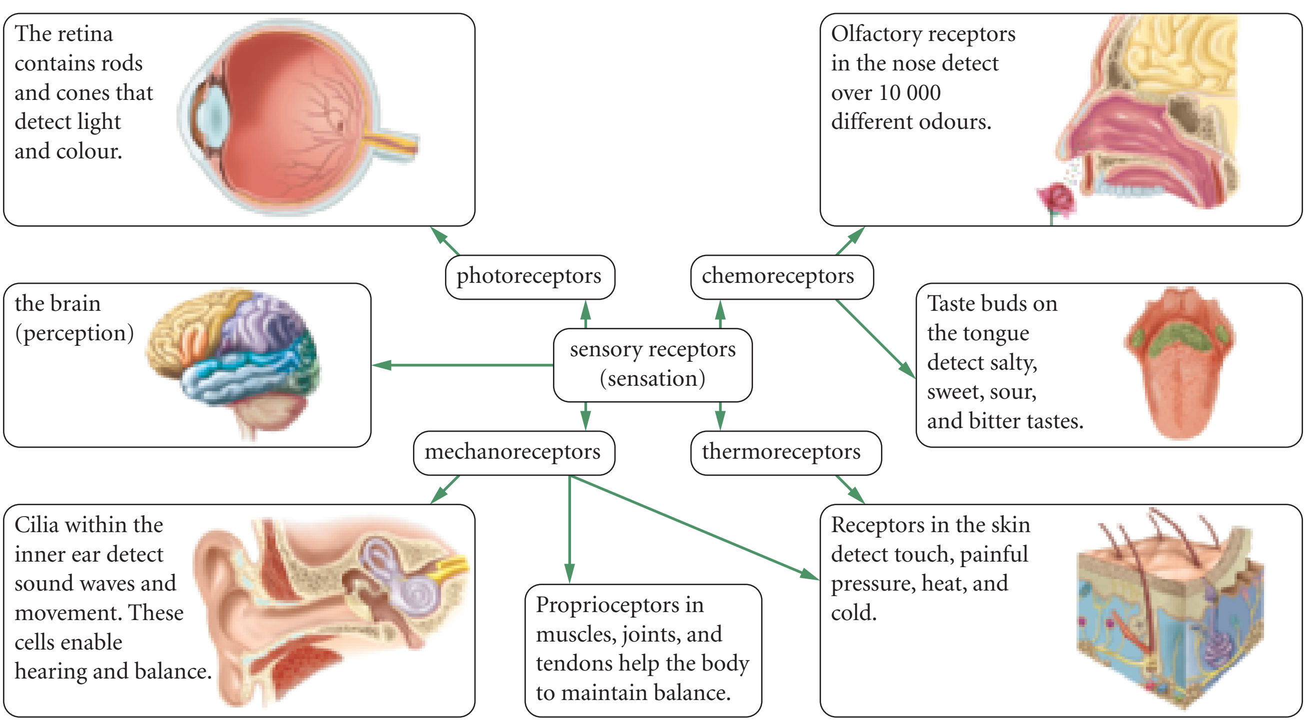
Hearing aids that amplify sound can sometimes be used to treat conduction deafness caused by damage to the outer or middle ear. Noise-induced hearing loss, caused by destruction of the hair cells, is more difficult to treat. It results in a loss of ability to hear sounds of specific frequencies.

Hair cells in the semicircular canals of the inner ear allow for rotational equilibrium (balance). Hair cells in the utricle and saccule of the inner ear allow for gravitational equilibrium (balance). Proprioceptors are another type of mechanoreceptor involved in coordination.

Tastes are detected by chemoreceptors in the taste buds of the tongue. Smells are detected by chemoreceptors in the nose.

The skin contains receptors for light touch, pressure, pain, heat, and cold. Sensors in the nose, tongue, and skin all help the nervous system maintain homeostasis.

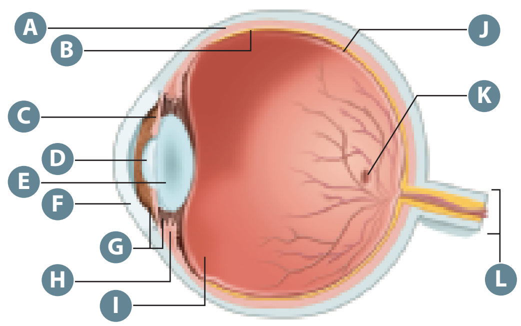
Chapter 12 Graphic Organizer



Chapter 12 REVIEW

Understanding Concepts

1. List the major structures in the pathway of neural conduction from the organ of smell to the appropriate area of the brain.
2. Draw a table in your notebook with the following headings: Photoreceptors, Mechanoreceptors, Chemoreceptors, Thermoreceptors. For each type of receptor, list what it detects and provide an example of a human sense organ that contains this receptor.
3. Copy the diagram of the eye into your notebook. Label the visible structures, and indicate their functions. Also indicate the locations and functions of the rods and cones.



4. Describe how the touch receptors transduce energy into a form that the nervous system can use.
5. People who have lost a limb in a war or accident often report feeling sensations and even extreme pain in the limb that is no longer there. The cause of this phenomenon, called phantom limb syndrome, is unclear. Why is it possible for someone to perceive a sensation despite missing the associated sense receptors?
6. Explain how the inner ear and brain distinguish sounds of different frequencies and different volumes.
7. Once sensory neurons for a specific odour are stimulated, insensitivity to that odour rapidly occurs both in the sensory neurons of the nose and in the brain. What is this phenomenon called? Why would it be an adaptive advantage in certain circumstances?
8. Explain what happens to the pupils of your eyes if you walk into a dark movie theater after a stroll outside on a sunny day. What is this reflex called?
9. Which kind of photoreceptor would you expect to be most numerous in the retinas of an animal that hunts at night? Explain your reasoning.
10. When you close one eye, you may notice a blind spot in your field of vision. What is the blind spot? Why do you not see it all the time?
11. Use word processing or graphics software to make a flowchart mapping the events that occur from the time the light of a full Moon reaches your retina to the time your brain perceives it. ICT
12. Studies show that some people who play action video games can process visual information faster and pick out more objects in a scene compared to people with little or no experience playing video games. Which area(s) of the brain must have been affected in the video game players?
13. Which receptors does your body rely on when you are standing still for a photo? Explain where these receptors are located, how they are stimulated, and how they send information to the brain.
14. What happens in your eyes when you focus on the words on this page? What is the process called? Use graphics software to sketch what happens to the lens of the eye when you focus on the words, and then when you look out the window at a bird in a tree. ICT
15. Using an example, compare rotational equilibrium with gravitational equilibrium. Identify the specific structures involved.
16. The early stages of glaucoma tend to affect the peripheral vision. Why might someone with early stage glaucoma want to avoid driving at night?
17. Which senses might be affected by an injury to one of the temporal lobes of the brain?
18. Use word processing software to make a flowchart tracing the pathway of a sound wave as it travels through the outer, middle, and inner ear. Indicate where the auditory information is sent to the brain. Also indicate the principal structures involved and their functions, and the specific area of the brain where the perception of sound occurs. ICT
19. A heavy machinery operator is tested for hearing loss. It turns out that the operator has trouble hearing some frequencies of sound, but not others. Explain why.

Applying Concepts

20. List some possible effects of sensory deprivation on homeostasis. Suggest a hypothesis to explain why these effects occur.
21. A severe blow to a particular area of the head can cause blindness. Describe how you would design a safety helmet to protect a cyclist from damage to the visual centres of the brain.

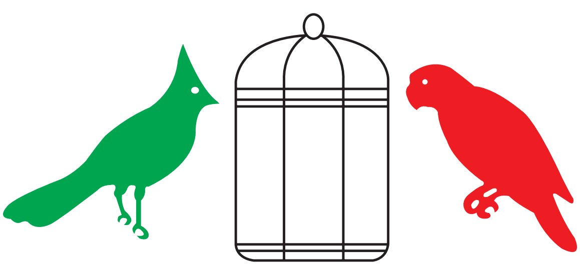
22. How could you design a technology to treat red-blue colour blindness?

23. Scientists have devised both retinal and cochlear implants to compensate for non-functional sense receptors. Explain what such devices could offer people who have vision or hearing problems, compared with technologies such as eyeglasses and hearing aids.

24. Most parts of the body continue to grow new cells and discard old cells. The lens of the eye, however, is unique because it continues to get larger over time, and old, dead cells cannot escape. The lens of an 8-year-old has a mass of about 130 mg, while the lens of an 80-year-old has a mass of about 225 mg. Given this information, why do you think older people often need eyeglasses?

25. A dog's sense of smell is so keen that a dog can detect illegal drugs, and even evidence of bladder cancer in human urine. Suggest possible structural adaptations that a dog might have that would enable it to have such a superb sense of smell.

26. Stare at the green bird in the diagram for at least 1 min. Then look in the cage. Do you see the bird in the cage? Now stare at the red bird for 1 min. Then look in the cage. What do you see? The resulting effect in each case is called an afterimage. How would you explain the cause of an afterimage, given that the cone cells of the retina lose their sensitivity when they become fatigued?



27. Dogs have two types of cones in the retina: one type detects blue-violet light and the other type detects yellow light. Based on this information, which colours do you think dogs are most likely to see? Which colours would dogs likely have trouble distinguishing?

Making Connections

28. Using what you know about threshold potential (Chapter 11) and sensory receptors on the skin (Chapter 12), explain why some individuals seem to be more tolerant of pain than others.

29. Researchers have discovered that premature babies with apnea, a condition that causes them to stop breathing during sleep, can be somewhat helped by having them smell the scent of vanilla. Provide a possible explanation for this effect.

30. Deadly neurotoxins produced by some organisms, such as the rattlesnake and black widow spider, could have medical implications. One neurotoxin from rattlesnake venom blocks receptors on postsynaptic neurons. Venom from the female black widow spider stimulates exocytosis of synaptic vesicles from neurons. Speculate how these neurotoxins might affect the body, and suggest a possible medical use for each of them.

31. Would you use a technological device to enhance your eyesight beyond natural human capabilities, perhaps so that you could see farther and with more clarity, or sense infrared or ultraviolet light? Justify your response.

32. Throughout the world, many natural habitats are quickly disappearing as a result of human activities. Explain how this situation might affect the discovery of new medications.

33. The ancient Greeks, Egyptians, Sumerians, and Native Americans used an extract of willow bark known as salicin to treat aches and fever. The extract was later patented in a product known as Aspirin™. Some neurotoxins that Western scientists are now researching for use as painkillers have also been used in the traditional practices of Aboriginal peoples for centuries. Should traditional knowledge of medications continue to be patented and sold? If so, who should be paid for the patents on such "discoveries"?