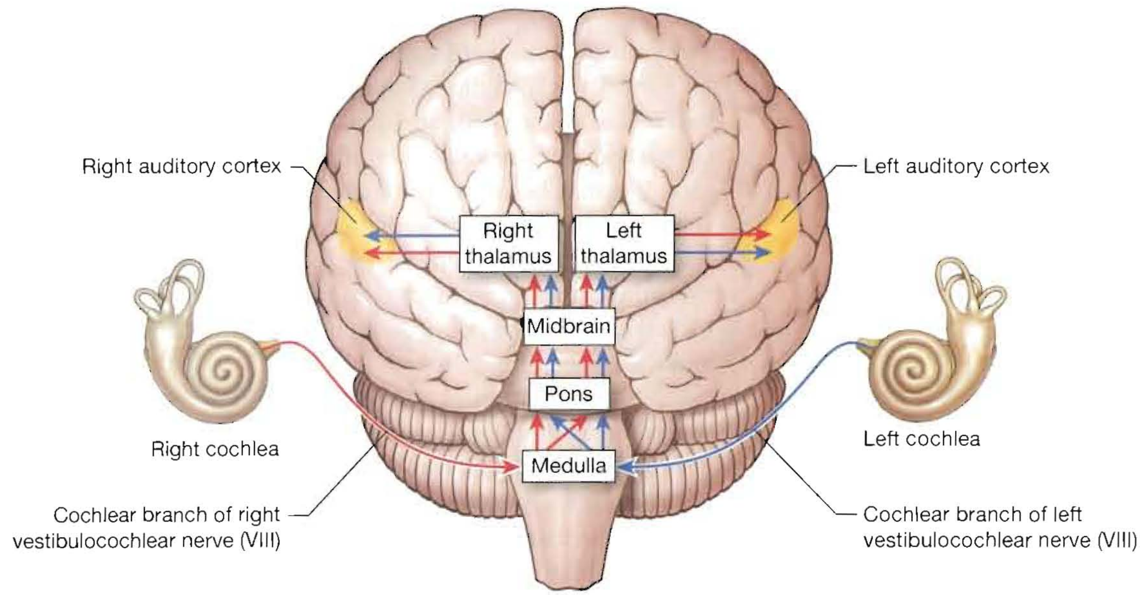


FIGURE 10-24 *Auditor*
pathways

Hearing is probably our most important social sense. Suicide rates are higher among deaf people than among those who have lost their sight. More than any other sense, hearing connects us to other people and to the world around us.

BIOTECHNOLOGY

COCHLEAR IMPLANTS

One technique used to treat sensorineural hearing loss is the cochlear implant. The newest cochlear implants have multiple components. Externally, a microphone, tiny computerized speech processor, and transmitter fit behind the ear like a conventional hearing aid. The speech processor is a transducer that converts sound into electrical impulses. The transmitter converts the processor's electrical impulses into radio waves and sends these signals to a receiver and 8–24 electrodes, which are surgically placed under the skin. The electrodes take electrical signals directly into the cochlea and stimulate the sensory nerves. After surgery, recipients go through therapy so that they can learn to understand the sounds they hear. Cochlear implants have been remarkably successful for many profoundly deaf people, allowing them to hear loud noises and modulate their own voices. In the most successful cases, individuals can even use the telephone. To learn more about cochlear implants, visit the web site of the National Institute for Deafness and Other Communication Disorders (*www.nidcd.nih.gov/health/hearing*).

CONCEPT CHECK

18. Map or diagram the pathways followed by a sound wave en- tering the ear, starting in the air at the outer ear and endinc on the auditory cortex.
19. Why is somatosensory information projected to only one hemisphere of the brain but auditory information is projecte to both hemispheres? (*Hint:* See Figs. 10-5 and 10-9.)
20. Would a cochlear implant help a person who suffers from nerve deafness? From conductive hearing loss? Answers: p. 3

THE EAR: EQUILIBRIUM

Equilibrium is a state of balance, whether the word is used describe ion concentrations in body fluids or the position of t body in space. The special sense of equilibrium has two comp nents: a dynamic component that tells us about our moveme through space, and a static component that tells us if our he is not in its normal upright position. Sensory information frc the inner ear and from joint and muscle proprioceptors tells o brain the location of different body parts in relation to one a other and to the environment. Visual information also plays important role in equilibrium, as you know if you have ev gone to one of the 360° movie theaters where the scene tilts su denly to one side and the audience tilts with it!

Our sense of equilibrium is mediated by hair cells lini the fluid-filled vestibular apparatus of the inner ear. These nc neural receptors respond to changes in rotational, vertical, a horizontal acceleration and positioning. The hair cells functi just like those of the cochlea, but gravity and accelerati rather than sound waves provide the force that moves t stereocilia.

When the cilia bend, tip links between them open and close ion channels. Movement in one direction causes the hair cells to depolarize, and with movement in the opposite direction, they hyperpolarize (see Fig. 10-22). Vestibular hair cells, like cochlear hair cells, have a single kinocilium located at one side of the ciliary bundle. The kinocilium creates a reference point for the direction of bending.

The Vestibular Apparatus Provides Information About Movement and Position

The **vestibular apparatus**, also called the *membranous labyrinth*, is an intricate series of interconnected fluid-filled chambers. (In Greek mythology the labyrinth was a maze that housed the Minotaur.) In humans, the vestibular apparatus consists of two saclike **otolith organs**—the **saccule** and the **utricle**—along with three **semicircular canals** that connect to the utricle at their bases (Fig. 10-25a ●). The otolith organs tell us about *linear acceleration* and head position. The three semicircular canals sense *rotational acceleration* in various directions.

The vestibular apparatus, like the cochlear duct, is filled with high-K^+, low-Na^+ endolymph secreted by epithelial cells. Like cerebrospinal fluid, endolymph is secreted continuously and drains from the inner ear into the venous sinus in the dura mater of the brain.

If endolymph production exceeds the drainage rate, buildup of fluid in the inner ear may increase fluid pressure within the vestibular apparatus. Excessive accumulation of endolymph is believed to contribute to *Ménière's disease*, a condition marked by episodes of dizziness and nausea. If the organ of Corti in the cochlear duct is damaged by fluid pressure within the vestibular apparatus, hearing loss may result.

The Semicircular Canals Sense Rotational Acceleration

The three semicircular canals of the vestibular apparatus monitor rotational acceleration so they are oriented at right angles to one another, like three planes that come together to form the corner of a box (Fig. 10-25b). The horizontal canal monitors rotations that we associate with turning, such as an ice skater's spin. The posterior canal monitors left-to-right rotation, such as the rotation when you perform a cartwheel. The superior canal is sensitive to forward and back rotation, such as doing a somersault.

At one end of each canal is an enlarged chamber, the **ampulla** [bottle], which contains a sensory structure known as a **crista** [a crest; plural *cristae*]. The crista consists of hair cells and a gelatinous mass, the **cupula** [small tub], that stretches from floor to ceiling of the ampulla, closing it off (Fig. 10-25c). Hair cell cilia are embedded in the cupula.

How is rotation sensed? As the head turns, the bony skull and the membranous walls of the labyrinth move, but the fluid within the labyrinth cannot keep up because of inertia. In the ampullae, the drag of endolymph bends the cupula and its hair cells in the direction *opposite* to the direction in which the head is turning.

For an analogy, think of pulling a paintbrush (a cupula attached to the wall of a semicircular canal) through sticky wet paint (the endolymph) on a board. If you pull the brush to the right, the drag of the paint on the bristles bends them to the left (Fig. 10-26 ●). In the same way, the inertia of the fluid in the semicircular canal pulls the cupula and the cilia of the hair cells to the left when the head turns right.

If rotation continues, the moving endolymph finally catches up. Then if head rotation stops suddenly, the fluid has built up momentum and cannot stop immediately. The fluid continues to rotate in the direction of the head rotation, leaving the person with a turning sensation. If the sensation is strong enough, the person may throw his or her body in the direction opposite the direction of rotation in a reflexive attempt to compensate for the apparent loss of equilibrium.

The Otolith Organs Sense Linear Acceleration and Head Position

The two otolith organs, the utricle [*utriculus*, little bag] and saccule [little sac], are arranged to sense linear forces. Their sensory structures, called **maculae**, consist of hair cells, a gelatinous mass known as the **otolith membrane**, and calcium carbonate and protein particles called **otoliths** [*oto*, ear + *lithos*, stone]. The hair cell cilia are embedded in the otolith membrane, and otoliths bind to matrix proteins on the surface of the membrane (Fig. 10-25d). If gravity or acceleration cause the otoliths to slide forward or back, the gelatinous otolith membrane slides with them, bending the hair cell cilia and setting off a signal.

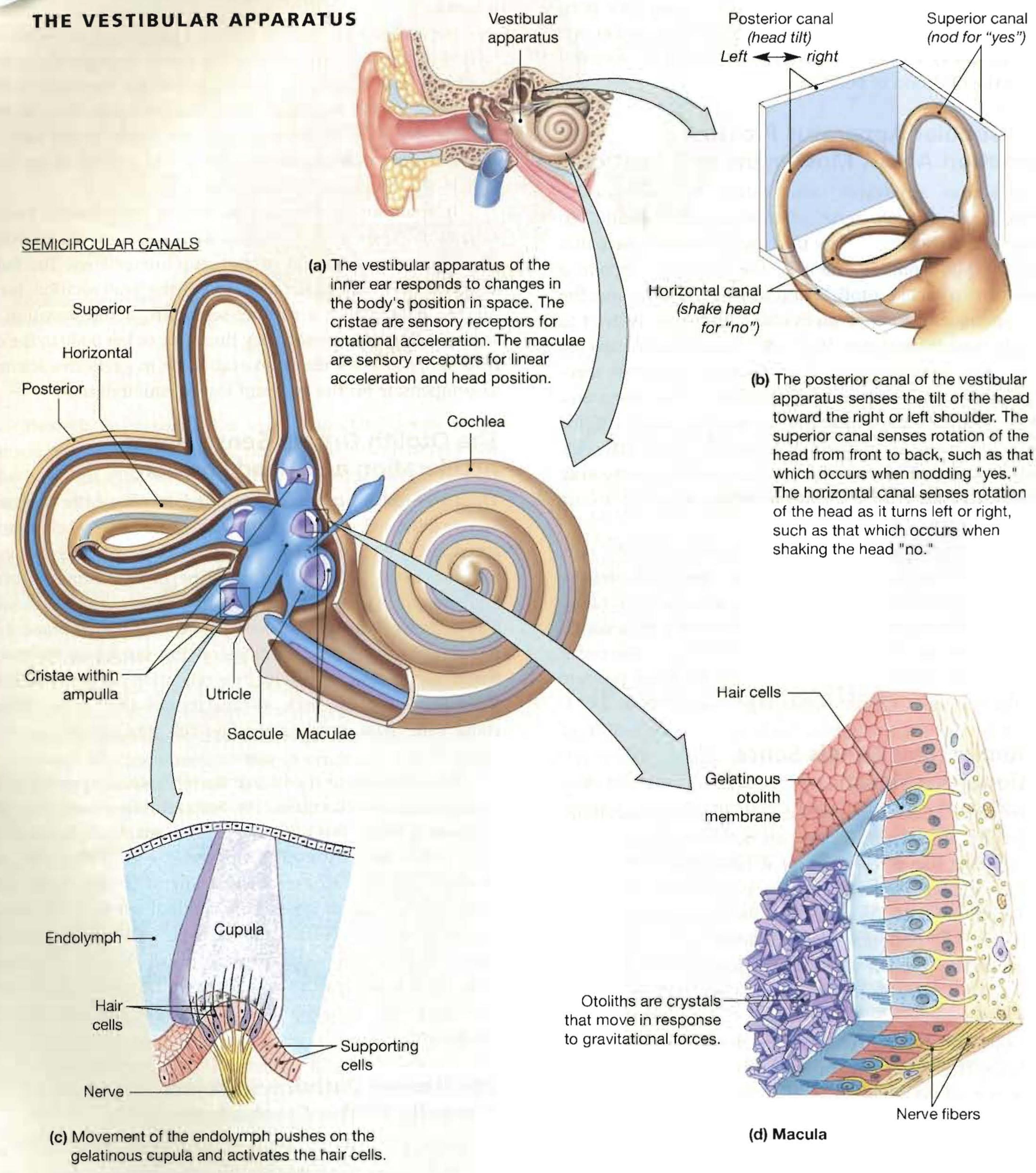
The maculae of the utricle sense forward acceleration or deceleration as well as head tilt. For example, the maculae are horizontal when the head is in its normal upright position (Fig. 10-27a ●). If the head tips back, gravity displaces the otoliths, and the hair cells are activated (Fig. 10-27b). In contrast, the maculae of the saccule are oriented vertically when the head is erect, which makes them sensitive to vertical forces, such as dropping downward in an elevator. The brain analyzes the pattern of depolarized and hyperpolarized hair cells in order to compute head position and direction of movement.

Equilibrium Pathways Project Primarily to the Cerebellum

Vestibular hair cells, like those of the cochlea, are tonically active and release neurotransmitter onto primary sensory neurons of the **vestibular nerve** (a branch of cranial nerve VIII, the vestibulocochlear nerve). Those sensory neurons either synapse

ANATOMY SUMMARY

THE VESTIBULAR APPARATUS



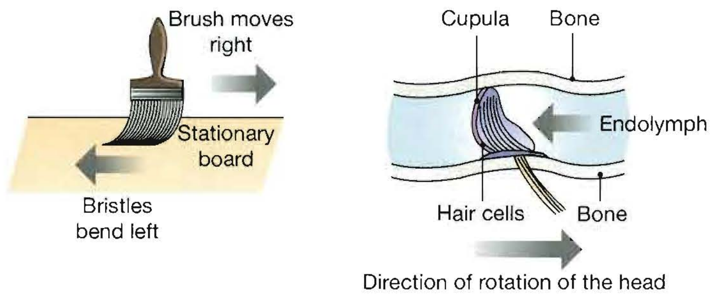
(a) The vestibular apparatus of the inner ear responds to changes in the body's position in space. The cristae are sensory receptors for rotational acceleration. The maculae are sensory receptors for linear acceleration and head position.

(b) The posterior canal of the vestibular apparatus senses the tilt of the head toward the right or left shoulder. The superior canal senses rotation of the head from front to back, such as that which occurs when nodding "yes." The horizontal canal senses rotation of the head as it turns left or right, such as that which occurs when shaking the head "no."

(c) Movement of the endolymph pushes on the gelatinous cupula and activates the hair cells.

(d) Macula

FIGURE 10-25



When the head turns right, endolymph pushes the cupula to the left.

● **FIGURE 10-26** ***Rotational forces activate hair cells in the cristae.*** When the head turns, inertia keeps endolymph inside the ampulla from moving as rapidly as the surrounding cranium.

in the *vestibular nuclei* of the medulla or run without synapsing to the cerebellum, which is the primary site for equilibrium processing (Fig. 10-28 ●). Collateral pathways run from the medulla to the cerebellum or upward through the reticular formation and thalamus.

There are some poorly defined pathways from the medulla to the cerebral cortex, but most integration for equilibrium occurs in the cerebellum. Descending pathways from the vestibular nuclei go to certain motor neurons involved in eye movement. These pathways help keep the eyes locked on an object as the head turns.

RUNNING PROBLEM

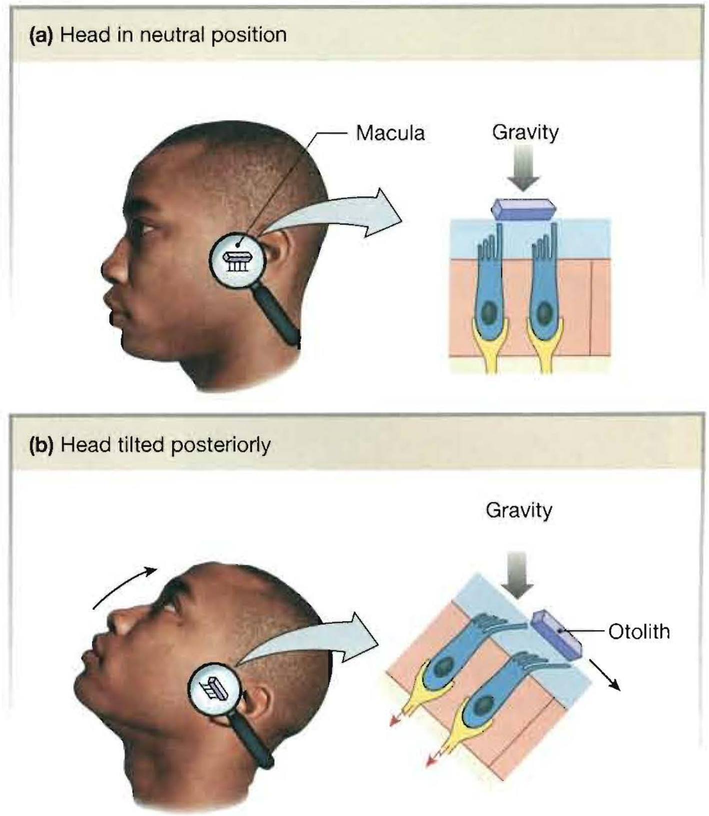
Although many vestibular disorders can cause the symptoms Anant is experiencing, two of the most common are positional vertigo and Ménière's disease. In *positional vertigo,* calcium crystals normally embedded in the otolith membrane of the maculae become dislodged and float toward the semicircular canals. The primary symptom of positional vertigo is brief episodes of severe dizziness brought on by a change in position, such as moving to the head-down position called "downward-facing dog" in a yoga class. People with positional vertigo often say they feel dizzy when they lie down or turn over in bed.

Question 3:

When a person with positional vertigo changes position, the displaced crystals float toward the semicircular canals. Why would this cause dizziness?

Question 4:

Compare the symptoms of positional vertigo and Ménière's disease. On the basis of Anant's symptoms, which condition do you think he has?



● **FIGURE 10-27** ***Otoliths move in response to gravity or acceleration.***

CONCEPT CHECK

21. The stereocilia of hair cells are bathed in endolymph, which has a very high concentration of K^+ and a low concentration of Na^+. When ion channels in the stereocilia open, which ions move in which direction to cause depolarization?
22. Why does hearing decrease if an ear infection causes fluid buildup in the middle ear?
23. When dancers perform multiple turns, they try to keep their vision fixed on a single point ("spotting"). How does spotting keep a dancer from getting dizzy? Answers: p. 383

THE EYE AND VISION

The eye is a sensory receptor that functions much like a camera. It focuses light on a light-sensitive surface (the retina) using a lens and an aperture or opening (the pupil) whose size can be adjusted to change the amount of entering light. **Vision** is the process through which light reflected from objects in our environment is translated into a mental image. This process can be divided into three steps:

1. Light enters the eye and the lens focuses it on the retina.
2. Photoreceptors of the retina transduce light energy into an electrical signal.
3. Neural pathways from retina to brain process electrical signals into visual images.