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The Vestibular System

The vestibular system within the inner ear detects both the position and motion of the head in space. The chief components of this system are the semicircular canals that contain hair cells specialized for sensing circular (angular) movement and the otolith organs that contain hair cells specialized for sensing linear movement. See Figure 1.

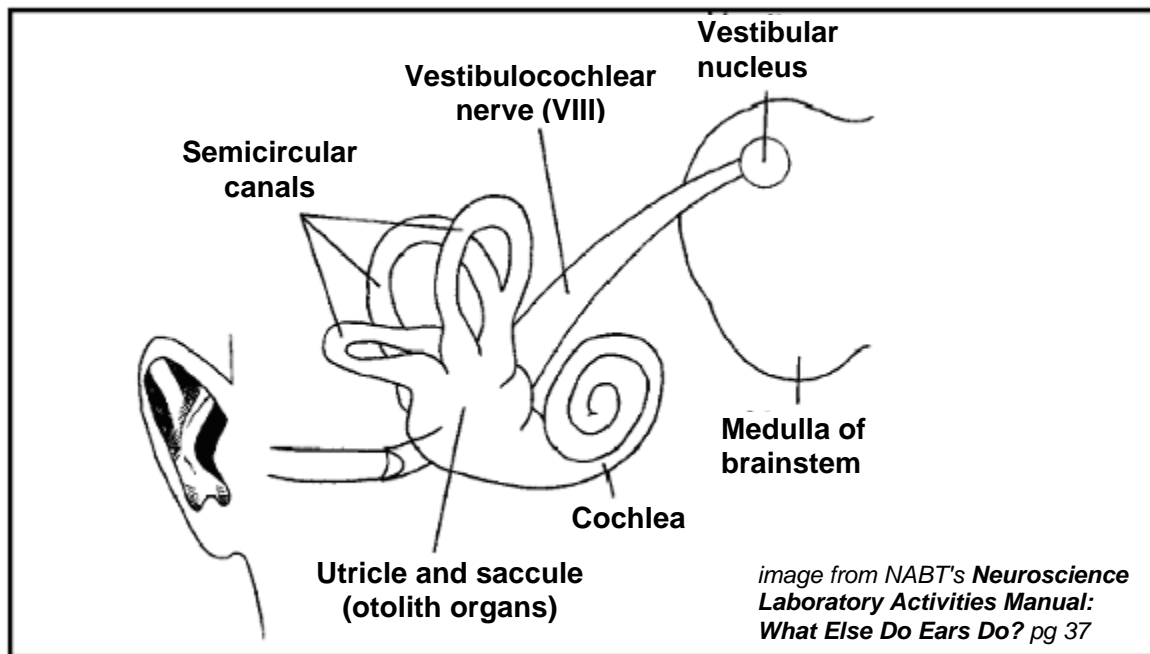


Figure 1: The Vestibular System

The semicircular canals are interconnected with the main sacs in the human ear: the utricle and the saccule which make up the otolith organs. These organs are responsible chiefly for detecting linear movement, such as the sensation experienced when a person rides in an elevator.

This lab focuses on the semicircular canals, fluid-filled inner-ear structures designed to detect circular or angular motion. In situations such as riding in a Tilt-a-Whirl™, rolling at high speed in an airplane, performing ice skating or ballet spins, or spinning in a circle, your body detects circular motion with these canals. Sometimes this sense of moving in a circle may lead to dizziness or, in extreme cases, even nausea. People who have something wrong with this motion-sensing system often suffer from a condition known as *vertigo* and feel as if they are spinning even when they are not.

Each ear contains three semicircular canals. Each set of canals is oriented in a different plane that corresponds to the major rotations of the head. The planes of the canals approximate head movements when the head is moved to indicate “no” (horizontal) and “yes” (posterior), and is tilted from shoulder to shoulder (superior). See Figure 2.



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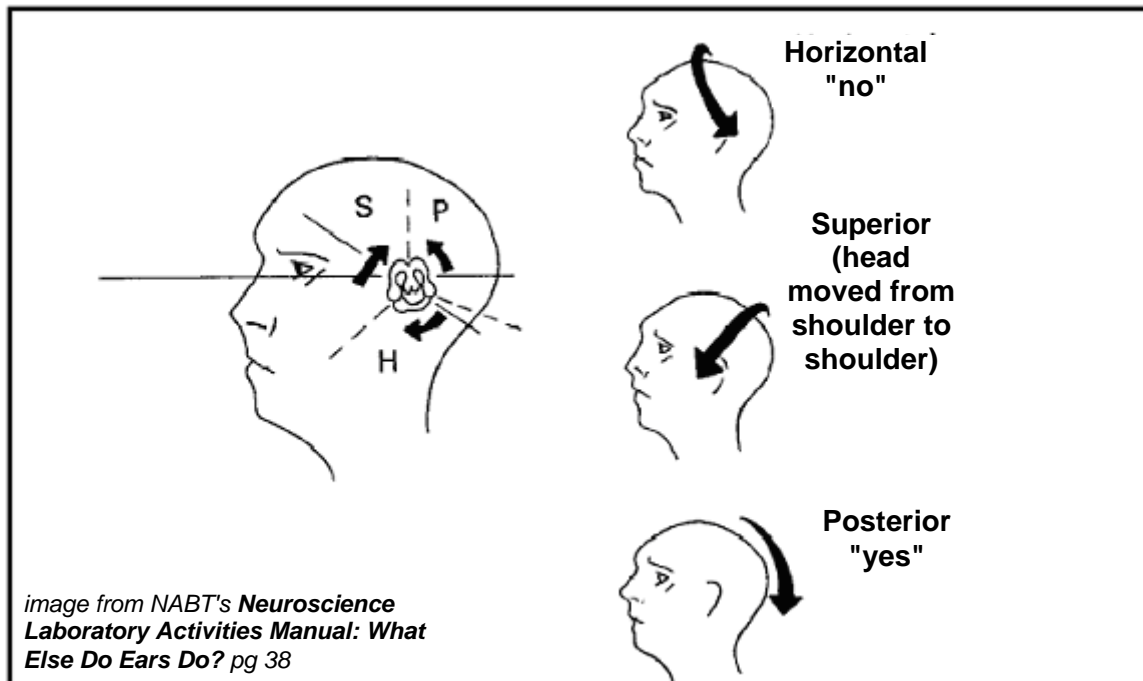


Figure 2: Planes of Rotation of Semicircular Canals

The vestibular system senses linear and angular acceleration. An example of linear acceleration is the sensation experienced when a person rides in an elevator. The sensation usually is felt when the elevator starts and stops. Linear acceleration also is sensed during take-off and landing in an airplane. The otolith organs are responsible for the linear sensation. An example of angular acceleration is the sensation that occurs when the body is off balance. The semicircular canals respond to these movements. It is not known how the otolith organs and the semicircular canals work together in response to different situations.

How does the vestibular system accomplish its subtle and complex tasks? The semicircular canals are a series of circular chambers filled with fluid. Each canal has a highly specialized section to detect motion and transduce (change) it into a nerve signal. These specialized regions contain receptor cells. Each receptor cell contains a set of hairs or *cilia* that extend into the semicircular canal. If the fluid and the canal move at different speeds, the hairs are subjected to a shearing force because they are anchored on only one end. This force causes receptor cells to depolarize and send a signal to the adjacent nerve. The sensory cells therefore convert mechanical energy into electrical energy by detecting movement and sending a signal to the central nervous system.

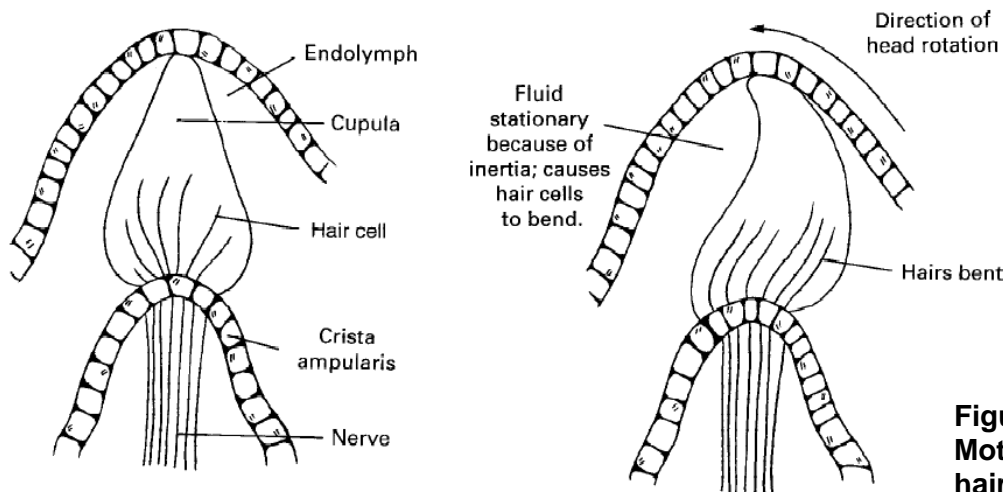
The act of spinning in **Engage -- Walking the Line** will help demonstrate how the system works. When a person begins to spin, he/she senses rotation in the direction of the spin. The reason for this sensation is that the semicircular canals move but, due to inertia, the fluid in the canals does not move immediately. The movement of the canal bends the hairs and triggers an electrical signal. Thus, the hair cells are bent in the opposite direction of the spin. If the person continues to spin, eventually the fluid's inertia is overcome and it begins to move at the same rate as the semicircular canals. During this



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period, little or no bending of the hairs occurs so no signal is sent and the person experiences little sense of movement.

If the fluid and the canals again move at different speeds -- as when the person spins faster, slower, or stops spinning -- the hairs will bend again and the sensory cells will send signals. When the person stops spinning, for example, the semicircular canals cease to move but, due to inertia, the fluid continues to move. The hairs now bend in the same direction as the spin was made and opposite to the direction they bent when the spin was started. This now causes people to feel as if they are moving in the direction opposite the spin. The result is dizziness. The faster the person spins, the longer the dizziness lasts because the fluid takes longer to stop moving. See Figure 3.



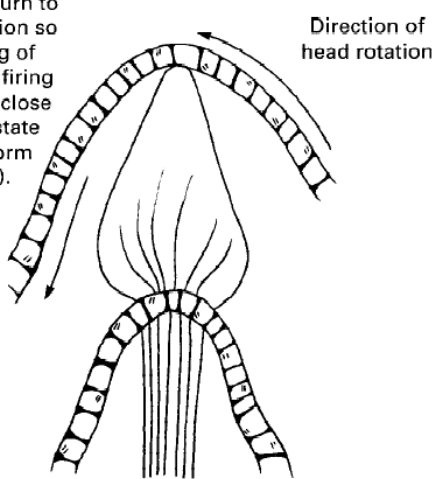
Fluid stationary because of inertia; causes hair cells to bend.

a. At rest (before spinning)

b. Spinning begins

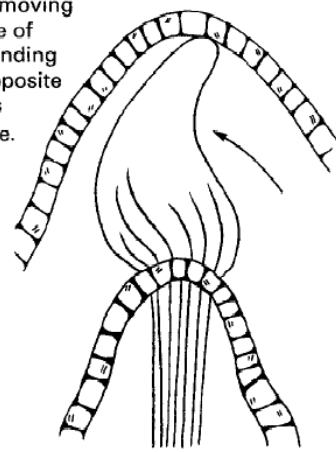
Figure 3: Motion of the hairs in the semicircular canals before, during, and after spinning

Fluid and canals gradually return to resting position so no bending of cilia occurs (firing of nerves is close to resting state with uniform velocity).



c. During spinning

Canals stationary; fluid keeps moving because of inertia, bending hairs in opposite direction as before.



d. Spinning stops

image from NABT's Neuroscience Laboratory Activities Manual: What Else Do Ears Do? pg 40



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If you ask people who have just finished spinning to walk a straight line, they usually will walk lines that curve in the direction of their spins due to the continued motion of the fluid in their semicircular canals. If, however, you ask people to stop spinning and walk an actual straight line, such as a stripe on a football field, they usually can accomplish the task, even though they may tend to lean in the direction they were spinning. They are able to walk straight lines because they can use input from their visual systems to override information from their vestibular systems.

Another example of the visual system being able to overcome the effects of the vestibular system is found in ballet dancing and ice skating. These performers prevent dizziness as they spin by “spotting” — focusing their eyes on a point in the field of vision.

The manner in which the semicircular canals detect motion is modeled by the motion of fluid in a spinning dish. At first, the fluid does not move when the dish is spun. Once the fluid has begun to spin, however, it continues to do so, even if the dish is no longer spun. This is due to inertia, whereby a body remains at rest or continues in uniform motion until acted upon by an outside force. Movement of the hairs in the semicircular canals causes the sensory cells to send a stream of action potentials to the eighth cranial nerve that leads to the vestibular nuclei in the brainstem. The information then goes to the cerebellum, thalamus, and somatosensory cortex where a reflex pathway is set up in the oculomotor system that controls the movement of the eyes. See Figure 4 for a diagram of the vestibular-oculomotor connection.

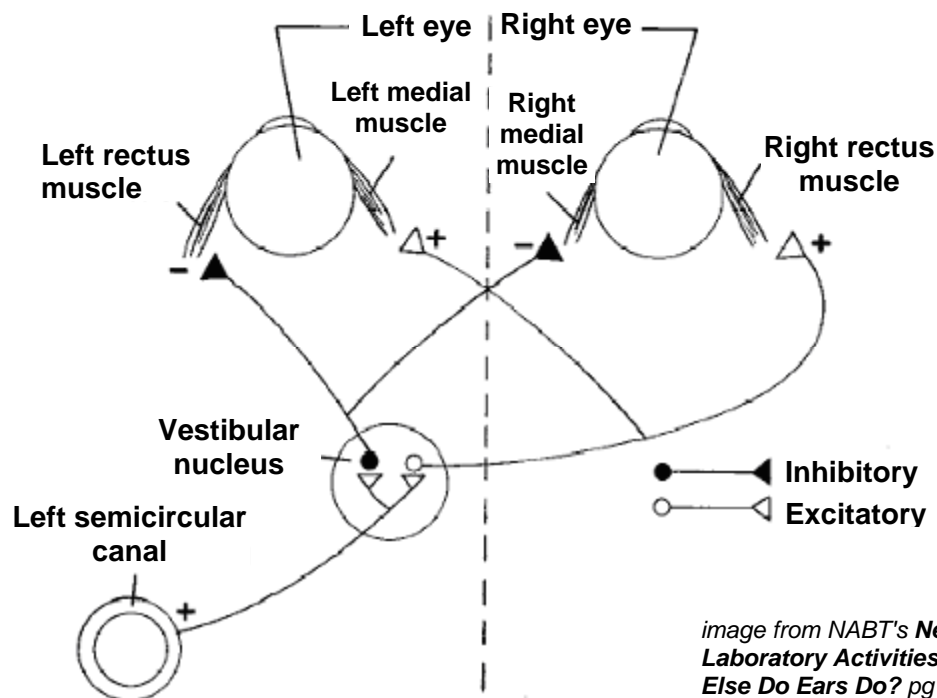


image from NABT's *Neuroscience Laboratory Activities Manual: What Else Do Ears Do?* pg 41

Figure 4: The vestibular-oculomotor connection



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This pathway helps the eyes to remain fixed on a visual field. For example, if you are rotating to the right, the vestibular nucleus excites firing to the right rectus muscle and the left medial muscle, pulling both of your eyes to the right (in the direction of spin). Simultaneously, the left rectus and right medial muscles are inhibited which prevents your eyes from being pulled back to the left. It is important to note that this inhibition does not prevent your eyes from being returned to normal position—it just slows it down so that your eyes may follow the spin. Continued movement of the fluid in the horizontal semicircular canals thus causes jerky, side-to-side movements of the eyes called *nystagmus* (Nis-'stag-mus). The students will observe this side-to-side eye movement associated with the eye and inner ear. It is seen immediately after the student stops spinning in a circle. Figure 5 indicates how this works.

Physiologic Nystagmus

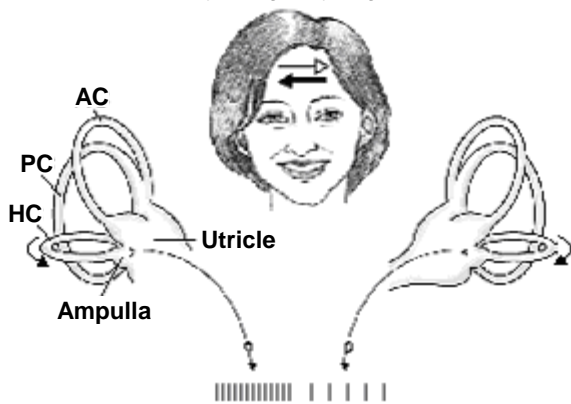


Figure 5: Rotational-Induced Nystagmus

The person is spinning to her left. In the figure, thin straight arrows give the direction of slow movement; thick straight arrows give the direction of fast movement; curved arrows give direction of endolymph flow in the horizontal semicircular canals. AC--anterior canal, PC--posterior canal, HC--horizontal canal.

image from http://www.hearct.com/balance_southbury_connecticut.php

This reflex movement is caused when the fluid in the canal displaces the hair cells in a direction opposite to their initial position when they started spinning. This stimulates the eyes to move quickly in a direction opposite of the spin. The eyes will continue to move back and forth until the motion of the fluid stops. **Explore: Eye Tracking** demonstrates how the connection between the semicircular canals and the eyes helps to keep the visual field as stable as possible to provide information about the orientation of the body continuously.

A practical application of the reflex connection between the semicircular canals and the eyes can be demonstrated in the following way. Look at the words on this page and turn your head to the right. As your head moves to the right, your eyes stay focused on the page by moving to the left at the same rate of speed that you move your head to the right.

The ability to see the words clearly even as you move your head is possible because of the coordination of input information between the eyes and canals. Another application of this reflex connection is used by physicians to diagnose and detect problems in the vestibular system. Warm and cold water are placed in the ear canal. The thermal currents of the water are sufficient to move the hair cells, resulting in nystagmus.