National Aeronautics and Space Administration

The Vestibular System

Educator Notes

Learning Objectives

- Identify structures of the human vestibular system.
- Define and demonstrate pitch, roll, and yaw.
- Describe how the vestibular system supports our perception of motion, spatial orientation, and balance.

Safety

- Spinning may cause students to experience symptoms of motion-sickness. Students should immediately stop the study if the subject experiences anything beyond mild symptoms.
- Inspect the testing zone to ensure the spinning chairs are in working order and remove any nearby environmental hazards.
- To prevent injury or accidental falls, ask student subjects to remain seated during the trials until they are fully oriented.

Investigation Preparation

STEMonstration Video

- Watch the Vestibular System STEMonstration video found at https://nasa.gov/stemonstrations.
- Write down the words roll, yaw, and pitch on the board and go over each term as a class. Ask students to move their heads to demonstrate each movement.
- Project a picture of the vestibular system's labyrinth on the board. Highlight the following parts for student reference: semicircular canals, otolith organs (saccule and the utricle), and discuss how each one functions to help us orient ourselves.

Facilitate Investigation

Test

- Hand out one copy of the Vestibular System Student Worksheet to each group.
- Project the background information from the student worksheet on the board and read it out loud while students listen and follow along. Pause, check for understanding, and reference the vestibular system's labyrinth diagrams as needed.
- Before performing this demonstration, form small groups of four to five students. Review the roles for students to perform within their groups during the investigation. After the subject performs all four trials, rotate roles to allow each student an opportunity to be the subject.
  - **Subject:** Sits in the chair and responds to operator signals.
  - **Operator:** Rotates and signals the subject.

Grades 6 to 12

Suggested Pacing

60 minutes total

- STEMonstration Video–10 min
- Test–40 min
- Share–10 min

Materials

Provide one per group unless otherwise specified.

- Disposable earplugs (one pair per student)
- Disposable eye masks (one per student)
- Flashlight
- Spinning office chair
- Vestibular System Student Worksheet
- Neck pillow
- Stopwatch or watch

National STEM Standards

- HS-LS1-2
- HS-LS1-3
- MS-LS1-1

  - **Technician:** Tracks the spin time for each subject and measures deviant distance.
  - **Data Recorder:** Assesses subject's symptoms after each trial and records data for the group.
- Distribute one pair of earplugs and an eye mask to each student. Provide one spinning chair to each group and ensure each group has a stopwatch or a watch to track spinning time.
- As a class, select four highly visible landmarks, each located on a different wall in the classroom (i.e. wall clock, exit sign, a poster on the wall). For consistency, choose landmarks roughly the same size and about three to four feet from the floor. Alternatively, the teacher can place multi-colored construction paper or numbered pages on the walls to use as landmarks. List the four landmarks on the board for students to reference during the investigation.
- As a class, thoroughly go over the procedures and demonstrate each of the four trials. Discuss signals with the class before allowing students to begin working on their investigation. The subject must keep their earplugs and eye mask on while responding to the operator's signals. Have students review these signals with their group each time a change in roles occurs. Dim the lights slightly to make it easier for students to identify the direction of the flashlight. Keep the room as quiet as possible to keep the subjects from receiving auditory cues during the investigation.

Operator Signals	Subject Responses
One tap	Subject uses flashlight to indicate "up" direction
Two taps	Subject uses their head to indicate direction according to trial (yaw, roll, or pitch)
Three taps	Subject uses flashlight to indicate direction of landmark

- Students start the lab investigation and record results on their group's worksheet.

Share

- Engage students with a class discussion using the following questions. Ask students to reference their group's results.
  - How did the student subjects feel after spinning and moving their head?
  - Was there a correlation between relatively short deviant distances and subject symptoms?
- Engage students with the following questions asking them to reference their group results and the results from the trials conducted aboard the space station in the STEMonstration video. Replay the STEMonstration video for reference, if needed.
  - Did the subject correctly indicate "up" in trial 1? Why or why not?
  - How did the earplugs and eye masks effect the subject's ability to correctly identify up?
  - How did the earplugs and eye mask effect the subject's ability to correctly locate the designated landmark?
  - What similarities and differences did you expect between the trials completed on the space station and in your classroom?
  - What similarities and differences did you not expect between the trials completed on the space station and in your classroom?

Extensions

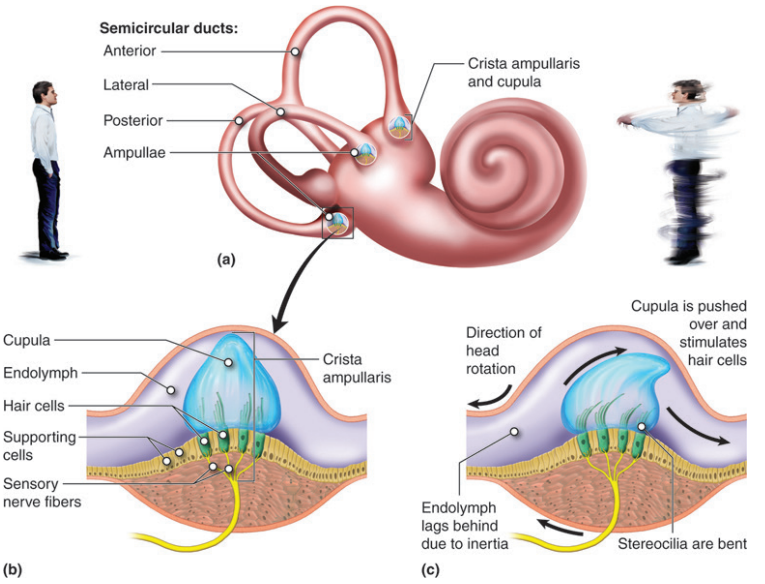
- Trained rotators like gymnasts and dancers perform repetitive rotations without experiencing balance difficulties. Students use statistical software to compare the results of trained rotators in your class to the results of non-trained rotators.
- As a class or in small groups, discuss how hearing or vision loss might impact an individual's perception of motion, spatial orientation, and balance. Consider how adaptive equipment like mobility canes, wheelchairs, or hearing aids help individuals with disabilities navigate their environments.
- Encourage other classes and grade levels to complete this investigation. Students use statistical software to compare findings based on age, whether they are trained rotators, gender, or other factors of interest.

Vestibular System Student Worksheet

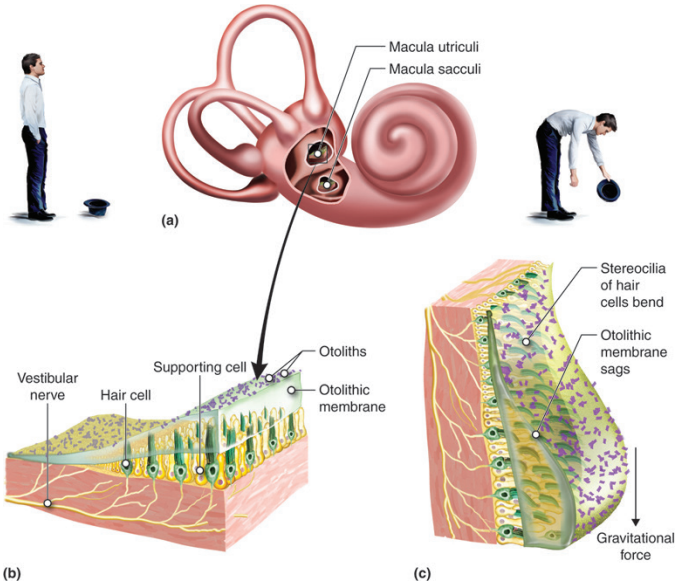
Background

Movement

The ability to collect, process, and respond to information from the environment is essential for the survival of all organisms. The system responsible for providing information on motion, orientation, and what we perceive as balance is the vestibular system. It allows us to sense a variety of movements and maintain our position or equilibrium in a variety of environments. A movement is a change in position which may include a change in speed, direction, or acceleration. Linear acceleration is a change in speed with or without a change in direction, while angular acceleration is a change in both speed and direction. If you are moving in a straight line and increasing or decreasing your speed, you are experiencing linear acceleration. Gravity, a force directed to the center of a mass, causes a linear acceleration. If you are rotating and increasing or decreasing your angular speed, you are experiencing angular acceleration. The vestibular system senses linear acceleration and angular acceleration differently.



Structure and Function of the Semicircular Canals. The three canals each have an ampulla containing a crista ampullaris and cupula (a). When the head is stationary, the cupula, and embedded stereocilia, are not bent (b). When the head rotates in the same plane as one of the canals, the fluid in the canal (endolymph) lags, leading to bending of the stereocilia in the cupula, which initiates nerve impulses. Credits: Lumen Learning



Structure of the Maculae. The macula utriculi (macula of the utricle) lies horizontally while the macula sacculi lies vertically (a). If the head is tilted, the dense otolithic membrane will cause the stereocilia of the hair cells to move from the straight position (b) to the bent position (c), sending signals to the central nervous system that the head has been tilted forward. Credits: Lumen Learning

The Vestibular System

The vestibular system contains several parts beginning with structures in the non-auditory part of the inner ear. The inner ear has a series of interconnected chambers called the labyrinth. In the labyrinth, there are three semicircular canals oriented in different planes to detect different motions. Yaw is the movement a head makes to indicate “no”. Pitch is the movement a head makes to indicate an exaggerated “yes”. Roll is the movement a head makes when rotating from one shoulder to the next. Each canal contains fluid called endolymph. With movement along the plane of a canal, the fluid distorts a small membrane in the canal (the cupula) and bends tiny hairs embedded in it, sending information to the brain on these specific movements.

The Vestibular System

The labyrinth also includes the otolith (ear stones) organs. These organs contain the saccule and the utricle to detect movement along the vertical and horizontal planes. Much like the semicircular canals, these organs also have tiny hairs and a gelatinous layer with small calcium carbonate crystals. With linear acceleration, these crystals move and bend the hair cells.

The movement of materials in both the semicircular canals and otolith organs illustrate inertia, or the resistance of an object to change its movement. Any object with mass has inertia and requires a force to accelerate it. If a structure experiences force, it and anything attached to it accelerates. When you move your head, the semicircular canals attached to it move also. The fluid, however, is not attached, so its' movement lags slightly. This lag causes distortion and bending of the tiny hairs, providing the information on movement. Eventually, the fluid catches up with the attached structures and the sensation of movement ceases. When the head movement stops, the fixed structures of the semicircular canal also stop. The fluid, however, having inertia, resists the change and continues to move, causing the hairs to bend in the opposite direction. Although the head has stopped moving, this lag gives the sensation of movement opposite the original direction of motion.

In a weightless-simulated environment, the semicircular canals sensing angular acceleration respond as they do on Earth. In the otolith organs, the movement of the gelatinous membrane also exhibits inertia and lag, causing the hairs to bend opposite to the direction of motion. The otolith organs respond primarily to linear acceleration. Liner acceleration can be horizontal as experienced inside of a moving car, or vertical as experienced in a moving elevator. Since gravity is a linear acceleration, the vestibular system's response in a weightless-simulated environment is different than on Earth.

Balance in Space

"*For NASA to achieve its goal of sending humans beyond Low Earth Orbit, it is vital we understand the effects of spaceflight on the human body. One challenge to human exploration is the change in gravity fields. The weightless-simulated environment of space can affect the body's ability to collect, process and respond to information. Understanding these effects and how the body adapts is essential to protect crew health and help ensure a safe, successful mission.*"-Dr. Mark Shelhamer, Professor at Johns Hopkins University School of Medicine and former chief scientist of NASA's Human Research program

On Earth, gravity assists in orienting our body to sense which way is down. When our bodies no longer experience the pull of gravity, the semicircular canals function as they do on Earth, while the otolith organs do not. Our brains process movement using the structures of our inner ears, along with visual cues in the environment. In the weightless-simulated environment of space, however, the vestibular system receives mixed messages, and it takes more time for our brains to determine which way is down. As a result, many first-time astronauts aboard the space station get space sickness or space adaptation syndrome. This is a period where the body is adjusting to the new weightless-simulated environment and trying to orient itself.

Although there is not an up or down in space the way we perceive it on Earth, astronauts acclimate to their environment by designating an up and down on the station. The space station modules and labels on the panels are all oriented in the same direction. When read the same way we do here on Earth, the labels provide a visual cue to help astronauts orient themselves. When the astronauts return to Earth, their bodies must once again readapt to Earth's gravitational pull.

Procedures

- In groups of four to five students, assign the following roles to perform during the investigation. The data recorder writes the name of the student responsible for each role on the student worksheet. Alternate roles allowing each student the opportunity to participate as the subject. Use a different data table for each new subject.
  - **Subject:** Sits in the chair and responds to operator signals.
  - **Operator:** Rotates and signals the subject.
  - **Technician:** Tracks the spin time for each subject and measures deviant distance.
  - **Data Recorder:** Assesses subject's symptoms after each trial and records data for the group.
- Choose one of the four landmark options given by your teacher. Use this same landmark for the duration of this investigation.
- Review the following operator signals and subject responses.

Operator Signals	Subject Responses
One tap	Subject uses the flashlight to indicate "up" direction.
Two taps	Subject uses their head to indicate direction according to trial (yaw, roll, or pitch)
Three taps	Subject uses flashlight to indicate direction of landmark

Trial 1: Perception of Up

1. As a group, discuss operator signals and subject responses. Once seated, the subject puts on earplugs and an eye mask.
2. The operator gently rotates the chair clockwise and/or counterclockwise randomly for 20 seconds while the subject keeps their head in an upright position.
3. After a gentle stop, the operator signals the subject with a single, gentle tap on the shoulder to indicate up using the flashlight.
4. Data recorder records whether the subject was able to correctly indicate up and any subject symptoms on the group's worksheet.

Trial 2: Yaw

1. As a group, review operator signals and subject responses.
2. The subject identifies the chosen landmark and then sits in the chair. Once seated, the subject puts on earplugs and an eye mask.
3. The operator gently rotates the chair clockwise and/or counterclockwise randomly for 20 seconds while the subject moves their head in a continuous yaw motion (exaggerated "no" motion)
4. After a gentle stop, the operator signals the subject with three gentle taps on the shoulder. Still blindfolded with earplugs and seated, the subject uses the flashlight to point to where they think the landmark is located. The data recorder places a sticky note on the wall in the middle of where the subject indicated the landmark. The data recorder and the technician measure the deviant distance and/or angle from the center of the landmark to the center of the sticky note. Round the distance to the nearest centimeter.
5. Data recorder records the deviant distance and any subject symptoms on the group's worksheet.

Trial 3: Pitch

1. As a group, review operator signals and subject responses. Once seated, the subject puts on the neck pillow, earplugs, and an eye mask.
2. The operator gently rotates the chair clockwise and/or counterclockwise randomly for 20 seconds while the subject moves their head in pitch (an exaggerated yes motion).
3. After a gentle stop, the operator signals the subject with a single, gentle tap on the shoulder to indicate up using the flashlight.
4. Data recorder records whether the subject correctly indicated up and any subject symptoms on the datasheet.

Trial 4: Roll

1. As a group, review operator signals and subject responses. Once seated, the subject puts on the neck pillow, ear plugs, and an eye mask.
2. The operator gently rotates the chair clockwise and/or counterclockwise randomly for 20 seconds while the subject moves their head in roll (shoulder to shoulder motion).
3. After a gentle stop, the operator signals the subject with a single gentle tap on the shoulder to indicate up.
4. Data recorder records whether the subject was able to correctly identify up and any subject symptoms on the group's worksheet.
5. Once all four trials have been performed by the subject, have the subject remove the ear plugs and eye mask. Ensure the subject is fully oriented before standing up. Alternate roles and complete a new data table for each new subject.

Data

Record data for each participant in the data tables below. You do not need to record data for the areas containing a dash in the data table. Use a different data table for each new subject.

Data Table: Subject 1 _____

Operator:_____, Technician:_____, Data recorder:_____

Trial	Did the subject correctly identify "up"?	Was the landmark correctly identified?	Deviant distance from landmark (meters)	List any symptoms the subject is experiencing. (dizziness, disorientation, nausea, headache, etc.)
Trial 1: Perception of Up		-	-	
Trial 2: Yaw	-			
Trial 3: Pitch		-	-	
Trial 4: Roll		-	-	

Data Table: Subject 2 _____

Operator:_____, Technician:_____, Data recorder:_____

Trial	Did the subject correctly identify "up"?	Was the landmark correctly identified?	Deviant Distance from landmark (meters)	List any symptoms the subject is experiencing. (dizziness, disorientation, nausea, headache, etc.)
Trial 1: Perception of Up		-	-	
Trial 2: Yaw	-			
Trial 3: Pitch		-	-	
Trial 4: Roll		-	-	

Data Table: Subject 3 _____

Operator:_____, Technician:_____, Data recorder:_____

Trial	Did the subject correctly identify "up"?	Was the landmark correctly identified?	Deviant Distance from landmark (meters)	List any symptoms the subject is experiencing. (dizziness, disorientation, nausea, headache, etc.)
Trial 1: Perception of Up		-	-	
Trial 2: Yaw	-			
Trial 3: Pitch		-	-	
Trial 4: Roll		-	-	

Data Table: Subject 4 _____

Operator:_____, Technician:_____, Data recorder:_____

Trial	Did the subject correctly identify "up"?	Was the landmark correctly identified?	Deviant Distance from landmark (meters)	List any symptoms the subject is experiencing. (dizziness, disorientation, nausea, headache, etc.)
Trial 1: Perception of Up		-	-	
Trial 2: Yaw	-			
Trial 3: Pitch		-	-	
Trial 4: Roll		-	-	

Data Table: Subject 5 _____

Operator:_____, Technician:_____, Data recorder:_____

Trial	Did the subject correctly identify "up"?	Was the landmark correctly identified?	Deviant Distance from landmark (meters)	List any symptoms the subject is experiencing. (dizziness, disorientation, nausea, headache, etc.)
Trial 1: Perception of Up		-	-	
Trial 2: Yaw	-			
Trial 3: Pitch		-	-	
Trial 4: Roll		-	-	