National Aeronautics and
Space Administration

Educational Product	
Educators & Students	Grades 7 - 12

EB-2002-09-011-KSC

Educational Brief

The Effects of Space Flight on the Human Vestibular System

How does the human body maintain a sense of body position and balance on Earth, while flying in an airplane, or traveling through space?

Introduction

The presence of sensory and response systems is a universal attribute of life as we know it. All living organisms on Earth have the ability to sense and respond appropriately to changes in their internal and external environment. Organisms, including humans, must sense accurately before they can react, thus ensuring survival. If our senses are not providing us with reliable information, we may take an action which is inappropriate for the circumstances and this could lead to injury or death.

Above: Mealtime for the STS-45 crew. Up and down are a matter of personal perspective.

How Many Senses?

We are all familiar with the question, "How many senses do humans have?" The answer we hear most often is five: sight, taste, smell, hearing, and touch. (Touch itself includes heat, cold, pressure, and pain.) Actually, there are many other senses — hunger, thirst, kinesthetic, etc. One of the most powerful of the other senses is the vestibular sense, provided by the *vestibular system*. It is our ability to sense body movement combined with our ability to maintain balance (equilibrium). The human body has a remarkable ability to sense and determine the direction and speed in which it is moving and maintain balance (postural equilibrium).

Human beings have the ability to walk a tightrope, do repeated pirouettes in a ballet performance, combine twists and turns when diving, or perform triple toe loops while ice skating…all (usually) without losing balance and while keeping track of the relative position of arms and legs with respect to the rest of the body. Incredible!

How does the human body sense and control the movement so precisely? How do we maintain balance while putting ourselves through a wide variety of spinning and tumbling activities that are inherently "unbalancing"? When we are in motion, how do we know in what direction and at what speed we are moving? How do these important body senses change or adapt when we fly in an aircraft or enter the microgravity* environment of low Earth orbit? Can these sensory and response systems, which work so well here on Earth, provide us with inaccurate and potentially harmful information when we fly as pilots or astronauts? Let's find out!

Maintaining postural equilibrium, sensing movement, and maintaining an awareness of the relative location of our body parts requires the precise integration of several of the body's sensory and response systems including visual, vestibular, *somatosensory* (touch, pressure, and stretch receptors in our skin, muscles, and joints), and auditory. Acting together, these body systems constantly gather and interpret sensory information from all over the body and usually allow us to act on that information in an appropriate and helpful way.

Body movements undertaken in our every day "Earth-normal" environment usually do not upset our sense of balance or body orientation. However, we have all experienced dizziness and difficulty walking after spinning around in a circle. How does the unique gravitational condition encountered in space flight affect an astronaut's sense of body orientation, movement, and balance?

Astronauts experience similar sensations of dizziness and disorientation during their first few days in the microgravity environment of space. Upon returning to Earth after prolonged exposure to microgravity, astronauts frequently have difficulty standing and walking upright, stabilizing their gaze, and walking or turning corners in a coordinated manner. An astronaut's sense of balance and body orientation takes time to re-adapt to Earth-normal conditions.

Something about the vestibular system obviously adapts to changing conditions, but what? Why? How? Might a better understanding of this microgravity-induced vestibular function help people back on Earth prevent the dizziness, disorientation, and susceptibility to falling that some older people experience? Answers to these important and interesting questions require us to know more about the anatomy (structure) and physiology (function) of the human vestibular system on Earth as well as in space.

For many years, NASA has been investigating the human vestibular system's adaptation to the space environment. Important experiments were performed on STS-40 (Spacelab-1), STS-58 (Spacelab-2), and STS-90 (Neurolab). Future flight experiments will help us to better understand the physiology of our vestibular system by building on what we have learned from previous missions and ground-based research.

Things to Know:
Vestibular Anatomy and Physiology

Please refer to Figure 1 as we learn some important and interesting facts and terms about the ear and vestibular anatomy and physiology.

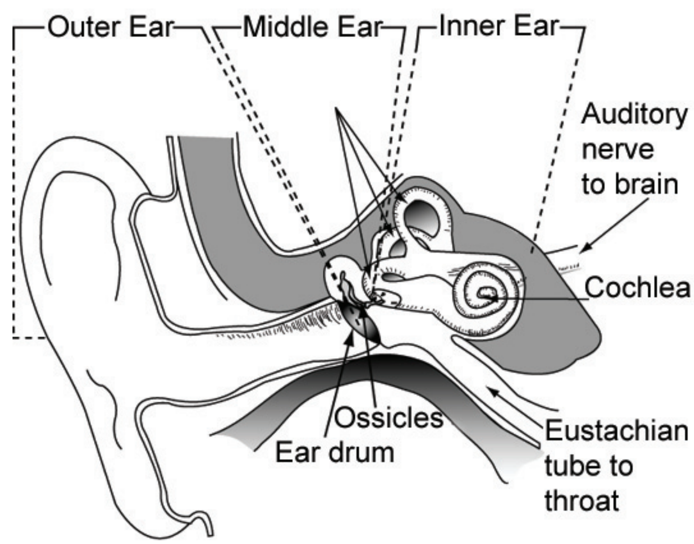


Figure 1: The Outer, Middle, and Inner Ear

*Microgravity is an environment created by freefall in which gravity's effects are greatly reduced. For more information about the topic of microgravity you can refer to NASA's Microgravity Teacher's Guide [EG-1997-08-110-HQ]. See "Additional Resources" at the end of this Educational Brief for information on how to obtain this product.

The ear is made up of several smaller structures that can be organized into three distinct anatomical regions: an outer ear which extends from outside the body through the ear canal to the tympanic membrane (ear drum); a middle ear, an air-filled cavity containing three tiny bones (ossicles) that transmit and amplify sound between the ear drum and the cochlea (where the sense of hearing is located); and the inner ear, composed of the cochlea and the vestibular system.

The vestibular system (Figure 2), which is key to our senses of balance, motion, and body position, is comprised of three *semicircular canals* connected to two membranous sacs called the *saccule* and *utricle*. The saccule and utricle are often referred to as the *otolith organs*. The otolith organs allow us to sense the direction and speed of *linear acceleration* and the position (tilt) of the head. The semicircular canals allow us to sense the direction and speed of *angular acceleration*.

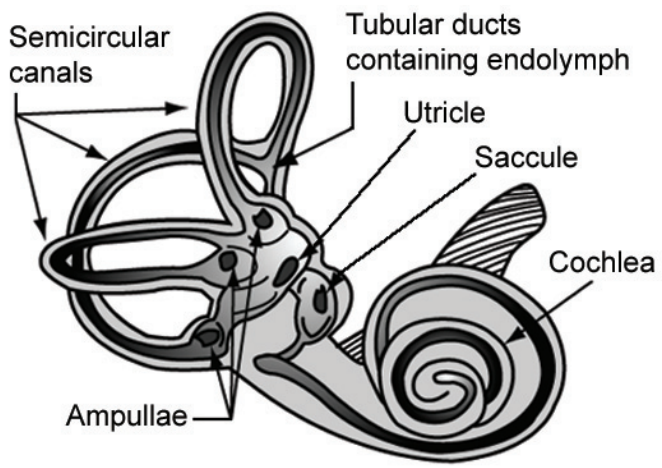


Figure 2: The Vestibular System - semicircular canals and otolith organs

The semicircular canals are oriented along three planes of movement with each plane at right angles to the other two. Pilots and astronauts call these three planes of rotation *pitch* (up and down; nod your head "yes"), *roll* (tumbling left or right; move your head from your left to your right shoulder or vice versa), and *yaw* (lateral movement left and right; shake your head "no"). See Figure 3.

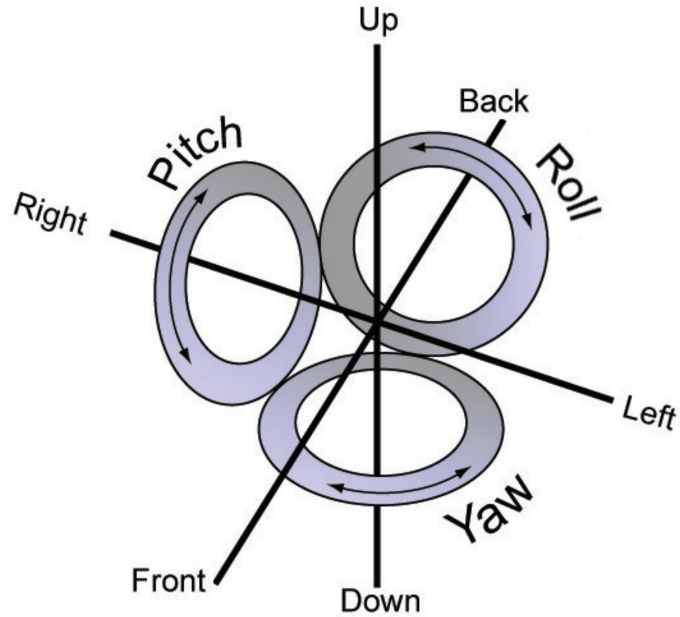


Figure 3: Roll, Pitch, and Yaw planes of motion

What's the difference between angular and linear acceleration? Linear acceleration is a change in velocity (speed increasing or decreasing over time) without a change of direction (straight line). Angular acceleration is a change in both velocity and direction at the same time. For example, imagine you are in a stopped car. The driver of the car steps on the accelerator and you accelerate straight ahead. The driver steps on the brake pedal and you decelerate to a stop. Then the driver puts the car in reverse and you accelerate straight backwards, and then the driver slams on the brakes once again. You have just experienced linear acceleration and deceleration in both forward and backward directions. Your movement was along a straight line and your otolith organs helped you sense these linear accelerations and decelerations.

Imagine yourself on a roller coaster. You start out accelerating straight ahead, just like in the car. Suddenly, the track dips almost straight down and you "pitch" forward. Then the nose of your car (and you) comes almost straight up. You have just experienced downward and upward pitch. The roller coaster, while staying perfectly flat on the track, now takes a severe left turn followed by a right turn. You have just "yawed" to the left and right. Now comes the really fun part. Your roller coaster and the track do a complete 360-degree roll, first to the left and then to the right. Makes you dizzy just thinking about it, right? You have just experienced the three planes of angular acceleration; pitch, yaw, and roll. An aircraft, a spaceship, or any vehicle operating in three-dimensional space can accelerate in these three planes of rotation and often along more than one plane at the same time. Your semicircular canals enable you to sense these angular accelerations.

Although they are both located within the vestibular apparatus of your inner ear, are interconnected, and operate using similar physical principles, the sensory mechanisms which allow you to detect linear acceleration (otolith organs) are structurally and functionally different than those which allow you to detect angular acceleration (semicircular canals).

The vestibular system also helps you maintain a fixed gaze on a stationary or moving external object while you are undergoing complex head and body movements. Look at the clock on the wall. Now move your head sideways or up and down, or even in a circle. Your eyes stay fixed on the clock. With slow movement, the eyes are kept stationary by visual mechanisms only. As the speed of movement increases, the vestibular system takes over the image stabilization process. This reflexive eye movement, *nystagmus*, can be demonstrated by using a *Barany Chair*.*

Vestibular Physiology: How Structure Supports Function

Now that you understand the location and overall design of your vestibular system and its role in providing you with reliable sensory input, let's investigate the structure and functions of its two different components.

*Robert Bárány was a Nobel Prize winning physiologist, recognized for his research on the vestibular system. To learn more about the man and his work, see "Additional Resources".

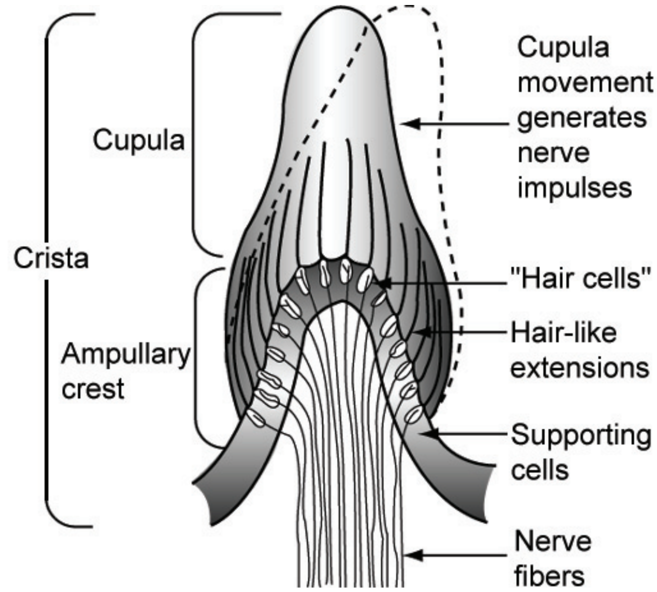


Figure 4: Crista (cupula and ampullary crest) When movement of the endolymph causes cupula to bend, sensory hair cells generate nerve inpulses which the brain perceives as angular acceleration.

First, look at Figures 4 and 6 for detailed views of the structures within the vestibular system. You will notice that all vestibular organs (semicircular canals, saccule, and utricle) functionally rely on a common type of receptor cell, called a *hair cell.*

The Semicircular Canals (Figures 4 and 5)

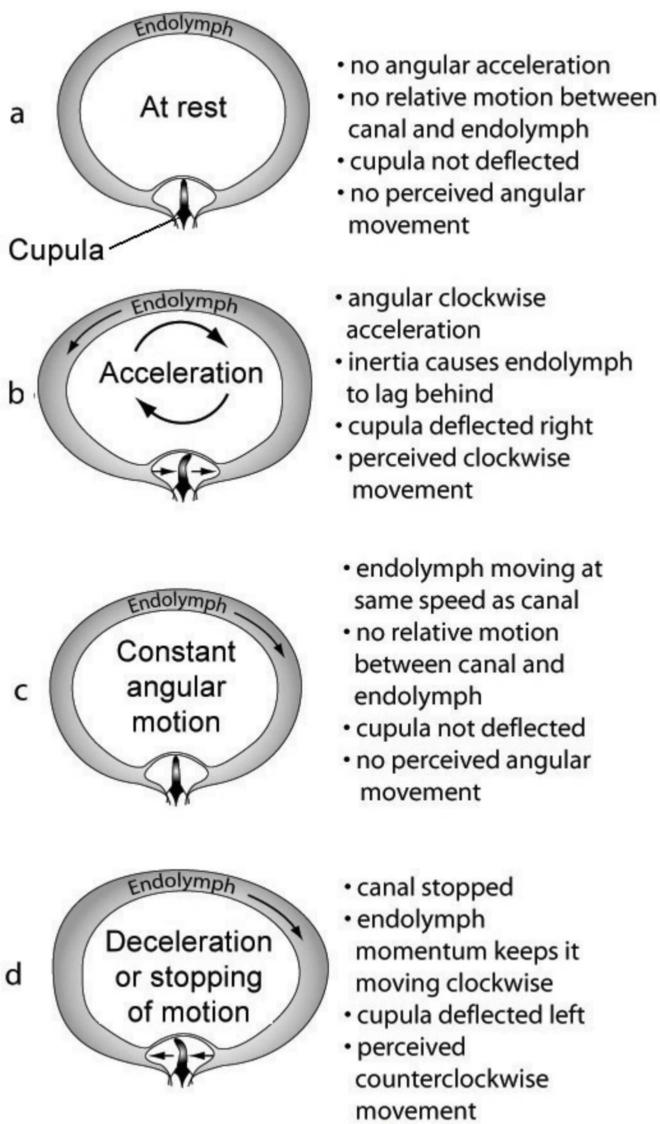
The semicircular canals are a set of three membranous tubes embedded within a bony structure of the same shape. The central cavity of each canal is filled with a fluid called *endolymph.* Each endolymph-filled canal has an enlarged area near its base called an *ampulla.*

Parts of the vestibular nerve penetrate the base of each ampulla and terminate in a tuft of specialized sensory hair cells. The hair cells are arranged in a mound-like structure called the ampullary crest. Rising above the ampullary crest is the *cupula,* consisting of the hair-like extensions of the hair cells surrounded by a gelatinous material arranged into a wedge-shaped structure. This structure consisting of the ampullary crest and the cupula is called a *crista*.

When the endolymph moves (or the cupula moves and the fluid remains stationary), the gelatinous tip of the cupula and the hair cell extensions embedded within it are displaced to one side or the other. When the embedded hair cells bend, they send a signal via the vestibular nerve to the brain where the information is evaluated and appropriate action is initiated.

The mechanics of how the semicircular canals actually function to “sense” angular acceleration may be more easily understood by reviewing

Figure 5: The effects of angular acceleration on the semicircular canals



the physics of *inertia*. The Law of Inertia states that “a body at rest remains at rest unless acted upon by an unbalanced force.” This is important because angular acceleration and deceleration primarily affect the semicircular canals and entirely depend on the relative movement of endolymph with respect to the cupula.

This means that if you were to begin accelerating along one of the three planes of rotation (pitch, roll, or yaw), structural components of the corresponding semicircular canal would begin moving immediately since they are attached to the rest of your head. However, the endolymph within that particular semicircular canal would tend to “remain at rest” due to inertia. See Figure 5a. It would lag behind the structural components, deflecting the cupula and generating a nerve impulse to the brain.

Initially, the membranous tubular and cellular structures move but the fluid does not. Thus, there is relative movement between the fluid and the rest of the semicircular canal. See Figure 5b. Eventually, due to friction and the drag it induces, the fluid begins to move at the same speed as the components within which it is contained. When this occurs, the cupula is not deflected and, even though your body is continuing to angularly accelerate, the acceleration is not “sensed.” You incorrectly perceive that you are stationary. See Figure 5c.

Now, let’s stop your angular acceleration suddenly. What happens? The moving fluid now has *momentum* and so it continues to move until friction and drag bring it to a stop. In other words, fixed structures of your semicircular canal stop immediately (since they are still attached to your head which is still attached to your body) but the endolymph fluid continues to move in the direction of the previous movement. The Law of Inertia also states that a body in motion will continue in motion in a straight line unless acted upon by an unbalanced force. Now, the cupula and the embedded hair cells are bent in the opposite direction. This causes you to incorrectly sense that you are accelerating in the direction opposite to your previous acceleration, even though you are completely stopped! See Figure 5d.

Don’t believe it? Later, experiments using the Barany Chair and semicircular canal models will demonstrate this phenomenon to you.

Saccule and Utricle (Figure 6)

The saccule and utricle are referred to collectively as “the otolith organs.” They sense linear acceleration and are affected by gravity. They also provide you with information concerning changes in head position (tilt). Because of the way they are situated within the vestibular apparatus, the saccule is more sensitive to vertical acceleration (like riding in an elevator) and the utricle is more sensitive to horizontal acceleration (riding in a car).

Both the saccule and the utricle contain a thickened patch of specialized cells called a *macula* that consists of sensory hair cells interspersed with “supporting” cells. The free hair-like tufts extending from the hair cells are embedded in a gelatinous otolithic membrane which supports small piles of calcium carbonate crystals on its surface. Collectively, these calcium carbonate crystals are called *otoliths*. The otoliths increase the mass of the otolithic membrane and give it more inertia. On Earth, when the head is tilted to the left or right, forward or back, the otoliths tend to move along the gravity gradient (downwards). Even a slight movement of the otolithic membrane is enough to bend hair cells and send sensory information to the brain. A similar inertia and gravity-dependent process occurs when you accelerate linearly — up or down, forward or backward.

The underlying physiology and functioning of the otolith organs are remarkably similar to those of the semicircular canals. Both systems depend upon inertia and the mechanical deflection of hair cells to initiate nerve impulses that are sent to the brain and interpreted as body movement. The brain then reflexively initiates appropriate “corrective” actions within the nervous, visual, and muscular systems to ensure that situational awareness and balance are maintained.

Let’s reexamine our previous example of rapidly accelerating straight ahead in a car. During forward acceleration, inertia causes the utricle’s otolithic membrane and its associated otoliths to lag behind the portion of the utricle that is firmly attached to the head. This in turn causes the hair cells, whose hair-like extensions are embedded within the otolith membrane, to be deflected backwards. This backward deflection stimulates sensory nerves to fire and this provides the brain with information on the direction and speed of acceleration. A similar process occurs within the saccule when you are in an elevator and it either begins to rise or descend rapidly.

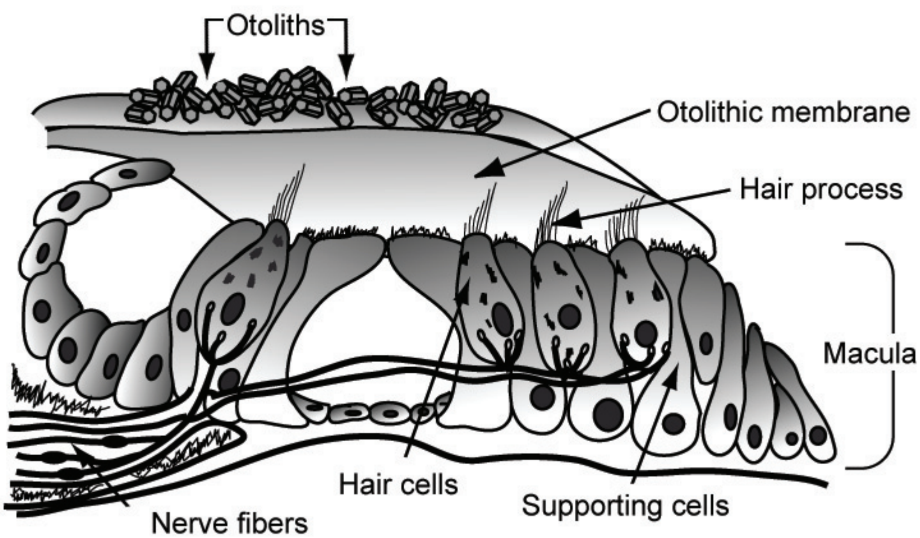


Figure 6: Otolith Organ (saccule or utricle); senses linear acceleration

Vestibular Sense

Humans sense position and motion in three-dimensional space through the interaction of a variety of body proprioceptors, including muscles, tendons, joints, vision, touch, pressure, hearing, and the vestibular system. Feedback from these systems is interpreted by the brain as position and motion data. Our vestibular system enables us to determine body orientation, senses the direction and speed at which we are moving, and helps us maintain balance.

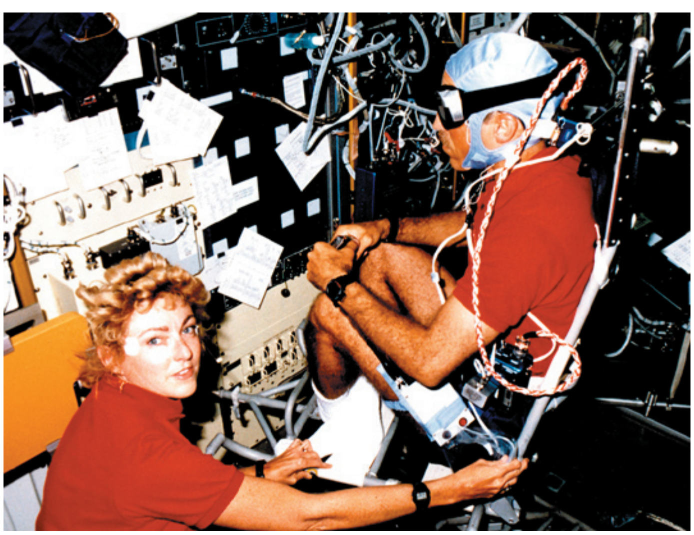
When there is no visual input as is common in many flight situations, we rely more heavily on our vestibular sense for this information. However, in flight and in space, our vestibular system, which is designed to work on the ground in a 1g environment, often provides us with erroneous or disorienting information.

Some of these spatial disorientation effects result in illusions that can be induced for the purpose of scientific research, or even just for fun. Filmmakers and designers of high-tech amusement park rides often use these techniques to pull us into the action and give us a more thrilling adventure. In the laboratory, scientists can use a special rotating seat, called a Barany Chair, to intentionally induce spatial disorientation in their test subjects. This allows the researcher to study how the vestibular system adapts to and functions in various conditions and situations. The next section of this guide describes vestibular experiments that can be done in the classroom and are similar in approach to research that is currently being conducted by NASA.

Understanding the workings of the various organs that comprise this system will lead to improved adaptation strategies for astronauts entering a microgravity environment and returning to an Earth-normal environment. It will also help military and civilian pilots and people on Earth who are prone to dizziness and disorientation. We all benefit from NASA's scientific research on the vestibular system.

Movies Can Make You Sick

Giant screen film theaters in museums and science centers often feature productions containing wild treetop level flight scenes. The screen is so large that viewers often feel like they are part of the action even when they are sitting perfectly still. People will lean with the airplane as it maneuvers. Without arm rests, some people would actually lean far enough over to fall to the floor. The visual effect can be nauseating because the visual and vestibular systems are in conflict. However, feelings of nausea are easily corrected by simply closing the eyes. Sensory conflict and all sensations of motion then stop.



Left: Astronaut James P. Bagian, Mission Specialist, sits in a Barany Chair while wearing an accelerometer and electrodes that record head motion and eye movements during rotation. Payload Specialist Millie Hughes-Fulford assists with the test during the STS-40 mission.

Creating Vestibular Illusions in the Classroom

The following activities use a Barany Chair to isolate the vestibular sense so that motion is interpreted solely on the basis of vestibular feedback. Four powerful vestibular illusions (spatial disorientation phenomena) are described here and can be performed in the classroom. The illusions provide a fun, hands-on opportunity to demonstrate the physiology of the semicircular canals. In these experiments, how the volunteer positions his or her head while the chair is being rotated determines which of the illusions is experienced. Among other effects, the test subject should falsely sense motion when none is taking place, perceive motion in a different direction from that which is actually taking place, or fail to detect motion at all.

By removing or lessening visual and auditory clues, vestibular inputs dominate. To aid in isolating the vestibular system, for Illusions 1, 2, and 3, a blindfold is placed over the volunteer's eyes and all observers remain silent. These conditions are necessary because the failure to sense motion is a difficult illusion to achieve. The illusions are easily interfered with by unintended feedback from other sensory systems. For example, a person whispering will provide auditory cues to the test subject that the chair is or is not rotating. If the room you are using has light and dark areas, the volunteer will see changes in brightness through the eyelids during rotation. For illusions 1, 2, and 3, a blindfold and ear covers will make it easier to achieve the desired effect. **Safety Reminder: Do not use a blindfold or ear covers for Illusion 4.**

Preparation

The instructions for building a Barany Chair start on Page 12. Although the vestibular illusions that will be described work best with a Barany Chair, acceptable results can be obtained by using a swivel office chair. Bearings on office chairs do not permit continuous rotation, so additional pushing is needed. Also, office chairs are lower to the floor and feet may bump or drag, ruining the illusions.

To effectively create the illusions, it is essential that the pushes used to rotate the chair be smooth and uniform. Whether using the Barany Chair or a standard office chair, it is recommended that you practice pushing the chair and bringing it to a rapid but gentle stop.

Clear an area of your classroom large enough to accommodate the chair in its center with observer students in a circle several feet back. Ideally, the room will be windowless or have room-darkening shades. Place the chair in the middle of the room and make sure it is level.

Selecting Test Subjects

The vestibular illusions created by the Barany Chair can produce nausea in some test subjects. Ask volunteers if they are able to ride spinning amusement park rides without becoming sick. Even though the Barany Chair moves much more slowly than the rides, it can produce sickness. Most people should be able to experience Illusions 1 and 2 with only momentary disorientation. Illusions 3 and 4 produce stronger effects.

Important Safety Note: Remain near the chair and be ready to offer physical assistance in case the rider loses balance and risks falling off the chair. Do not attempt any of the illusions without a "spotter."

Illusion 1 – Sensing Yaw Motion

What to Do

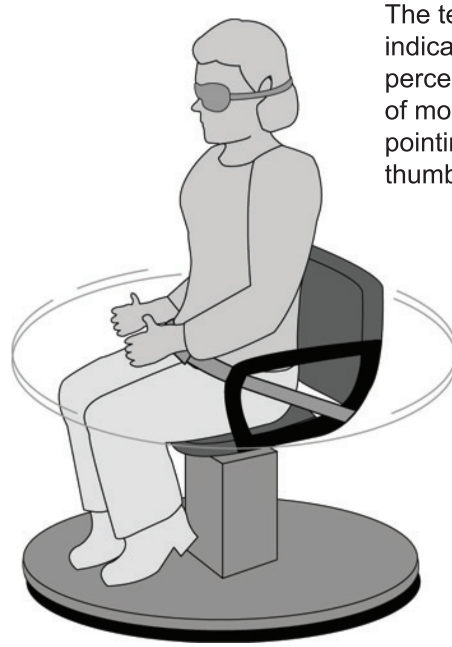
The volunteer sits on the chair with head upright and fists on his or her thighs in the “two thumbs up” position. Tell them to rotate their wrists so that the thumbs point in the direction of movement. If the movement changes to a different direction, the wrists should be rotated so that the thumbs point in that direction. If the volunteer does not perceive any motion, the thumbs should be pointed upwards. Cover the volunteer’s eyes with the blindfold and touching only the seatback of the chair, give the chair a spin. Push the chair hard enough to rotate it eight to ten times. If necessary, give the chair an additional gentle push to keep it rotating. Gripping the chair back, slow the chair to a rapid but smooth stop. Wait a few moments to observe thumb movements and then remove the blindfold. Tell the volunteer to stare at a fixed point on the wall.

What Happens

At first, the volunteer will point thumbs in the same direction the chair is rotating. After stopping the chair, the volunteer will reverse the direction of the thumbs, indicating a feeling of movement in the opposite direction. Upon opening his or her eyes, the volunteer will experience rapid side-to-side flicking motions of the eyes that can be observed by staring directly at the volunteer’s face.

Why

The rotation of the chair causes the endolymph within the yaw axis semicircular canal to begin moving. At first, the inertia of the fluid causes it to lag behind the motion of the subject’s body. This causes the cupula and its hair cells to bend. Now stimulated, the hair cells send signals to the brain telling it that motion has been initiated and in what speed and direction. When the chair is stopped, the momentum of the now moving endolymph causes it to continue moving even though the volunteer’s head and semicircular canals have stopped. The hair cells are now bent in the exact opposite direction as before. This sends a false signal to the brain that the direction of motion has reversed. Nystagmus, an involuntary flicking eye movement, shows the link between the vestibular and visual systems. This reflex occurs when the brain mistakenly believes the body is still moving in this Illusion and instructs the eyes to “look ahead”. The eyes track objects that the brain believes are coming into the field of vision even though the view isn’t changing.



The test subject indicates the perceived direction of movement by pointing his or her thumbs.

Safety Precautions

- The Barany Chair is not an amusement ride. Please follow the directions and exercise caution when it is being used.
- Use the safety lap belt and a spotter at all times.
- Assist students in getting in and out of the chair. A small step stool may be helpful.
- Following demonstrations, allow students to sit in a non-rotating chair until any dizziness wears off.
- Perform only one illusion at a time. Allow a few minutes for the effects of the first illusion to wear off before beginning another.
- Screen candidates for motion sickness, but keep a plastic bag or container nearby in the event of illness.

Vestibular Illusion 2 – Failure to Sense Motion

What to Do
Follow the same set-up used for Illusion 1. Put a dark blindfold on the volunteer and provide ear protection to diminish auditory clues. Rotate the chair as before and have the volunteer identify the direction of motion with their thumbs. Keep the chair spinning 10 or 15 times before very gently stopping it. As with the first illusion, the volunteer should point his or her thumbs in the direction of perceived movement or upward if the volunteer perceives that motion has stopped.

What Happens
The volunteer will perceive the start of motion by pointing his or her thumbs in the direction of rotation. After a number of rotations, the volunteer will point the thumbs upward even though the chair is still rotating. Finally, the volunteer will point thumbs the opposite direction from the first movement to indicate counter rotation.

Why
As with the first illusion, endolymph in the yaw semicircular canal will lag behind the initial motion. Signals sent to the brain will be interpreted as bodily rotation in a particular direction. Gradually, the endolymph in the yaw semicircular canal will catch up with the motion, and stimulation of the hair cells in this canal will stop. The brain will falsely interpret the lack of hair cell stimulation to mean that the chair has come to rest. Later, when the chair slows down or stops, the momentum of endolymph will cause it to continue to flow through the yaw canal. Stimulation in the opposite direction will be falsely interpreted as movement in the opposite direction.

Vestibular Illusion 3 – Sensing Roll Motion

What to Do
Have the volunteer grip the arm rests with both hands. After putting the blindfold in place, instruct the volunteer to drop his or her chin to the chest and close the eyes. Spin the chair at least ten times then bring it to a smooth stop. Tell the volunteer to sit up straight and open their eyes. **Safety Reminder: Be sure to use a spotter when performing this illusion.**

What Happens
The volunteer will experience a powerful cartwheeling sensation to the left or right (depending upon the spin direction) upon opening his or her eyes. The volunteer will find it difficult to remain sitting straight up and will tend to lean aggressively to one side or the other.

Why
By tilting the head forward, the roll axis semicircular canal will be brought into the same plane of rotation as the Barany Chair. By stopping the chair and tilting the head back to the vertical position, the roll axis will be repositioned while the endolymph fluid is still moving in the roll axis canal. This will cause a strong sensation of cartwheeling movement. The volunteer will try to lean in the opposite direction to compensate for the effect.

Vestibular Illusion 4 – Sensing Pitch Motion

What to Do
Have the volunteer grip the arm rests with both hands. Instruct the subject to close their eyes, lean forward slightly, and turn their head as far to one side as possible. Spin the chair at least eight times in the direction the volunteer is facing, then bring it to a smooth stop. Tell the volunteer to sit back and raise his or her head to the upright position and open their eyes. **Safety Reminder: Do not use a blindfold or ear covers when performing Illusion 4. Be sure to use a spotter when performing this illusion.**

What Happens
The volunteer will sense that he or she is tumbling backwards and may have a difficult time sitting up.

Why
By leaning forward and tilting the head to the side, the pitch axis semicircular canal will be brought into the same plane of rotation as the motion of the Barany Chair. After stopping and returning to the upright position, endolymph fluid will continue to move in the pitch axis canal. This will cause a strong sensation of tumbling. The volunteer will readjust his or her body position in order to counteract the perceived movement.

Important Safety Note: While it is possible to simultaneously stimulate all three semicircular canals with the Barany Chair, it is **not** recommended. Simultaneous stimulation of the three canals can lead to total spatial disorientation sensation and illness.

Other Uses for the Barany Chair

The classroom version of the Barany Chair is ideal for a variety of other demonstrations of physics and technological challenges.

Conserving Angular Momentum – Hand the volunteer small barbells to extend at arm's length during the initial rotation. By bringing the barbells in toward the chest, the rotation rate will increase. The rotation rate increases because the barbells are traveling in a smaller circle than before. To conserve their angular momentum, the rotation rate has to increase. Extending the barbells back outward slows the rotation rate, but angular momentum is still conserved. This demonstration gives the illusion of getting something for nothing.

Newton's Laws of Motion – Hand the volunteer an electric leaf blower. While preventing the cord from wrapping too tightly around the pedestal, have the student turn on the blower and direct the exhaust at right angles. The chair will begin to accelerate. After a few rotations, the exhaust should be directed the other way so that the chair decelerates. The rotational movement of the chair demonstrates Newton's First and Third Laws of Motion. The rate at which the chair accelerates or decelerates demonstrates the Second Law of Motion.

Working In Space – Firmly hold a threaded pipe joint over the head of the volunteer. Have the volunteer screw a pipe nipple tightly into the joint. The chair simulates microgravity and Newton's Third Law of Motion comes into play. Without a fixed anchor point, the astronaut rotates in the opposite direction from the turning motion. This demonstration illustrates why space-walking astronauts require foot restraints as they work in space.

Barany Chair - Construction Guidelines

The classroom version of the Barany Chair consists of a pedestal base, bearing mechanism, and a chair with armrests and a seat belt. The Barany Chair pictured here uses an executive style office chair seat. Any kind of office chair can be used, but an armchair is recommended.

The construction plans in this guide will enable you to construct a Barany Chair using power tools and basic hand tools. Most materials for the chair are available from a hardware or lumber store. The chair bearing, obtainable from an auto parts store or automobile salvage yard, is a rear axle bearing from a front wheel drive vehicle. Complete material lists are included in the assembly diagrams. The total cost for the chair, assuming all parts are purchased, will be approximately $150.00.

Constructing the Base, Page 14

The base for the Barany Chair consists of a square frame constructed from 2”x4” lumber and a thick plywood platform made from two 24” square pieces of 3/4” plywood glued together. An alternate base can be constructed from an unfinished round wooden tabletop, available from lumberyards. The top should be approximately 30” in diameter and 1 1/2” thick. To make the Barany Chair a bit easier to move, you may wish to attach heavy-duty floor glides to the bottom of the base. Adjustable glides are available at hardware stores and will also allow you to level the chair, if necessary.

Constructing the Pedestal, Page 15

The bearing and the chair seat will be attached to a pedestal mounted on top of the base. The pedestal consists of a square set internal frame made from 2”x2” or 2”x4” lumber. The frame is held together with screws and glue. Plywood or 3/4” clear pine boards are used to cover the outside of the frame. This facing provides additional strength and improves the appearance of the pedestal. Glue and screw three of the facing sides, but use screws only for the fourth side. This leaves you an access door so you can complete the assembly and tighten bolts and nuts when necessary.

The top of the pedestal is made of two layers of 3/4” plywood that are glued together. Before gluing, the main hole for the bearing mechanism must be drilled. To accommodate the bearing specified on Page 16, use a hole saw to cut two different sized holes in the plywood sheets that will form the top of the pedestal. The lower plywood sheet must have a 2 1/2” hole and the upper sheet must have a 3” hole. The two holes must be concentric to fit the bearing. If a different bearing is used, cut the mounting holes to fit its size. Drill the bolt mounting holes for the bearing. Insert the bearing and bolts and tighten the nuts to hold it firmly.

The pedestal can be mounted permanently to the base with screws and glue, or made removable by attaching it to the base with nuts and bolts. Tee-nuts can be inserted into drilled holes from the bottom of the platform. These remain in place even when the chair is disassembled.

Selecting and Preparing the Chair Seat

Office supply and furniture stores offer a wide range of office chairs. A “task chair” with arms is recommended. Before selecting a chair, check to make sure it does not have a seat tilt adjustment. While a chair with tilt adjustment will work, the method for mounting the pipe nipple and lock nuts may have to be modified. Task chairs without tilt adjustments have simpler seat brackets and are easier to mount.

Office chair seat brackets usually consist of a metal plate with a hole for inserting the tubular pedestal that extends upward from the legs and casters. The custom-made 3/4” galvanized pipe nipple substitutes for the tubular pedestal.

If you purchase a new chair, do not attach the pneumatic tube to the bracket. The pipe nipple will be used instead. If using an existing chair, the tube has to be removed. Remove the chair seat and tap the bracket until the tube slips out of the bracket. The tubular pedestal, legs, and casters are not needed for the Barany Chair.

Building the Bearing Mechanism and Attaching the Chair to the Pedestal, Pages 16 and 17

A 3/4” pipe nipple has to be specially made to fit the chair and the bearing. The nipple can be cut and threaded for a modest charge at a hardware store. The exact length of the nipple will depend upon the design of the seat bracket of the office chair you use.

The bearing specified in this guide is a replacement hub bearing for a 1995 Nissan Sentra. Any similar bearing can be used, but you may need to adjust the diameters of the holes at the top of the chair pedestal. Before gluing the top together and assembling the rest of the pedestal, make sure that the bearing fits snugly.

Thread two 3/4” galvanized lock nuts onto the long threaded end of the nipple. Insert the nipple into the hole for the pneumatic tube and thread a third lock nut onto the nipple to tighten the nipple in place. Be sure to use at least one lock nut immediately beneath the bracket. The bracket is now attached to the seat bottom.

Set the rigid coupling, shown in the mechanism diagram, over the bearing. Lower the chair over the pedestal until the pipe nipple slides through the coupling and into the hole of the bearing. Hold the nipple in place with another lock nut underneath the bearing. When tightened properly, the chair should have no wobble and be able to spin freely.

Right: The completed Barany Chair.

Attaching the Safety Lap Belt, Page 17

A safety lap belt can be made from wide hook-and-loop tape or from webbing and buckles, available from an outdoor or sporting goods store that features climbing equipment. Attach the rear ends of the belt to the chair uprights. Cut the strap length to fit your students. Be sure to use the safety lap belt whenever you use the Barany Chair.

Maintenance Instructions

If the chair seat begins to wobble as it rotates, tighten the lock nuts until the chair no longer wobbles.

Barany Chair -
Base Construction

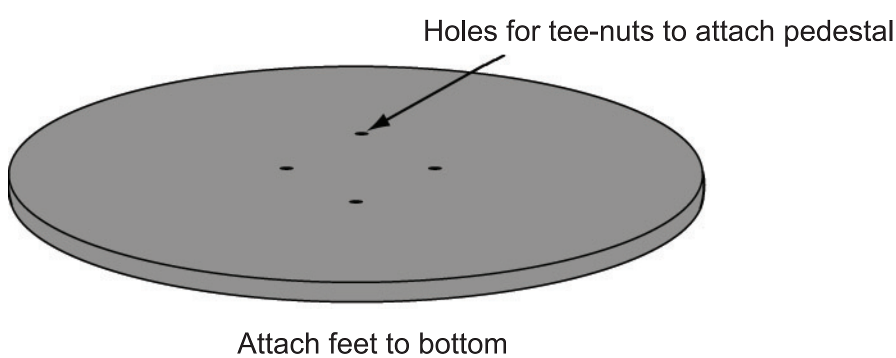
Construction Notes:
- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Classroom Barany Chair.
- Unfinished wood tabletops are available from hardware and lumber stores.
- Drill four holes in through the top to match the bolt holes in the pedestal. Slip tee nuts into these holes from the bottom of the base. When the bolts from the pedestal are screwed into the nuts, the flange on the nuts will draw the base and the pedestal together snuggly.
- Attach rubber feet to the bottom of the pedestal around the rim. Feet are available from hardware stores and come with screws or nails to mount them to the bottom.

Materials List

Number	Quantity	Item	Specifications
1	1	round table top	30” diameter
2	4	tee-nuts	3/16”
3	4	lumber	8’x2”x4”
4	4	rubber feet	screw or nail type

Tools

Electric hand drill - 3/8” or 1/2”
Drill bit for tee-nut holes
Screw driver or hammer to attach feet



Barany Chair - Pedestal Construction

Construction Notes:

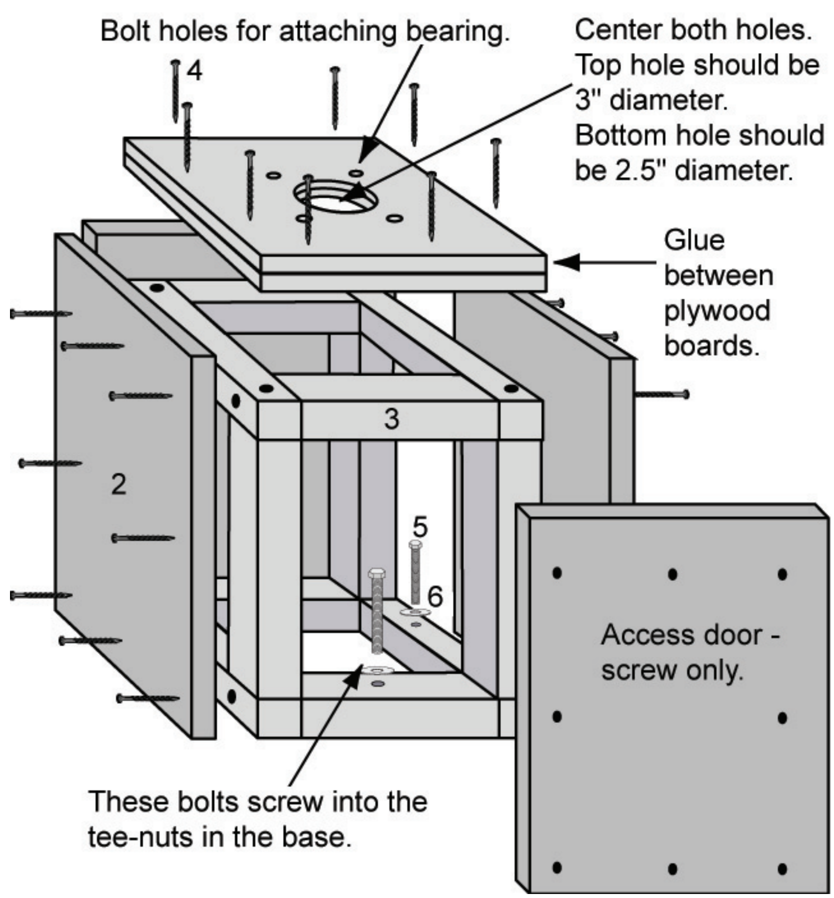
- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Barany Chair.
- The interior square set frame should be constructed from 2”x2” or 2”x4” lumber. The finished size of the pedestal should be 12” wide, 12” deep, and 12” to 15” high depending upon the height of your students. The lengths of the frame pieces you cut will depend upon the size of the wood you use.
- Screw and glue the square set frame together. Be sure to countersink the holes so that the screw heads are flush with the wood. Offset the pilot holes of intersecting screws so that they do not hit each other.
- Face the frame with 3/4” clear pine or plywood. Screw and glue three of the sides but attach the fourth side with screws only. This becomes an access door for tightening bolts.
- The top platform is made from two 3/4” plywood pieces glued together. Before gluing, determine the center of each board. Drill a 2 1/2” hole with a hole saw through the center of the lower board. Drill a 3” hole through the center of the top board. Align them carefully before gluing.
- This design shows 3/16” by 3 1/2” hex bolts used for attaching the pedestal to the base. The bolts extend downward from the pedestal frame into tee-nuts in the base. This permits easy removal of the pedestal from the base. If preferred, the pedestal can be permanently fixed to base with glue and screws.

Materials List

Number	Quantity	Item	Specifications
1	1	wood glue	carpenter grade
2	2	plywood	48”x48”x3/4”
3	4	lumber	8’x2”x4”
4	56	wood screws	#10, 3” Phillips
5	4	hex bolts	3/16” x 3 1/2”
6	4	cut washers	3/16”

Tools

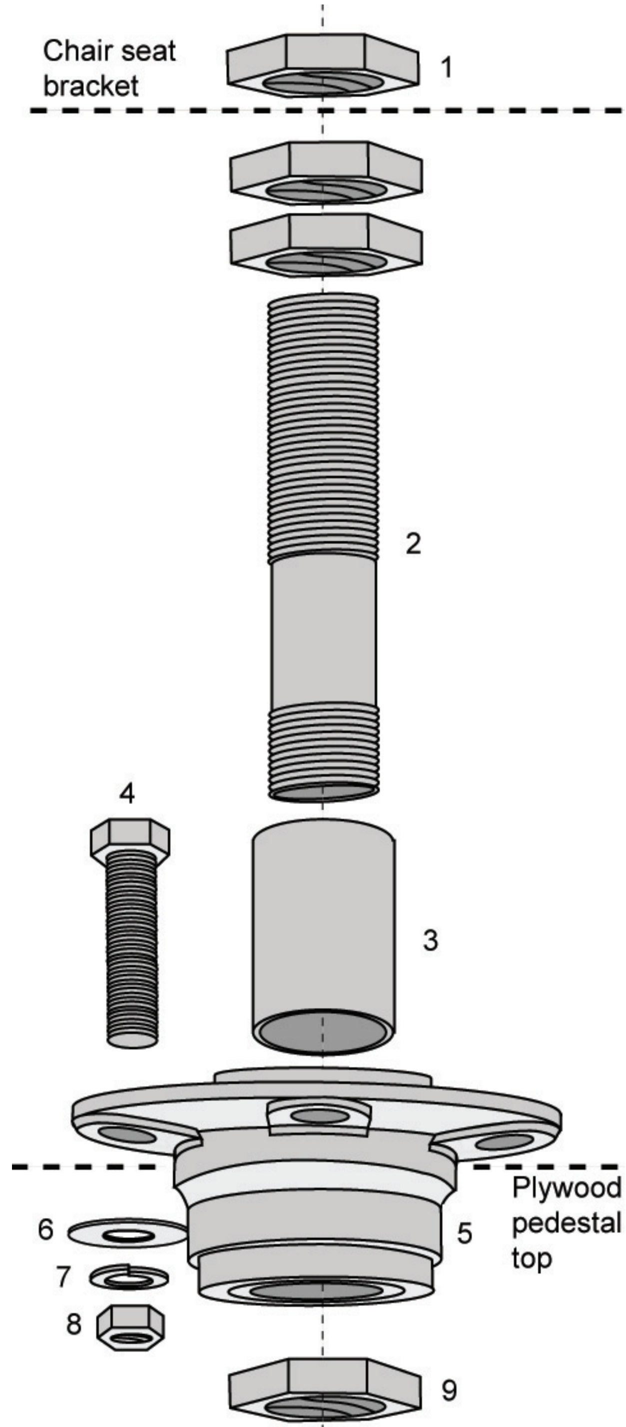
Electric hand drill - 3/8” or 1/2”
Hole saws - 3” and 2 1/2” with drill attachment
Drill bit for pilot holes
Countersink bit
Phillips screwdriver or Phillips drill bit
Crosscut hand saw
Ruler
Carpenter’s square



Barany Chair - Bearing Mechanism

Construction Notes:

- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Barany Chair.
- Except for the bearing, all metal parts are available from hardware stores.
- The bearing is available from auto parts stores. It is a free-spinning rear axle bearing from a front-wheel drive automobile. The underside of the bearing is tapered, necessitating two different sized holes in the plywood bearing platform.
- The horizontal dashed lines indicate where the mechanism is attached to the seat bracket of the chair and to the plywood platform.
- The rigid coupling comes from hardware electrical departments. It serves as a spacer.
- The galvanized pipe nipple has to be made specially for the Barany Chair. Hardware stores will cut and thread a pipe for you for a small charge. Before specifying the final length and threading, examine the seat bracket of the office chair you are using. You may require a slightly longer or slightly shorter nipple than called for here. The upper end of the nipple will require about 4” of thread while the lower end should require only about 1”.



Materials List

Number	Quantity	Item	Specifications
1	3	lock nuts	3/4” galvanized
2	1	pipe nipple	6”x3/4” galvanized
3	1	rigid coupling	1” (to fit 1” conduit)
4	4	hex bolts	5/16”x2 1/2”
5	1	rear axle hub bearing	BCA hub bearing #512025 (1995 Nissan Sentra)
6	4	lock washers	5/16”
7	4	cut washers	5/16”
8	4	hex nuts	5/16”
9	1	lock nut	3/4” galvanized

Barany Chair - Assembly

Construction Notes:

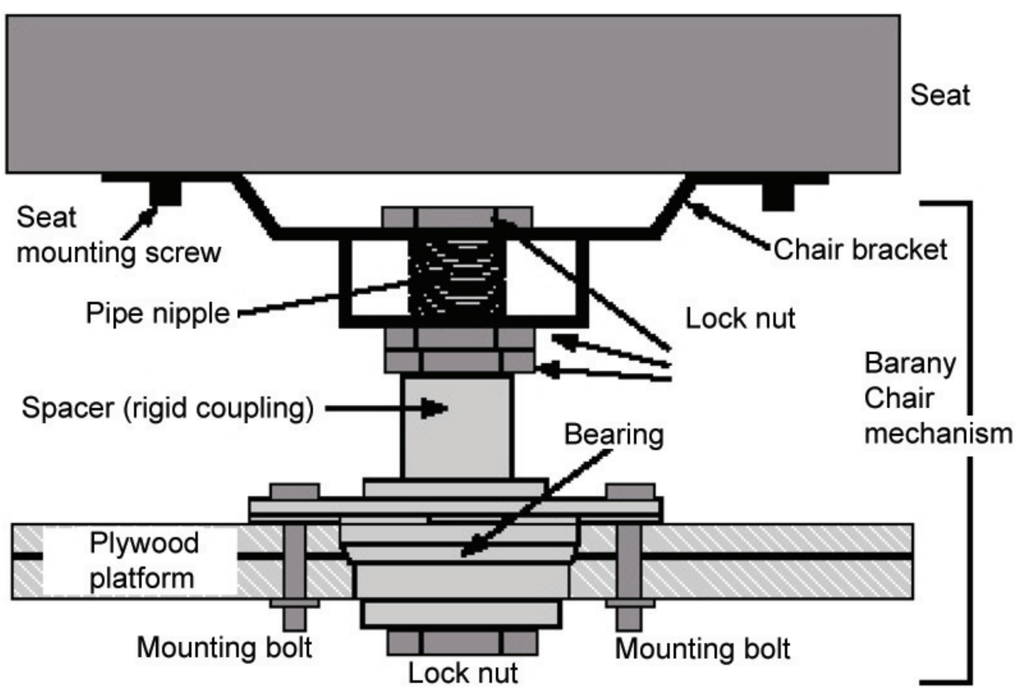
- Be sure to follow all manufacturer instructions for safe operation of tools and use of materials employed in the construction of the Barany Chair.
- Remove the seat bracket from the bottom of the seat.
- Twist two lock nuts onto the long threaded end of the pipe nipple. Keep them loose and below the point where the bracket will rest.
- Insert the nipple into the seat bracket hole and twist another lock nut on the upper end of the nipple. Tighten the first and the second lock nut to the bottom of the bracket. The two lock nuts working together will resist later loosening.
- Reattach the seat bracket to the seat.
- Slide the other end of the pipe nipple through the spacer and then into the hole of the bearing. (The bearing should already be firmly attached to the wooden pedestal of the Barany Chair.) Make sure the chair rotates freely above the pedestal.
- Reach through the access door of the pedestal and tighten the remaining lock nut onto the lower end of the pipe nipple. The chair should now rotate freely with no wobble. Close the access door.
- Attach the safety lap belt to the back or the rear of the arms of the chair. The Barany Chair is now finished and ready to be used.

Materials List

Quantity	Item	Specifications
1	chair seat	from office chair, non-tilt, with armrest
1	safety lap belt	wide hook-and-loop tape or webbing and buckles, available from an outdoor or sporting goods store

Tools

Set of wrenches
Screwdriver



Supplementary Teaching Aids

Several items may help your students visualize the principles and concepts of the vestibular system. Included on Pages 18-21 are directions for building and using three models of the semicircular canal functions.

- Three axis canal model
- Gelatin ring mold model
- Semicircular canal demonstration model

A three-dimensional cutaway model of the human ear may also be helpful and can be obtained from a school science catalog.

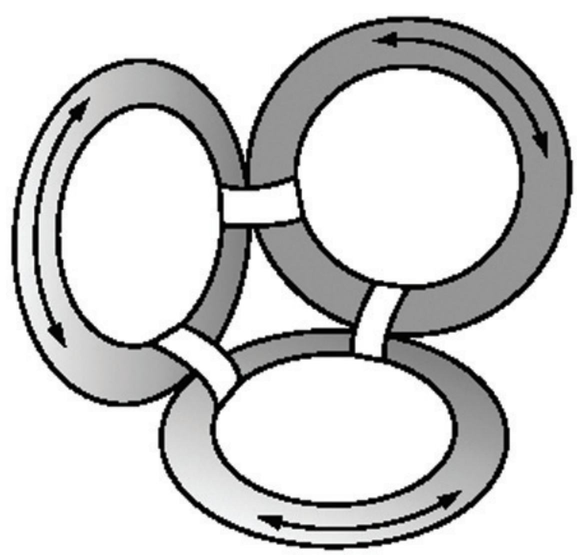
Three Axis Canal Model

Materials List

Quantity	Item	Specifications
1	9’ vinyl hose	clear, 1” diameter
3	plastic hose connectors	size to fit vinyl hose
1	plastic tape	clear
1	water and basin	
1	glitter, ~3 teaspoons	

1. Cut the hose into three equal lengths.
2. Put about a teaspoon of glitter in a length of hose and immerse the hose in water. Remove all air from the hose.
3. Firmly attach the hose ends to a connector to form a loop. Be careful not to introduce air.
4. Remove the hose from the water and repeat the process with the other two hoses.
5. Join the hose rings together as shown below.

To use: Place the model on the seat of the Barany Chair and rotate. Only the fluid in the yaw plane canal will move. The glitter will help you see the motion. Try different orientations of the model on the chair to see what effects it has on the different canals. Compare these orientations to the vestibular illusions.



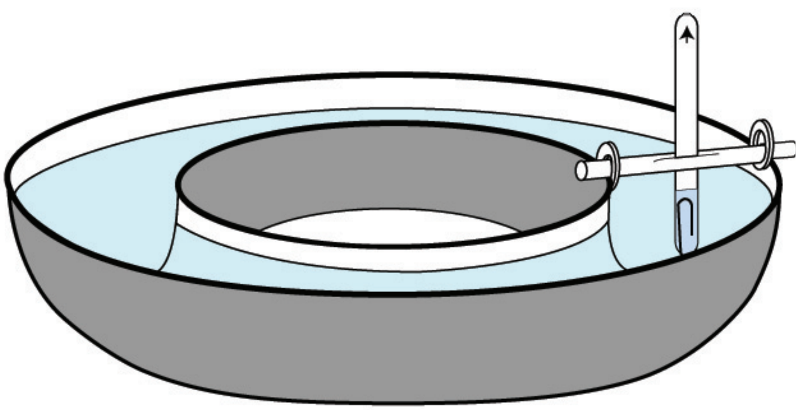
Gelatin Ring Mold Canal Model

1. Glue the two washers on the rim of the mold as shown in the diagram below.
2. Cut a slit through the sides of the straw at the midpoint.
3. Slide the straw through the two washers.
4. Slip the craft stick through the slits in the straw so that the lower end almost touches the bottom of the mold.
5. For ballast, attach a paperclip to the lower end of the craft stick.
6. Place the model on the turntable and fill halfway with water.

To use: Slowly rotate the mold. Inertia causes movement of the water to lag behind. This will tilt the stick so that it is pointing in the direction of motion. As friction with the mold walls causes the water to begin to move, the stick will return to the upright position. When the mold is stopped, the momentum of the water will cause the stick to point in the opposite direction. This is a visual demonstration of what happens during Vestibular Illusion 2.

Materials List

Quantity	Item
1	gelatin ring mold
2	metal washers
1	plastic soft drink straw
1	wooden craft stick
1	hot glue gun and glue stick
1	paper clip
1	sharp knife
1	Lazy Susan turntable
	water



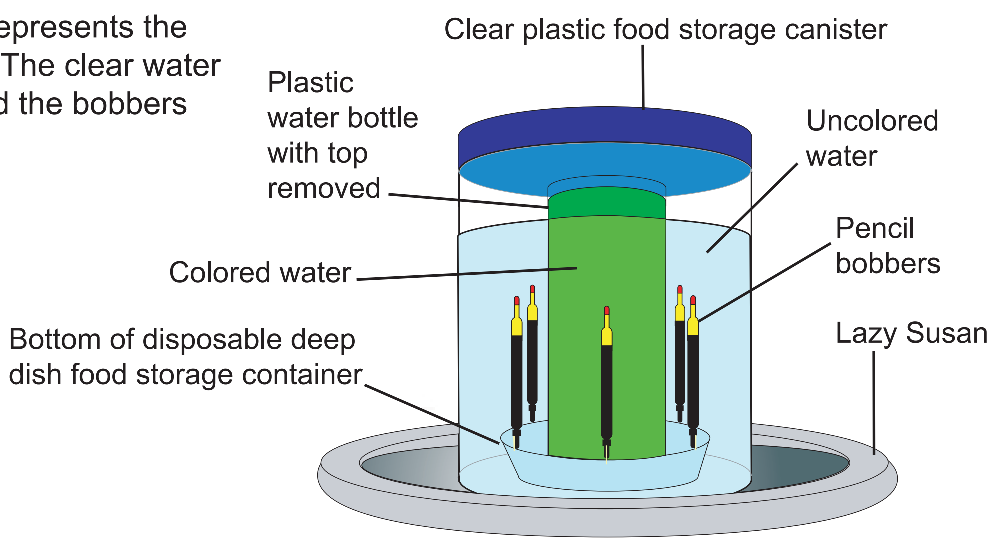
Place on turntable (Lazy Susan).

The Semicircular Canal Model - Construction

1. Punch six small holes equally spaced around the rim of the disposable food container.
2. Feed and knot short pieces of thread or fishing line to each hole and attach the bobbers to upper end of each line.
3. Adjust the position of the bobbers so that their lower ends almost touch the container rim.
4. Cement the food container to the inside center of the bottom of the large canister. Make sure no cement gets on the bobbers.
5. Cut off the upper end of the plastic water bottle. Cement the bottom of the bottle into the center of the storage container. Allow the cement to dry over night.
6. Set the Lazy Susan in the center of a table and place the semicircular canal model in the exact center.
7. Fill the water bottle almost to the top and sprinkle in several drops of food color to darken the water. This reduces visual distraction of bobbers on the opposite side of the model.
8. Add water to the canister until the bobbers are floating vertically.

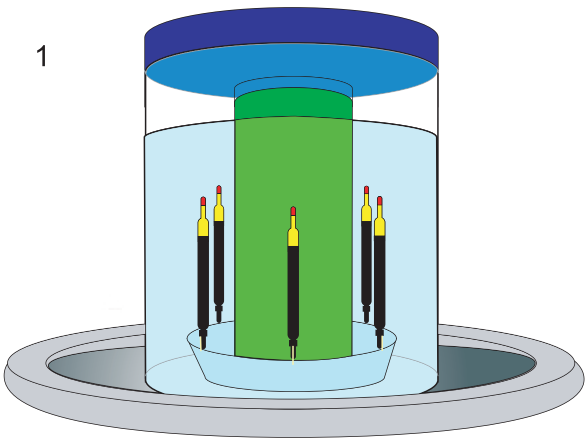
To use: Rotate the model at a constant speed in one direction. The bobbers will first lean in the opposite direction and then return to vertical. Stop the model and the bobbers will lean to the opposite direction. Explain to your students that the space between the interior water bottle and the inside wall of the canister represents the inside of a semicircular canal. The clear water represents endolymph fluid and the bobbers represent hair cells.

Quantity	Item	Specifications
1	clear plastic food storage canister	large round, 2-4 quart
1	disposable plastic food storage container	shallow round dish
1	clear plastic water or soda bottle	20-ounce or 1 liter
6	pencil bobbers	small (fishing supplies)
1	line	thread or fishing line
1	waterproof cement	aquarium sealant
1	scissors or sharp knife	
1	paper punch	
1	Lazy Susan turntable	
1	water	
1	food coloring	green or blue



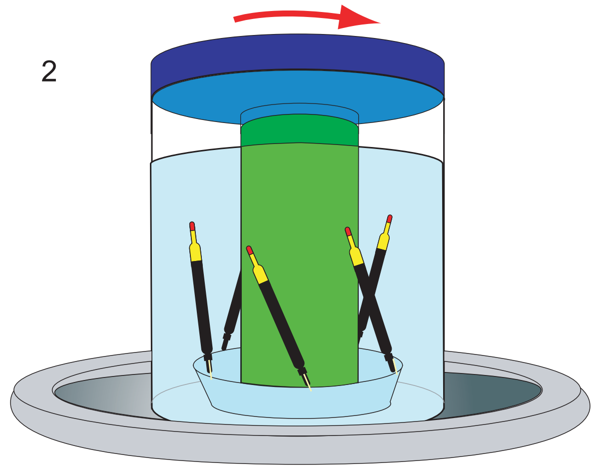
The Semicircular Canal Model - Demonstration

1



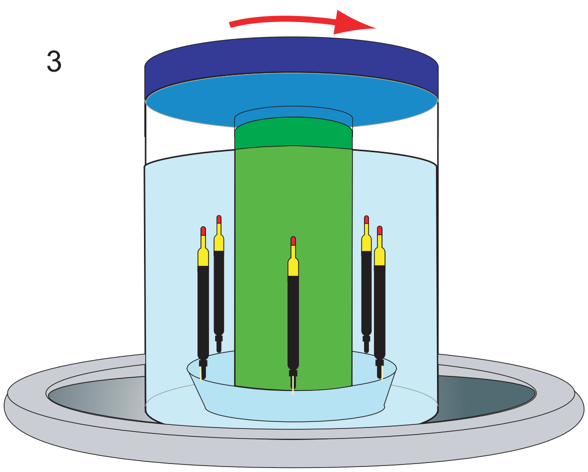
No rotational motion. Hair cells vertical. Brain senses no motion.

2



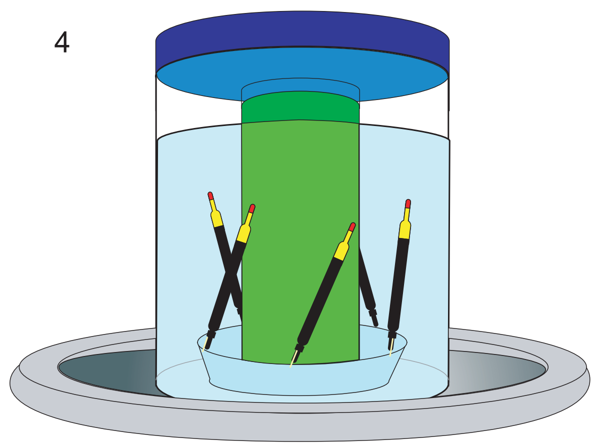
Counterclockwise rotation. Endolymph fluid lags behind. Hair cells lean in clockwise direction. Brain senses counterclockwise motion.

3



Rotation continues. Endolyph fluid catches up. Hair cells vertical. Brain no longer senses rotation.

4



Rotation stops. Endolymph continues moving. Hair cells lean in counterclockwise direction. Brain falsely senses clockwise rotation.

Glossary

Ampulla - expanded area within each semicircular canal which contains a crista; detects angular acceleration.

Angular acceleration - a simultaneous change in velocity and direction (as in spinning); sensed by the semicircular canals.

Barany Chair - a chair with a special bearing mechanism that rotates very smoothly; used for performing tests of the vestibular system.

Crista - within ampullary region of semicircular canal; name given to structure composed of ampullary crest (hair cells) combined with the cupula.

Cupula - one component of a crista; sits atop ampullary crest and is composed of hair-like extensions of sensory hair cells embedded within a gelatinous mass.

Endolymph - fluid within semicircular canals which, when moving, deflects the cupula and initiates the sensation of angular acceleration.

Hair cells - common name given to sensory cells located within the ampullary crest of semicircular canals and the macular region of saccule and utricle (otolith organs).

Inertia - the fundamental property of inert material tending to resist changes in its state of motion.

Linear acceleration - a change in velocity without a change in direction (up and down or side to side); sensed by the otolith organs.

Macula - thickened area within saccule and utricle consisting of hair cells and supporting cells. In both the saccule and utricle, the macula is covered by the gelatinous otolithic membrane containing otoliths.

Momentum - tendency of a body in motion to resist a change in that motion.

Nystagmus - repeated eye movement designed to stabilize gaze during head movement.

Otoliths - calcium carbonate crystals adhering to and embedded within the otolithic membrane of saccule and utricle (otolith organs).

Otolith organs - comprised of the saccule and utricle; sense linear acceleration and head position (tilt).

Pitch - rotational motion carried out along a front-to-back vertical plane.

Roll - rotational motion carried out along a lateral vertical plane.

Saccule - one of the two types of otolith organs of the vestibular system; senses linear acceleration and position (tilt) of the head. It is especially sensitive to vertical movement.

Semicircular canals - three fluid-filled circular tubular structures within each inner ear which are arranged at right angles to each other and sense angular acceleration.

Somatosensory - integrated sensory system which combines individual inputs from skin, muscles, tendons, and stretch receptors throughout the body.

Utricle - one of the two types of otolith organs of the vestibular system; senses linear acceleration and is more sensitive to horizontal movement (as in riding in a car).

Vestibular system - senses body movement and helps maintain equilibrium; comprised of the semicircular canals and the otolith organs which sense angular and linear acceleration.

Yaw - rotational motion carried out along a horizontal plane.

Additional Resources

Internet Sites

Space Research - NASA's Office of Biological & Physical Research
Latest Biological and Physical Research news, research on the International Space Station, articles on research activities, educational resources
http://SpaceResearch.nasa.gov

Web of Life
Articles and information about the experiments and engineering behind NASA's Fundamental Space Biology research
http://weboflife.ksc.nasa.gov

Space Biology - An Educator's Resource
Geared toward high school and undergraduate college students and instructors. Topics cover research, resources, and images
http://www.spacebio.net

Neuroscience Laboratory at the NASA Johnson Space center
Facility description and latest research programs
http://www.jsc.nasa.gov/sa/sd/facility/labs/Neuroscience/neuro.htm

NASA Spacelink
One of NASA's electronic resources specifically developed for the educational community. Spacelink serves as an electronic library to NASA's educational and scientific resources, with hundreds of subject areas arranged in a manner familiar to educators. Using Spacelink Search, educators and students can easily find information among NASA's thousands of Internet resources. Special events, missions, and intriguing NASA web sites are featured in Spacelink's "Hot Topics" and "Cool Picks" areas.
http://spacelink.nasa.gov

NASA CORE
Established for the national and international distribution of NASA-produced educational materials in multimedia format. Educators can view the catalogue and order materials through the Central Operations of Resources for Educators (CORE) web site.
http://core.nasa.gov

NASA Education Home Page
NASA's Education Home Page serves as the education portal for information regarding educational programs and services offered by NASA for the American educational community. This high level directory of information provides specific details and points of contact for all of NASA's educational efforts, Field Center offices, and points of presence within each state
http://education.nasa.gov

NASA Life Sciences Data Archive
Space flight experiment results and photo gallery
http://lsda.jsc.nasa.gov

National Space Biomedical Research Institute
Education materials
http://www.nsbri.org/Education/index.html

Barany Chair History
http://www.nobel.se/medicine/laureates/1914/

Publications

(1998), *The Brain In Space, A Teacher's Guide With Activities for Neuroscience*, EG-1998-03-118-HQ, National Aeronautics and Space Administration, Life Sciences Division, Washington, DC. This publication can be obtained at the following address:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/The.Brain.in.Space/
NOTE: this URL is case sensitive.

(1997), *Microgravity - A Teacher's Guide with Activities in Science, Mathematics, and Technology*, EG-1997-08-110-HQ, National Aeronautics and Space Administration, Washington, DC. This publication can be obtained at the following address:
http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/Microgravity/
NOTE: this URL is case sensitive.

Long, Michael E. (2001), *Surviving in Space*, National Geographic Magazine, v. 199, n1, pp 6-29.

Evaluation

Please take a moment to evaluate this product at:

http://ehb2.gsfc.nasa.gov/edcats/educational_brief

Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.