TEACHER'S GUIDE

Cecilia's Story

Produced by Harvard Medical School
Minority Faculty Development Program
of Faculty Development and Diversity

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The Rationale for Case-Based/Problem-Based Learning

"Cecilia's Story" contains a realistic description of a medical problem. The intent is to use this case as an exercise in problem-based learning. The case presents a real problem that must be dealt with, for the sake of the distressed patient: consequently, it can stimulate and motivate learning about the cluster of scientific and medical issues embedded in the case. In this format, one starts with the problem, not with a conventional classroom discussion of the scientific issues (e.g. a chapter in the textbook and some lectures). Ideally, the teacher's role is to guide the discussion, advise the students where answers can be found, encourage them to explore this problem, and develop their own insights. Educational research indicates that one's own insights are remembered better than insights provided by someone else, and that independent or group studies are better than managed passive studies. By reaching the desired understandings themselves, students gain self-confidence and interest in the subject.

Real-life problems, like this medical case, often do not have conventional scientific boundaries; this reminds the students of the seamlessness of science, and it gives them an opportunity to rehearse important scientific ideas that are not narrowly biological. The case surfaces the important fact that current understandings of this problem are not complete; the hope is that some student(s) will be encouraged to join the honorable struggle to understand and cope. This case offers a view of the variety of careers that are relevant to coping with this problem.

The case is divided into several parts (e.g. IA, IB, IIA, etc.). Each of these parts corresponds with a specific lesson. For this reason, **the case should not be passed out in its entirety at the outset**. Students should receive the part of the case that is discussed in the lesson. Thus, each part of the case is provided only after students have fully considered preceding parts. This is what happens in real life and it encourages students to be detectives – to pay close attention to the facts of the case as they unfold and to be creative in formulating hypotheses.

Good luck in using this case!

Key Concepts in Brain Structure and Function

(Adapted with permission from Mary's Mystery, Minority Faculty Development Department HMS)

At the heart of this medical case is a disorder of the nervous system. The case provides a context for learning about the vestibular system: its role in balance, on earth and in space, and its disorders. More generally, this case provides an opportunity to learn (or review) some basic understandings about our nervous systems: how this organ system can produce not only the behaviors described in this case but also an extraordinary range of mental activity and behavior regulation. It is these activities and behaviors that help to define us as a unique species. These include our highly developed language abilities. Closely related are the complex cultures that we develop and transmit (for example: through education). We have an aesthetic sense (art); we have an ethical sense (rules and laws). We have opposable thumbs and the wonderful manipulative abilities of our hands that allow us to make elaborate devices and do complex things with them. These, of course, are functions generated or controlled by our nervous systems. Our brains are our strong suit.

Another way of getting to this is by comparing ourselves to some other species with native abilities that surpass ours:

Unlike birds and insects, we cannot fly.
Unlike fish and whales, we cannot spend long periods underwater.
Unlike porcupines or tigers, we are not well protected against predators.
Unlike polar bears or seals we are not well protected against extreme cold
Unlike bees, we cannot see light in the ultraviolet part of the spectrum.
We cannot move as fast over the ground as jaguars or horses.
We are not as strong as elephants or gorillas.

However, we manufacture airplanes, submarines, weapons, clothing, automobiles, bulldozers, etc. that allow us to exceed the native abilities and feats of these species. It is our inventiveness, skills and social/economic structures that allow us to build and distribute these products. This has allowed us to spread into ecological niches where we otherwise could not survive. Again, it is our brains that are the seat of our ingenuity, skills and social behavior.

How, then, does this wonderful nervous system work? First, let us remind ourselves what a tough question this is by examining more specifically some of the functions the brain carries out:

PERCEPTIONS: For example, the rich, colorful, 3D moving pictures we have in our heads (i.e., our ongoing visual sensations) or the rich experience of sound (e.g., music). This stream of visual (or auditory) images is constructed by the brain.

THINKING: This includes calculation (e.g., math) and forward planning (e.g., we don't need to do the experiment of stepping in front of an oncoming car to see what happens) – also hopes, fantasies and, perhaps, dreams.

MEMORY AND LEARNING: We can store and retrieve vast amounts of information and, also, through repetition, greatly improve our skills (as in playing a sport or musical instrument).

EMOTIONS and MOODS: These appear to be labels conveying something about the *significance* to us of our perceptions, thoughts or memories. Emotions and moods are quite diverse: love, affection, hate, annoyance, anger, fear, sadness, joy, anxiety, etc. This diversity seems to reflect the variety of threats and opportunities we encounter in our complex physical and social environments.

DESIRES and MOTIVATIONS: Why do we get up in the morning; why do we care about other peoples' opinions of us? One of the tenets of psychology is that all behavior is motivated, that rewards (and punishments) help to shape our behaviors.

BEHAVIOR: The evolutionary significance of each of these functions, in the end, is that they influence our behaviors. We can move about and interact with our environments to enhance our chances of surviving and thriving.

Finally, and perhaps most mysteriously, the brain is the seat of CONSCIOUSNESS: the source of our awareness, the insistent sense of self we have, and our awareness of the external world.

Although an enormous amount of knowledge has been accumulated by neuroscientists in the last several decades, the brain is so complex that a huge amount remains to be learned. However, we can now see the basic principles and broad outlines of how the nervous system works. Knowledge of these basic attributes provides a framework for organizing the rapid development of new information and understanding. In the paragraphs that follow, five of these attributes, or *key concepts*, are described (they appear capitalized and in bold). Vocabulary words relevant to the biology of the nervous system are underlined.

The nervous system is a fantastically complex **COMMUNICATIONS NETWORK (Key Concept 1)**. As in any communications network there are individual units that generate signals which allow the units to interact with each other – like transistors in a computer or computers in a network. In the nervous system the interacting units, of course, are primarily the nerve cells or neurons. They interact with each other at synapses. A synapse is a specialized structure formed at a point of contact between the axon of the sending neuron and the dendrite of the receiving neuron. Axons and dendrites are generally highly branched, forming "trees" or arborizations. The axonal and dendritic components of the synapse, then, are usually small branches. The axonal branch may end at a synapse or it may continue on to make another synapse elsewhere on the dendritic tree of the same or another neuron. The axon terminal is specialized to secrete a particular active chemical, a neurotransmitter. (There is a variety of different transmitters at different types of synapses.) The dendrite – particularly the part of the dendrite contacted by the axon terminal – is also specialized. It has receptors that recognize that particular neurotransmitter and can respond to it. Depending on the identities of the neurotransmitter and receptors, the effect on the receiving neuron may be either excitatory or inhibitory.

On an individual neuron there is a flickering variation, from one fraction of a second to the next, in the constellation of synapses activated by the arrival of axonal nerve impulses. If, at any moment, aggregate excitation in the receiving neuron, evoked by the secreted puffs of excitatory neurotransmitter, sufficiently exceeds aggregate inhibition, evoked by the puffs of inhibitory neurotransmitter, the neuron generates its own impulses which travel down its divergent axonal branches, activating a new population of synapses on the array of its target neurons. This convergent and divergent spread of neuronal activity appears to endow the impulses in a given neuron with a certain symbolic significance. And as we go up the neuronal hierarchy, further from the primary sensory inputs, the significance (the meaning) of the impulses becomes more complex and abstract. Synapses are not only the sites of communication, but where learning appears to take place. Synapses are at the center of the operations of the brain. Of course the nerve impulses or action potentials are also essential in this process.

As stated above, the neuronal communications network of the brain is complex. The more we learn about it, the more complex it seems to be. Gram for gram the human brain appears to be the most complex thing in the known universe – complex in the sense of the number of specified particularities. One aspect of this complexity is the sheer number of things. In the human brain there appear to be 10^{11} – 10^{12} neurons. Moreover, a typical neuron receives hundreds or thousands of synapses. The total number of synapses in the brain is on the order of 10^{15}. But the complexity is not just a matter of large numbers. A microscopically small drop of water contains as many molecules as the synapses in the brain, yet does not exhibit a lot of meaningful complexity because a water molecule can associate with any others it encounters. In contrast, a neuron does not communicate with just any other neuron. Which neurons talk to which is very particular. The neurons are synaptically interconnected with great specificity and precision. In essence, there is a wiring diagram. So the next major notion we need, to account for the what the brain can do, is its **COMPLEXITY (Key Concept 2)**. The third notion is the **SPECIFICITY (Key Concept 3)** of wiring of the brain. The two are closely related because most of the complexity is a reflection of the specificity (together with the huge numbers of neurons and synapses).

The wiring diagram is a very important concept – it specifies how information is processed and over what routes the information, in the form of nerve impulses, flows. Ultimately, the wiring diagram determines the relationship between what comes into the nervous system and what goes out. In short, it determines behavior – not just simple reflexes, but also complex behavior. Information comes in through many sensory pathways and is brought together with huge amounts of stored information, and may be modified by emotional context. All of this leads to the activation of complex and subtle motor programs which may be highly dependent on learning, on training. Of course, this includes the muscles that control speech and writing with all that that implies.

This is not meant to imply that the nervous system is hard-wired in the sense that the same input always gives the same output. On the contrary, the nervous system is always changing. We say it exhibits **PLASTICITY (Key Concept 4)**. One way the brain is changed is by its interaction with the environment. How does this come about? In at least a couple of ways. We know, for example, that the strength of synaptic transmission, whether a synapse transmits a strong or a weak message, can be quite variable. This may occur because the activity of a given synapse is altered by hormones or by neurotransmitter compounds (like dopamine, serotonin or neuropeptides) secreted from neighboring neurons which, in turn, may be responding to environmental contingencies. In addition, when a synapse is activated intensively, simply the fact that it has been heavily used may alter its function. Such changes appear to underlie learning. Whenever we learn something, changes occur in our brain, apparently in our synapses. So, we see that the neuronal networks not only process information, they are changed by the information they process. It is hard to emphasize too strongly that the brain is a highly plastic device. In terms of evolution, the plasticity of synapses in the brain is a major source of our adaptability to our environments – we learn how to cope. It seems unlikely that we could survive without this ability.

So what we see as hallmarks of the nervous system are a large number of elements and great complexity, with precise specificity of interconnections, and extensive plasticity; complex, modifiable neuronal circuits. These are major principles we need to pay attention to in trying to understand how our nervous systems work.

There is a fifth important principle. Although the brain is complex, it exhibits impressive **ORDERLINESS (Key Concept 5)**. If you examine a brain, you will find that it has major divisions and within each division, subdivisions and subsubdivisions, etc. There is a huge number of discernably different areas. If you then look at another brain, you will find the same patterns. This may not seem surprising. It just means that the brain has an anatomy like every other part of the body. On the other hand, it is a great relief that in spite of the enormous complexity of the brain, it is not just a jumble. The orderliness of the brain appears, to a large extent to be a result of orderly mechanisms during development that determine the specificity of the neuronal connections. The orderliness of the brain means that it can be studied – one brain is so similar to another that people can make reproducible observations and experiments. In addition, the orderliness of structure underlies the orderliness of function. This means that a neurologist can predict where a lesion is in the brain by paying attention to the symptoms – something you may practice during the this case. Knowing *where* the problem is in the nervous system is almost always the first step in understanding *what* the problem is.

"Cecilia's Story" Includes Aspects of the Following National Science Education Standards:

Grades 5 - 8

Science as Inquiry

- ❖ Abilities necessary to do scientific inquiry
- ❖ Understandings about scientific inquiry

Physical Science

- ❖ Motions and forces
- ❖ Transfer of energy

Life Science

- ❖ Structure and function in living systems
- ❖ Regulation and behavior
- ❖ Diversity and adaptation of organisms

Earth and Space Science

- ❖ Structure of the earth system
- ❖ Earth in the solar system

Science and Technology

- ❖ Abilities of technological design
- ❖ Understanding about science and technology

Science in Personal and Social Perspectives

- ❖ Personal health
- ❖ Natural hazards
- ❖ Risks and benefits
- ❖ Science and technology in society

History and Nature of Science

- ❖ Science as a human endeavor
- ❖ Nature of science
- ❖ History of science

Grades 9 - 12

Science as Inquiry

- ❖ Abilities necessary to do scientific inquiry
- ❖ Understandings about scientific inquiry

Physical Science

- ❖ Interactions of energy and matter

Life Science

- ❖ Matter, energy and organization in living systems
- ❖ Behavior of organisms

Science and Technology

- ❖ Abilities of technological design
- ❖ Understanding about science and technology

Science in Personal and Social Perspectives

- ❖ Personal and community health
- ❖ Natural and human-induced hazards
- ❖ Science and technology in local, national, and global challenges

History and Nature of Science

- ❖ Science as a human endeavor
- ❖ Historical perspectives

"Cecilia's Story" Includes Aspects of the Following National Council of Teachers of Mathematics Curriculum and Evaluation Standards:

GRADES 5 – 8

- Problem solving
- Communication
- Reasoning
- Connections
- Computation and estimation
- Patterns and functions
- Algebra
- Measurement

GRADES 9 – 12

- Problem solving
- Communication
- Reasoning
- Connection

Notes for the Teacher's Guide to "Cecilia's Story"

Each of the lessons includes classroom activities. This allows the classroom teacher to *personalize* each lesson to the needs of the students. To assist the teacher in choosing *pertinent* activities, the following scale is used in each lesson:

Core – lessons, demonstrations, or lectures that are **core** to the case. These activities sections are in black ink.

Supplemental – **supplemental information** to major topics covered in the case. These sections are in blue ink.

Extension – information that is an **extension** into related areas. These sections are in violet ink and can be found in full in the Appendix at the back of this document.

- – indicates key items or questions the teacher may want to have the **students focus** on.

Hypothesis Testing Packet

The Hypothesis Testing Packet[1] is used throughout the case as a way for students to keep track of their observations and hypotheses throughout the case. The packet is divided into 5 columns which will guide the students through all the steps of the scientific method:

- Date/Lesson
- The Problem
- Your Observations
- Your Hypothesis/es
- Hypothesis Testing

In this manner, students will be able to apply the scientific method and use an iterative process to revise their hypotheses as they discover more about the case, the balance system, and Cecilia's problem. At the end of the case, the students will be able to observe how their ideas, knowledge and conclusions evolved throughout the examination of the case: this will show them how scientists conduct research by formulating hypotheses, testing them, and revising them.

Portfolio Assessment

The activities found in "Cecilia's Story" allow students to use the concepts and information they are learning about neuroscience and space. While some of the activities require one session to complete, others are on-going and encourage students to use and reflect on what they have learned in previous lessons. One way that both students and teachers can record what the students have learned is to develop a portfolio throughout the case. Portfolios demonstrate what students have learned. The format for "Cecilia's Story" allows flexibility in choosing the most appropriate portfolio design for the classroom. Please feel free to have students use the portfolio system to document, maintain and reflect on their understanding of the material found in "Cecilia's Story."

[1] See Appendix 1

Notes for the Teacher's Guide to "Cecilia's Story"

This page represents the typical breakdown of the lessons contained in this Guide:

Lesson Objective: What the lesson will cover

Benchmarks for Science Literacy:
American Association for the Advancement of Science: Benchmarks met by the lesson

Example of Regional Standards:
Boston Public Schools (BPS) Learning Standards: District standards met by the lesson

Materials: Items needed for the lesson

I. **Lesson Opening**: Activity to prepare students for the lesson

II. **Lesson Body**

All the lessons contain clearly marked sections setting out the suggested sequence of activities. In the various headings, there is an indication of which part of the case the lesson relates to (e.g. Lesson II Parts IIA and IIB). Vocabulary words are underlined and definitions are provided in the Glossary, at the end of the Teacher's Guide.

a. **Teacher Directed Instruction**: The teacher directly gives information to the students.

b. **Teacher Guided Inquiry**: The teacher guides students through concepts raised by the case.

c. **Student Guided Inquiry**: Students are actively engaged in questioning and exploring new concepts.

III. **Independent Activity/Homework**

Students use information learned during the lesson; this can be done in class or as homework.

“Cecilia’s Story”

The Problem-Based Case Study

"Cecilia's Story" - Part IA

Hi, my name is Cecilia Rossi, and I will tell you a story of something that happened to me not too long ago. I am 39 years old, and I am a single mother of two boys: Marco (11) and Giulio (14). After my husband left us, I took a job as a clerk at the City Hall. Giulio works at the local convenience store on weekends, so he helps out with the bills a little bit, but basically I am the one who is responsible for putting food on the table, paying the bills and keeping our apartment clean: in short, my children rely on me, and I cannot afford to get sick or lose my job.

A few weeks ago, after getting wet on my way home from work, I woke up with a stuffy nose and a congested feeling. I did not go to the doctor because I did not want to take any time off from work, so I just spoke to my grandmother Cesara in New Jersey who told me to just stay warm, heat up some water to let the vapors humidify the air and clear my sinuses, and drink some boiled red wine with sugar, cinnamon and cloves right before going to bed. I was recovering well – my runny nose and cough were just about gone – until one morning, a few days later, I woke up and noticed I was feeling a little unsteady, as if I had been drinking a little. Since it did not seem to be anything serious, I sent my kids to school and went off to work. Throughout the morning, the unsteady feeling kept getting worse, and I started trying not to move my head too much to avoid the waves of nausea.

KEYWORDS - Part IA

- **Congested**
- **Humidify**
- **Sinus**
- **Unsteady**
- **Nausea**

"Cecilia's Story" - Part IB

Around 1:30, I noticed that I was sweating and that I had lost color and I was getting more and more nauseous. Since the symptoms were different from the cold a few days earlier, I thought that I was getting the flu and I decided to take the rest of the day off. My boss, Mr. De Gaulle, was not happy, but I clearly looked sick so he sent me home. Although somewhat dizzy, I made it home, even though the subway ride was awful. Within 20 minutes of getting home I felt like everything was spinning, and I rapidly felt nauseous, unsteady, and started vomiting. I lost my balance, dropped to the floor, and managed to crawl to the bathroom. I was afraid because I had never felt this bad so quickly when I had a cold.

KEYWORDS - Part IB

- **Symptom**
- **Dizzy/Dizziness**
- **Spinning**
- **Balance**

"Cecilia's Story" - Part IC

Marco came home around 3:00 PM and found me sobbing and vomiting and tried to get me back on to my feet, but I just could not stand up, so he sat by me and tried to comfort me. Some time later my older son, Giulio, came home and saw the condition I was in, so he called 911 and asked for an ambulance. I was really upset, not only because I was feeling sick, but also because I had no idea what was happening to me. I thought maybe I was having a stroke or a heart attack and I might die!

"Cecilia's Story" - Part IIA

When I arrived at the Emergency Ward of the Cedars County General Hospital I was pale, sweaty and still vomiting. The nurse who was there, Rex Ogawa, took some readings. I could not stand. He asked if I knew who I was, where I was, and approximately what time of the day it was, and I thought they were easy questions and answered without having to think about them too much. The nurse smiled and said "very well ma'am" so I assumed that meant I answered correctly. He then introduced me to Dr. Theodora Papadopoulos. I heard the nurse report to the doctor the values of the readings he had taken, which were:

PULSE:	98
BLOOD PRESSURE:	160/90
TEMPERATURE:	98.9F

The doctor said those were normal, and she then performed several tests and described them and the results as she was going along:

- she performed a hearing test by whispering in my ear, and then by using a tuning fork – I thought I could hear normally;
- she tested my muscle strength, tone, range of motion, and deep tendon reflexes with a reflex hammer;
- she listened to my lungs and heartbeat, and she told me to take deep breaths and relax – I tried but I was still very nervous;
- she tested my sense of touch, including on the soles of my feet; and
- she also checked my sense of joint position.

At the end of every test, she kept saying "fine," so I thought everything was OK, and while that made me feel good, it also made me feel even more nervous because I was sick, but I still did not know why!

After going through all these tests, Dr. Papadopoulos instructed Nurse Ogawa to help me up, but I just could not stand and *kept falling to the left side*. When Dr. Papadopoulos saw that, I heard her say "hmm," and she seemed like she was onto something.

KEYWORDS - Part IIA

- **Tuning Fork**
- **Reflex Hammer**
- **Tone (muscle)**
- **Range of Motion**
- **Deep Tendon Reflexes**
- **Joint Position**
- **Sense of Touch**

"Cecilia's Story" - Part IIB

Dr. Papadopoulos looked at my eyes and saw what she called a **"brisk right-beating nystagmus."** She said this suggested a vestibular disorder, namely **vestibular neuritis**. I heard her tell Nurse Ogawa that "all my other cranial nerve functions were normal."

Just to be on the safe side, they also performed an electrocardiogram and a CT scan. Both were normal, which was a relief to the doctor because that meant that my problem was not a heart problem or a brain tumor or a blood clot. After these tests, she was quite positive that the problem was in fact vestibular neuritis. She told me that this condition was likely caused by a viral infection of my vestibular nerve, which resulted in (the) vertigo and unsteadiness. Although I was still scared, I was finally relieved to know what I had and that it was not going to kill me, but I was going to have to deal with this for awhile.

KEYWORDS - Part IIB

- **Brisk Right-Beating Nystagmus**
- **Vestibular Neuritis**
- **Cranial**
- **Electrocardiogram**
- **CT Scan**
- **Heart Problem**
- **Brain Tumor**
- **Blood Clot**
- **Vertigo**

"Cecilia's Story" - Part IIC

I was begging Dr. Papadopoulos to give me something that would at least make me stop heaving and vomiting. She gave me an anti-emetic, which she explained was a medicine that would make me stop vomiting, and I fell asleep. I woke up about three hours later and I was no longer vomiting, but I was still vertiginous. Nurse Ogawa was there and told me the Doctor was going to discharge me and send me home with a prescription for meclizine ("Antivert"), an anti-emetic/vestibular suppressant.

While I was relieved to be going home, I was concerned because I still was not feeling well, and I had to ask my children to help me. I was also worried about what my boss would say, especially because he was not happy about letting me take the afternoon off and said that my symptoms were vague and that I should be fine the next day: since there was nothing visibly wrong with me, I was sure he was going to be difficult and think that I was exaggerating just so I could stay home with my children, especially because I was going to have to take some afternoons off for follow-up visits to the doctor. The Doctor told me that there are people with symptoms similar to mine that lose their vestibular sense permanently and, as a consequence, they have to go to rehab to learn how to function properly without their organ of balance. When I heard that I considered myself lucky, although I was still scared by my experience. My kids were also trying to be supportive, even though I could see they were somewhat confused. Last year, I managed to stay on top of things with a broken arm, and this year, I was all of a sudden relying on them, and they could not see anything wrong with me such as a bandage or a cast. I tried to describe the symptoms to them to make them realize how horrible my experience was, but I just sounded vague and confused, even to myself.

KEYWORDS - Part IIC

- **Vertiginous**
- **Meclizine**
- **Anti-Emetic**
- **Suppressant**

"Cecilia's Story" - Part IID

It has been a month since the first inset of my vestibular neuritis, and while I can say I have made a great amount of progress in recovering, it has been a very trying time. This disease not only affected me, but it also affected my family and the entire world around me.

The day after the attack, my kids still helped me and did what I told them to, but they seemed to be somewhat confused. After a few days, confusion seemed to turn into annoyance or frustration as if they did not fully believe or understand how bad I was feeling. I had to be careful with my head movements for a while, but on top of my actual medical problem, the hard part was dealing with the idea of an infection that hit me and incapacitated me so suddenly and quickly. Not being a very sympathetic person by nature, my boss was even less understanding about my situation: I was late on several days because I couldn't drive a car, and the motion of subways and buses made me feel sick, so I had to walk to work every morning. He yelled at me several times for that. I just had the feeling most people around me thought I was being weepy and lazy, while the real reason was that I felt fatigued and did not feel comfortable doing things that I would normally do, such as driving. Even smaller things like food shopping or simple social activities became a big obstacle for me.

However, I am happy to say that I am on the road to full recovery. The doctor said I am doing well and the unsteady feelings have been progressively fading. I am now getting back on track with my normal life: I think the obstacles I now have to overcome are also mental, since the very thought of getting behind the wheel or taking the subway still scares me a little. I also feel somewhat lucky because I met several other vestibular patients at the Hospital and many of them were afflicted by other disorders which left them with permanent damage; although they were strangers, I felt I could connect with them because they understood exactly what I was going through: it is hard to describe how limiting and debilitating a "vestibular disorder" is to people who have not had it.

Giulio and Marco are probably just as happy as I am about my recovery and good prognosis: they are simply glad they don't have to go grocery shopping for me anymore…

THE END

“Cecilia’s Story”

The Lessons

LESSON I: Using the Scientific Method to Investigate Balance

Guide for Parts IA and IB

Lesson Objectives:
- Students will review the scientific method.
- Students will investigate the system that maintains balance.

National Science Education Standards:
Science as Inquiry
- Abilities necessary to do scientific inquiry
  - Identify questions that can be answered through scientific investigations.
  - Design and conduct a scientific investigation.
  - Use appropriate tools and techniques to gather, analyze and interpret data.
  - Develop descriptions, explanations, predictions, and models using evidence.
  - Communicate scientific procedures and explanations.
  - Design and conduct scientific investigations.
  - Formulate and revise scientific explanations and models using logic and evidence.
- Understandings about scientific inquiry

Benchmarks for Science Literacy – American Association for the Advancement of Science:
1A: Scientific World View
- Scientists assume that the universe is a vast system in which the basic rules are the same everywhere. The rules may range from very simple to extremely complex, but scientists operate on the belief that the rules can be discovered by careful, systematic study.
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are numerous small modifications of prior knowledge. Change and continuity are persistent features of every aspect of science.
- No matter how well one theory fits observations, a new theory might fit them just as well or better, or might fit a wider range of observations. In science, the testing, revising, and occasional discarding of theories, new and old, never ends. This ongoing process leads to an increasingly better understanding of how things work in the world but not to absolute truth. Evidence for the value of this approach is given by the improving ability of scientists to offer reliable explanations and make accurate predictions.

1B: Scientific Inquiry
- Investigations are conducted for different reasons, including to explore new phenomena, to check previous results, to test how well a theory predicts, and to compare different theories.
- Hypotheses are used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data (both new and previously available).

Example of Regional Standards – Boston Public Schools Learning Standards:
Students will develop the abilities necessary to conduct scientific inquiry by:
- Designing and conducting scientific investigations.
- Formulating and revising scientific explanations and models using logic and evidence.
- Communicating and defending a scientific argument.

Materials:
- Pillow and Handkerchief for a blindfold
- Handouts:
  1. Appendix 1 (The Scientific Method)
  2. Appendix 2 (Hypothesis Testing Packet)
  3. Appendix 3 (Experiment worksheet)
  4. Appendix 4 (Procedures for balance experiment)
  5. Appendix 5 (Questions on systems)

Lesson Opening (Part IA)

Explain to the students they will be working with a case called, "Cecilia's Story." Medical case studies are a method used by medical schools to teach medical students basic concepts and principles of medical science.

The case study approach is useful because it allows the student to investigate these basic scientific concepts within a real-life context. Students will be given limited information, to which they must apply the scientific method to draw conclusions about the case. This approach is quite similar to one used by detectives.

Explain to the students that it will be their job to determine what happened to Cecilia, and why it happened. While this is not an easy task, ask the students how they might go about finding the answers they need.

Lesson Body
Teacher Directed Instruction (Core Part IA)

Have students read Part IA. Ask students what they think is going on in the case.

Students might suggest that Cecilia has one or more of the following problems:

- **Feeling congested in her chest**
- **Experiences coughing and runny nose**
- **Unsteadiness**
- **Nausea**

Allow the students to generate as many possible explanations for Cecilia's problem as they can. Push students to include evidence from what they have read to support their answers. If students have difficulty accomplishing this, use the following questions to assist their effort:

What do you know from what you read?
What evidence do you have to support what you think you already know?

Listen carefully to student responses to determine whether responses are direct, factual observations or inferences on what they have read. Explain to the students that scientist use the scientific method to learn what is not yet known. They rely on collected evidence and progressively rule out some possibilities, while focusing on others. The method prevents hasty or unsupported conclusions.

The following is a review of the steps of the **Scientific Method**:
(Used with permission from Mary's Mystery, Minority Faculty Development, HMS)

1. State a question about the problem you are dealing with or the phenomena that you have observed.
2. Based upon what you already know, formulate a hypothesis [make a guess] to answer the question.
3. Gather data to test your hypothesis.
4. Evaluate the data to determine whether the data fit the hypothesis.
5. Based on your evaluation of the data you can:
   a. Conclude that your hypothesis is a plausible explanation for your observations for now,
   b. Revise your hypothesis in a way that accounts for the data, or
   c. Reject the original hypothesis and devise another.
6. When there is new information, original hypotheses are re-evaluated.

In science, a concept is generally considered "understood" or accepted as "true" until someone, with further research and tests, finds a better explanation, and obtains evidence to support it. In science, a theory is different from an hypothesis or speculation. A theory is a well supported explanation that is very effective in helping us to understand some important natural phenomena. It has survived repeated experimental tests and can be replied on to make useful predictions. A coherent and durable theory is as close to "truth" as we get in science. Einstein's theory of relativity and Darwin's theory of evolution are good examples.

Teacher Guided Inquiry (Core Part IA)

Students have already begun considering questions about Cecilia's condition. Now ask students to propose possible explanations for the symptoms they generated in the earlier conversation. Accept any reasonable suggestions.

Possible hypotheses about what might be happening with Cecilia:

- **Cold**
- **Flu**
- **Pregnant**
- **Intoxicated (either alcohol or drugs)**
- **Suffered some head trauma**
- **Fever**
- **Sinus infection**
- **Too little food**

If the class does not come up with all of the possibilities, the students will have plenty of time to continue forming hypotheses about Cecilia's condition throughout the case. After the students have responded, remind the students that no further data has been collected or analyzed. Therefore, they have gone as far as they can go at this time. Have students begin their Hypothesis Testing Packet.[2]

Student Guided Inquiry (Core Part IA)

Ask the students to think about all of their hypotheses about Cecilia's problem. Tell the students to think about which body system corresponds to the symptoms reported by Cecilia. Explain to the students that a system is a group of organs working together to perform a specific function. Offer the following as examples of systems found in the human body:

- **Endocrine system:** the glands.
- **Circulatory system:** the heart, blood, veins and arteries.
- **Nervous system:** the brain, spinal cord, and nerves.
- **Musculo-skeletal system:** the bones and muscles.

Teacher Directed Instruction (Core Part IB)

Have students read Part IB. Ask students to consider which body system is responsible for Cecilia's condition. Allow students to come up with various possibilities. After students have given responses, direct their focus to what happened to Cecilia in Part IB. Ask students if something is wrong with her system of balance (Note: In Lesson II, students will begin by re-reading Part IB). Tell students they are going to watch a demonstration. The students should observe and record what happens during the experiment. Ask the students to silently consider the following statement: "What do you think would happen if a person closed his/her eyes while standing on a pillow with one leg raised?" Students should record their hypotheses, observations and data on the experiment handout.[3]

[2] See Appendix 1
[3] See Appendix 3 for this handout

Student Guided Inquiry (Core Part IB)

Balance Activity: How are we able to stand up against the constant pull of gravity? [4]

This experiment points out all the different systems in our body that help us to stand and keep our balance in the presence of gravity. The activities in this experiment also encourage students to think about what would happen if one or more of these systems were to malfunction or be completely eliminated. The point of the experiment is to illustrate that the brain uses information from all the systems involved in balance to create "a picture" of the body's position in space.

STRATEGY
(Used with permission from Subcommittee on Education of Non-Neurologists (SENN)**)**

Students should be sitting in such a way that allows them to completely see the demonstration. A student volunteer should be chosen from the class and be in bare feet. An adult should stand near the volunteer to prevent any falling.

PROCEDURE
(See Handout in Appendix 6)

1. Lay the pillow on the floor. The volunteer should place the blindfold over his/her eyes. Instruct the volunteer to stand on the pillow in bare feet with both arms extended.
2. Have another student write down the observations of the class on the chalkboard.
3. Instruct the volunteer to stand on one foot. [Teacher is standing next to volunteer, to prevent student from falling.] Write down observations.

DISCUSSION

Lead the class in a discussion directly pertaining to their observations of the experiment. Direct the discussion so that the class figures out that balance is dependent upon information from the pressure sensors in the skin and eyes.

Lead the discussion using the following open-ended questions:

- What happened when the volunteer stood on the pillow?
- Why is it difficult to stand on a pillow?
- Was it difficult to maintain balance with the blindfold?
- What sense was taken away with the blindfold?
- Why did the volunteer tip over at the end of the experiment?

[4] American Academy of Neurology. W3C. User Interface Domain. Available from http://www.aan.com

Independent Activity/Homework: (Parts IA and IB)

A. Students should write their findings from the demonstration on their experiment worksheet. The write-up should include all parts of the scientific method, including written observations and illustrations of what happened during the experiment. They should spend time thinking about their observations, their hypotheses, and their conclusions about the process (system) of balance. Students should place this worksheet in their portfolios.

B. Have the students consider the following questions, independently.[5]

- What systems in the body make you steady and able to stand up and walk?
- What movements or activities make you unsteady? Think about what happens when your foot goes numb, or you have an ear infection, or you are going up or down the stairs in the dark.
- Try to think of other situations or activities which make you feel unsteady, or dizzy.
- Do all these systems need to communicate somehow? Where and how are they connected?

[5] See Appendix 5 for this handout.

LESSON II: Discovering the Vestibular System

Guide for Part IC

Lesson Objectives:
- Students will use technology to gain further understanding of balance.
- Students will recognize the functions and parts of the vestibular system.

National Science Education Standards:
Life Science
- Structure and function in living systems.
- Regulation and behavior.
- Diversity and adaptation of organisms.
- Matter, energy and organization in living systems.
- Behavior of organizations.

Benchmarks for Science Literacy – American Association for the Advancement of Science:
4F: Motion
  - The change in motion of an object is proportional to the applied force and inversely proportional to the mass.
  - All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

Example of Regional Standards – Boston Public Schools Learning Standards:
- Students will develop the ability to do scientific inquiry by using technologies to improve investigations.
- Students will understand that each kind of organism represents a different strategy for solving basic life-sustaining problems. Strategies are revealed in organismic structures and functions.

Materials:
- Computer and Internet access
- Model of vestibular system
- Appendix 6 (Finding Data on the Vestibular System, text/questions)

Optional:
- Stellar CD-ROM

Lesson Opening (Part IC)

Students should begin by rereading Part IB and reading Part IC. Discuss the underlined words, making sure the students understand what each word means.

Students should continue making observations about Cecilia's condition. They should make note of changes they have observed in their reading of the case. Have students record any new observations in their Hypothesis Testing Packet. Have their hypotheses changed? They should write down any new hypothesis about what might be wrong with Cecilia.

Based on their new observations and the previous demonstration on balance, some students may have already made the assumption that something is wrong with Cecilia's system of balance. The following questions will help the students begin thinking about the body systems that might be affected by Cecilia's condition:

- Why do you think Cecilia could not walk or stand? Why do you think she had to crawl to the bathroom?
- Describe what you think happened when she tried to stand.
- Which systems are operating when a person is trying to stand upright?
- What do you think is happening when a person is unable to stand up properly?
- Why is Cecilia upset?
- Why is she so weak? (If the students propose that Cecilia may be weak because dehydrated from vomiting, the teacher may want to discuss the word "dehydrate," and ask students to hypothesize what they believe this word means.)
- Do you think Cecilia is vomiting simply because she is anxious, or do you think there may be another reason?

Lesson Body
Teacher Directed Instruction (Core Part IC)

After introducing the term "vestibular system," ask the students to think about where the word "vestibular" comes from and if they have ever heard it used in a different context. Vestibular derives from "vestibule." Ask the students if they know what the word "vestibule" means, in the context of other things, such as buildings, churches, houses, etc. A "vestibule" is an entrance hall that leads to another destination. Ask the students how this relates to the vestibular system. Guide the discussion so they will reach the conclusion that the system takes the name from its location in the head. The semicircular canals and the otolith organs are located in a sort of chamber, or "vestibule" in the inner ear.

The inner ear consists of the cochlea and the vestibular apparatus. The cochlea contains the receptors for hearing. The vestibular apparatus helps to inform the brain about the movement and position of the head in space. Together with information from joint and muscle receptors that signal the angle of the neck (the position of the head relative to the body), it also contributes to our awareness of the movements and positions of our whole bodies in space.

The vestibular apparatus has two functionally distinct components:

1. The semicircular canals. The first component consists of the three semicircular canals. These provide sensory information about rotational movements (angular acceleration) of the head in each of the three cardinal directions: swiveling the head from side to side (like shaking the head "no"), bending the head up and down (like nodding "yes") and tilting the head from shoulder to shoulder. Note that the plane of each of these movements is perpendicular to the planes of the other two, like the axis in a three dimensional graph. (Shaking the head "yes" is in one vertical plane; tilting the head from shoulder to shoulder is in the other vertical plane, perpendicular to the first; shaking the head "no" is in the horizontal plane, perpendicular to the other two.) The three semicircular canals that detect these movements, are also oriented so that the plane of each is perpendicular to the planes of the other two. Each semicircular canal consists of a roughly circular tube filled with a fluid (endolymph); the three tubes are interconnected so that the entire system is continuous and endolymph can flow in each tube in either direction. Rotation of the head in the plane of one of the semicircular canals causes endolymph to move relative to the walls of that canal (because of *inertia* – think of Newton's First Law of Motion).

In each tube there is a bulbous enlargement (the ampulla) where the sensory information arises. The ampulla contains two components: i.) a gelatinous mass (the cupula) that can be moved back and forth by the flow of endolymph; and ii.) a thickening or crest (the crista) containing the sensory hair cells. The cupula sits on top of the hair cells. One end (the "bottom") of each hair cell is contacted by vestibular nerve fibers. From the other end (the "top") of each hair cell projects a group of cilia ("hairs"). The cilia are imbedded in the cupula and are bent as the cupula is displaced by movements of the endolymph. In short, as the head rotates, the relative movement of the endolymph in the corresponding canal shifts the cupula and bends the cilia. Movement of the cilia in one direction causes the frequency of nerve impulses in vestibular nerve fibers to increase, while movement in the other direction causes the frequency of the nerve impulses to decrease. In this way the semicircular-canal system signals to the brain the direction of any head rotation (angular acceleration – either an increase or decrease in angular velocity).

As a supplemental exercise, you might supply the class with 3" x 5" index cards and ask students if they can orient three cards so that each one is perpendicular to the other two. They could then try to draw semicircular canals (in one corner) on each card and then put them together again to show the three canals appropriately in contact, and mutually perpendicular.

2. The otolith organs. The otolith organs of the vestibular system are the saccule and utricle. The saccule is designed to detect and signal linear acceleration of the head, especially in the up and down direction. The utricle is designed to detect and signal linear acceleration when the head tilts in any direction. Both organs have a small mass of calcium carbonate crystals (the major constituent of limestone and chalk, as well as bone). The otoliths (otolith means "ear stone" in Greek) are positioned over flexible "hairs" of the sensory receptors. When head position changes due to linear acceleration, the otoliths embedded in a gelatinous membrane tend to lag behind (inertia), bending the hair cell cilia. The result is that the impulse frequency in the vestibular sensory nerve fibers attached to the receptors in the saccule and utricle changes (rises or falls) in correspondence with the new head position. In fact, the sensory receptors are so arranged that some are more sensitive to a tilt of head position in one direction, while other receptors are more sensitive to tilt in another direction: Therefore, when head position changes, different subsets of vestibular nerve fibers change their activities in different ways. Recall that the semicircular canals are designed to detect and signal angular acceleration of the head.

For more information, refer to the following page, chosen from the book *Human Physiology in Space* by B. Lujan and R. White, illustrated by H. Bartner, which contains a detailed description of the vestibular system, including pictures. This is the same selection chosen for the students as an option for the student guided inquiry section of this lesson.[6] Pictures from the selection, also included in Appendix 6, are provided in the following pages. They can be used as visual aids during the lecture.

[6] See Appendix 6

The Vestibular System

(Used with permission from *Human Physiology in Space* by Lujan and White)

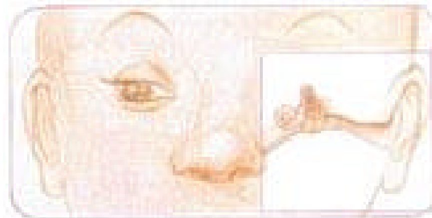
How do we remain standing despite the perpetual pull of gravity? Why can you whirl around suddenly without falling down? The vestibular organs (Figure 1), also called the vestibular apparatus, in the inner ear help maintain equilibrium by sending the brain information about the motion and position of the head. The vestibular organs consist of three membranous semi-circular canals (SCCs), and two large sacs, the utricle and saccule. All the vestibular organs share a common type of receptor cell, the hair cell. Let's examine the structure and function of the vestibular organs a little more closely.

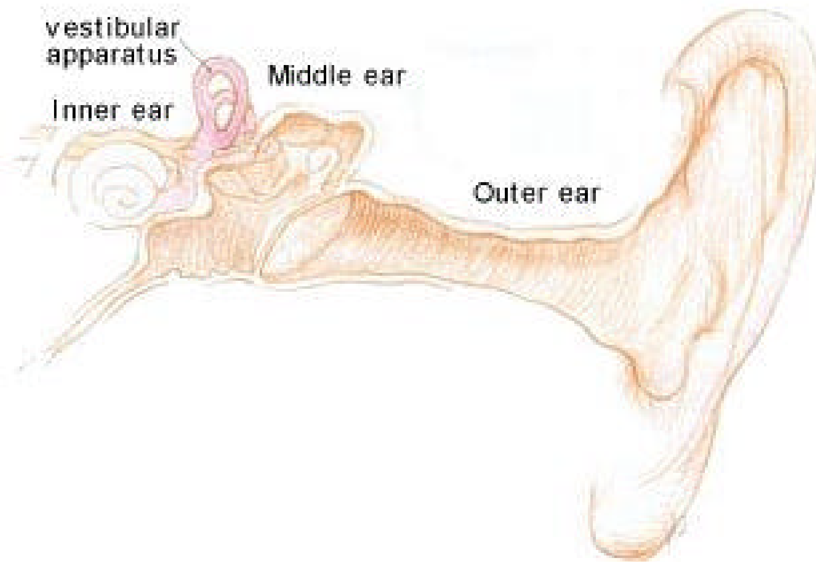
The three semicircular canals (SSCs) within the vestibular organ of each ear contain fluid and hair receptor cells encased inside a fragile membrane called the cupula (Figure 2). The cupula is located in a widened area of each canal called the ampulla. When you move your head, the fluid in the ampulla lags behind, pushing the cupula a very tiny bit which causes the hairs to also bend a very tiny bit. The bending hairs stimulate the hair cells, which in turn trigger sensory impulses in the vestibular nerve going to the brain to "report" the movement. Hair cells are amazingly sensitive. For example, a cupula movement of even a thousandth of an inch is detected by the brain as a big stimulus.

The three canals are positioned roughly at right angles to one another in the three planes of space. Thus, the canals react separately and in combination to detect different types of swiveling head movement. They detect when we nod in an up and down motion (pitch), when we tilt our head to the side towards our shoulder (roll), and when we shake our head "no" in a side to side motion (yaw). The semicircular canals are responsible for detecting any kind of rotational motion in the head.

Two other vestibular organs are located in membranous sacs called the utricle and the saccule. On the inside walls of both the utricle and the saccule is a bed (a macula) of several thousand hair cells covered by small flat piles of calcium carbonate crystals which look like sand, imbedded in a gel-like substance (Figure 2b). The crystals are called otoliths, a word which literally means "ear stones." In fact, the utricle and the saccule are often called the otolith organs.

When a person's head is in the normal erect position, the hair cells in the utricle lie approximately in a horizontal plane. When the head is tilted to one side, the stones want to slide "downhill." This moves the gel just enough to bend the sensory hairs. The bending hairs stimulate the hair cells, which in turn send a signal to the brain about the amount of head tilt. The stones also move if the person is accelerated forward and back, or side to side. Similarly, the hair cells in the saccule are oriented in somewhat of a vertical position when the head is erect. When a person tilts their head, or is accelerated up and down (as in an elevator), or moved forward and back, the otoliths move and a signal is sent to the brain. The signals from the otoliths in the saccule and the utricle complement each other and give us an integrated signal about our movement. The otolith organs are primarily responsible for detecting any degree of linear motion of the head.





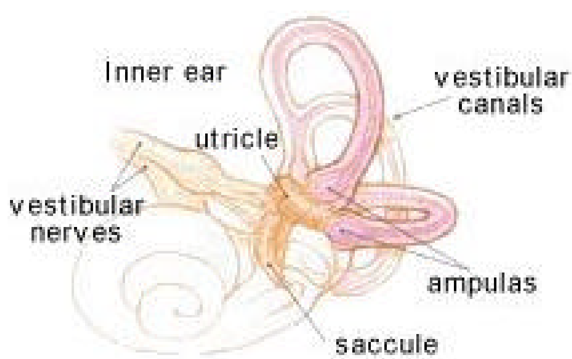


Figure 1: *The vestibular organs are located in the inner ear portion of the ear canal. The three vestibular canals detect rotational head movement and the otolith organs (located in the utricle and saccule) detect linear head movement (Images used with permission from Human Physiology in Space by B. Lujan and R. White).*

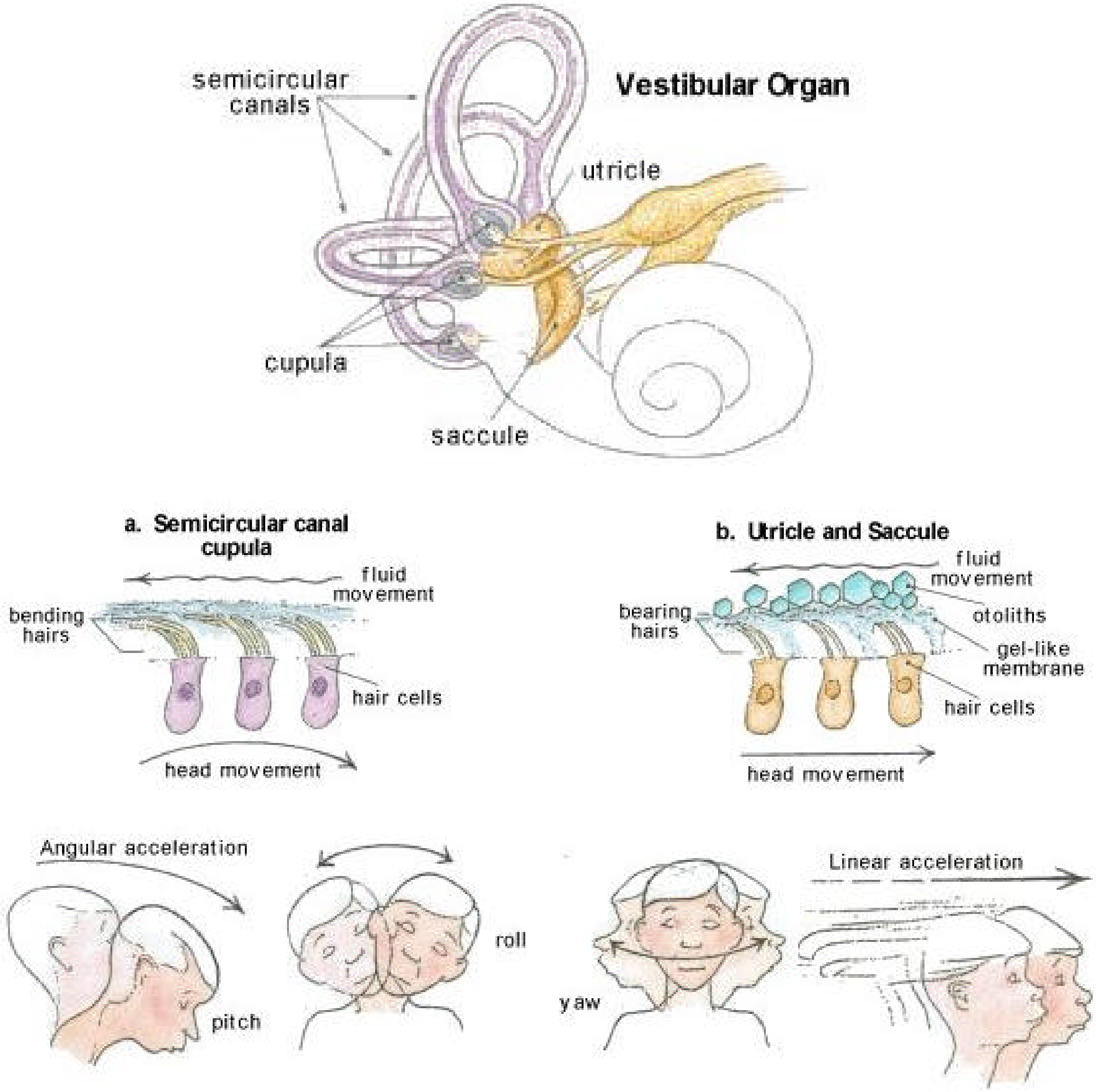


Figure 2: *a. The fluid in the semicircular canals bends the receptor hairs of the cupula in response to rotational head movement.*
b. The otoliths are embedded in a gel-like substance and, in response to linear head movements, the otoliths move and bend the receptor hairs (Images used with permission from Human Physiology in Space by B. Lujan and R. White).

Student Guided Inquiry (Core Part IC)

The following list represents several activities designed to help students understand the components and function of the vestibular system.

Option I (Core): Performing a web search on the vestibular system

Students will use the web to help gather information relevant to the case. This search should help the students clarify their hypotheses about what is wrong with Cecilia. Suggest that the students use the underlined keywords in their search. Naturally, "vestibular system," or any of the anatomical terms used in the lecture, can also be used as a keyword.

- Congested
- Sinuses
- Unsteady
- Nauseous
- Balance
- Spinning
- Vomiting

Option II (Core): Library/Resource Search

Students can use the library or any other resource area to gather information about the process of "balance" and "standing up." This is a replacement for classrooms without CD-ROM, Internet, or computer access.

Option III (Core): Finding data on the vestibular system

Students should read a selection on the vestibular system[7] and find answers to the following questions (also provided in Appendix 6). If there is no time to complete this assignment, students can take the selection home to read and examine the illustrations.

What is the main difference between the semicircular canals and the otolith organs?

The semicircular canals detect angular acceleration in three planes, while the otolith organs detect linear acceleration.

[7] Appendix 6. From *Human Physiology in Space: A Curriculum Supplement for Secondary Schools*. Barbara F. Lujan and Ronald J. White, Ill. Howard Bartner. The online version of this book can be found at http://nsbri.tamu.edu

Provide and explain several examples of activities (i.e., sports, jobs, etc.) in which the vestibular system is especially stimulated. Indicate whether the brain is processing information coming from the semicircular canals or the otolith organs.

Examples are skating, gymnastics, driving a race car, bungee jumping, flying a fighter jet, and any other occasions when the head moves in the gravitational field.

Option IV (Supplemental): Investigating the Stellar CD-ROM on the vestibular system

The Stellar CD-ROM summarizes the information about different systems needed in order to stand erect and maintain balance. The Stellar CD introduces the students to the vestibular system as one of the elements of balance. The recommended section of the CD-ROM is Section A. There are questions in this section for students to answer.

Option V (Supplemental): Examining a model of the vestibular system

Students will examine a model of the inner ear and vestibular system. While they may be unaware or unfamiliar with of the names of the parts, they should note the elements that are present in the inner ear.

Independent Activity/Homework (Part IC)

Students should pretend they are attending a national student science conference. The conference committee has asked that they present a talk on the vestibular system.

Using what they know already, students should write out the presentation they will give at the conference. Include any illustrations they might want to use in the presentation.

LESSON III: Watching the Vestibular System at Work

Guide for Part IC

Lesson Objectives:
Students will learn the working principles of the vestibular system.

National Science Education Standards:
Physical Science
- Motions and Forces.
- Interactions of energy and matter.
- Transfer of energy.

Benchmarks for Science Literacy – American Association for the Advancement of Science:
4F: Motion
- The change in motion of an object is proportional to the applied force and inversely proportional to the mass.
- All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

4G: Forces of Nature
- Gravitational force is an attraction between masses. The strength of the force is proportional to the masses and weakens rapidly with increasing distance between them.

10B: Uniting the Heavens and Earth
- Isaac Newton created a unified view of force and motion in which motion everywhere in the universe can be explained by the same few rules. His mathematical analysis of gravitational force and motion showed that planetary orbits had to be the very ellipses that Kepler had proposed two generations earlier.

Example of Regional Standards – Boston Public Schools Learning Standards:
Students will examine:
- Velocity
- Acceleration
- Circular motion
- Newton's First Law of Motion

Materials:
- One tube of water resistant super glue OR a hot glue gun
- Automatic turntable (such as one found in a pottery class), centrifuge, or other rotating device (such as a Lazy Susan or old record player)
- Set of false eyelashes or strands of another fuzzy or wispy material
- Clear glass jar or cylinder with lid
- Water
- Watch
- Note pad
- Pen or pencil
- Handouts:
  1. Appendix 7 (procedures for the experiment)
  2. Appendix 8 (table for recording data)
  3. Appendix 9 (corresponding questions for the experiment)

Lesson Opening (Part IC)

Allow students to discuss briefly what they learned from their research on the vestibular system. It might be helpful to record this data in a permanent place within the classroom. Students will be able to use this later in the case. If the students are not familiar with the basic physics principles related to the vestibular system, a brief overview on speed, acceleration and Newton's First Law of Motion are provided below.

Lesson Body

Teacher Directed Instruction (Core Part IC)

Velocity and Acceleration

Velocity is a measure of the distance traveled by an object in a finite amount of time. For a body at constant velocity, the basic physics equation is:

$$\mathbf{v = d/t}$$

where *v* stands for velocity, *d* is the distance traveled, and *t* the travel time. If you are in a car traveling at a constant velocity of 50 miles per hour, for example, this means you will travel 50 miles every hour. It is important to note that velocity is a vector quantity, which means that it has three main properties, magnitude, direction, and sense, and it can be represented by an arrow of a specific length pointing in a specific direction. To clarify this concept, consider this example: You are driving on a perfectly straight highway in a southwest-to-northeast direction. You state that you are going at 50 mph, bound northeast on this highway. Believe it or not, you just stated all the information you need to know about your velocity! Let us represent it in a vector diagram.

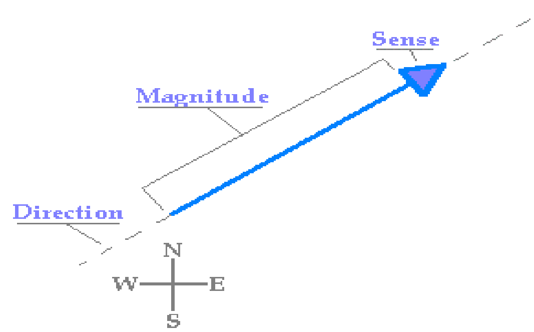


Figure 3: Vector Diagram

The length of your arrow represents the magnitude of your velocity vector (50), while the direction of your vector indicates your "line of action" (the highway on which you are traveling). If we stopped at this point, we would know how fast we are traveling and on which highway, but there are two opposite directions we could be traveling (SW or NE)! We then use our last piece of information (we are headed northeast) which indicates our sense. We now have a complete vector that represents our velocity in the car. Besides velocity, other examples of vectors are force, weight (points toward the center of the Earth), and acceleration. Note that very often direction and sense are unified as one piece of information.

Do not confuse speed with velocity! Speed is a scalar quantity, which means it is just a value (number) without any indication about direction or sense. For example, the speedometer in a car measures the speed (and not velocity!) because it simply displays a number (i.e., 50 mph) but it does not give you any indication about where you are going, or which highway you are on. Speed is therefore the magnitude of velocity. Velocity and speed are usually represented with one of the following units: "kilometers per hour" (kph), "miles per hour" (mph), "meters per second" (m/s), and "feet per second" (ft/s). Other examples of scalar quantities are mass, time and temperature.

In calculus, acceleration is defined as the rate of change of velocity with respect to time. This means that within a time interval, the final velocity is different from the initial velocity. In other words, anytime your velocity changes, you are accelerating (if your velocity increases) or you are decelerating (if your velocity decreases). The equation that links velocity and constant acceleration is:

$$\mathbf{a = v/t}$$

where a is the acceleration, v the velocity, and t is time. Imagine being stopped at an intersection as a red light goes to green and you step on the accelerator pedal, trying to apply a constant pressure. If you are able to measure the value of your velocity, or speed (assume 50 mph), after a specific amount of time (i.e., a minute), then you are accelerating at 50 miles per hour per minute, which means that every minute, if your acceleration is constant, you will be going 50 miles per hour faster than the previous. Just like velocity, acceleration is also a vector quantity. Acceleration is usually represented with the units of "meters per second square" (m/s^2) or "feet per second square" (ft/s^2), so you will have to use some conversion factors to go from "miles per hour per minute" to one of the standard units.

Newton's First Law of Motion

The English physicist, Isaac Newton (1642-1727), building on the ideas of Galileo (who died the year Newton was born), developed precise ways of understanding many aspects of the physical world: how objects move and how moving objects interact; the definitions of force, mass, and weight; the nature of gravity; the composition of white light. His quantitative "laws of motion" and theory of gravity made it possible to predict, with great accuracy, the movements of planets and the movements of objects on earth. These laws formed the foundation of modern physics and engineering. They went unchallenged for about 225 years until Einstein developed the theory of relativity in 1905. We now know from Einstein's theories, and from the experiments devised to test them, that with very great velocities approaching the speed of light and very great masses, like those associated with black holes, Newton's laws break down. Also, very tiny particles (like electrons) obey the surprising laws of quantum mechanics rather than the classical mechanics of Newton. However, when it comes to everyday objects, with their modest velocities and masses, Newton's laws still provide the basis for a precise and quantitative understanding.

Newton's First Law of Motion seemed counterintuitive when he first published it in his monumental *Principia Mathematica Philosophiae Naturalis* in 1686. It was generally believed at that time, and may still seem intuitively obvious to us, that the natural state of objects is to be at rest. We know that if we make an object move by pushing on it, it soon stops moving unless we apply a continuous force. It would be great if we could accelerate our cars to 65 mph at the beginning of our trip and then coast the rest of the way to our final destination. The reason we cannot is because of the counterforce of friction – the friction of the road on the tires, of the bearings on the axles, and of the air on the body of the car. To get a sense that this is correct, consider the following "example." First we take a rough-surfaced object, say an unplaned block of wood, and push it on a rough-surfaced substrate, say the sidewalk. Almost as soon as we stop pushing, the block stops moving because of the large amount of friction. Next, we take a block of smooth Teflon (or a hockey puck) and push it on a smooth patch of ice (much less friction). Long after we stop pushing, the Teflon block (or puck) continues to travel. Of course, there is still *some* friction between the puck and the ice and there is also friction between the puck and the air. What would happen if we could reduce all forms of friction to zero? Newton said that, in that case, once the object was moving, it would continue at the same velocity and in the same direction indefinitely! Newton expressed his First Law of Motion this way: "Every body persists in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by forces impressed on it." This phenomenon is also referred to as "inertia." A space ship traveling in outer space, to a distant planet, approaches the no-friction condition, as outer space is a near-perfect vacuum (with no air). If, during a space walk, an astronaut were not tethered to his/her orbiting space vehicle, and pushed off from the vehicle ("jumped"), he/she would continue moving away from the vehicle for a very long distance (unless intercepted).

Remember Newton's first law when you think about the movements of fluids in the semicircular canals. But, remember also that there is friction between the fluid and the walls of the canals; when the fluids are set in motion, they soon stop.

Student Guided Inquiry (Core Part IC)

After completing the activities, the discussion, and the web search, the students should have identified the vestibular system as one of the key systems responsible for balance. The following activity will show them how this system operates. The procedures for this experiment are also on Appendix 10, and the data collection table is on Appendix 8.
Remind students to use the scientific method.

(Used with permission from *The Brain in Space* by MacLeish and McLean)

In this activity, students will observe the importance of acceleration and deceleration in producing movement of hairs suspended in fluid. Students will be able to see how water within a rotating cylinder first accelerates, and then decelerates, as the movement stops. Because the speed is constantly changing during this movement, hairs within the cylinder will bend to different degrees. While accelerating, they bend more; while decelerating, they straighten. If rotation continues at a constant speed in a constant direction, the hairs remain in a stable unbent position.

In this exercise, students can observe and compare how the "hairs" move as a container of fluid is rotated in different directions, with acceleration and deceleration, and at a constant speed. These observations can then be compared to the way in which the vestibular organs respond to different types of head movements. Students can measure and compare the amount of time it takes to restore equilibrium with different degrees of motion and acceleration.

Procedures

1. At least one day before actually performing the activity, glue (or have the students glue) the false eyelashes or strands of other fuzzy material to the inside of the beakers, jars or glass cylinders. Attach to the side of the cylinder (not the bottom).
2. Organize students into pairs or groups of 3-4, depending on the amount of materials available.
3. Have one student from each group fill the cylinder with water. Let the water settle until it is completely motionless.
4. Direct the students to rotate the cylinder quickly 90° to the right (maintaining the vertical position of the cylinder) and observe what happens to the hairs on the eyelashes (Figure 4B).

5. Have the students rotate the cylinder 90° in the other direction and record observations.
6. After the motion stops, have students quickly rotate the cylinder 180° to the right, this time using a watch to measure the amount of time required for the hairs to return to a straight position. Have students record the time (Figure 4D).
7. Direct the students to repeat this procedure, with each student taking a turn at rotating the cylinder, observing the watch, and recording the time [all the students should try to rotate the cylinder at approximately the same rate]. Have them record the name of the person who rotated the cylinder and the person who observed the watch beside the measured time.
8. Have the students calculate the average time required for the hairs to come to rest after rotating the cylinder, and to record their calculations.
9. Have students quickly rotate the cylinder 90° to the right and then immediately rotate 180° to the left, measuring the time required for the hairs to stop moving. Have them record their observations.
10. Have students present their data from steps 7, 8, and 9 in tabular format. If a rotating device or turntable is available, have students place the cylinder on the device and rotate slowly (so are not to splash or dislodge the eyelashes) at an even rate for one minute. Have them time one minute using the watch. Ask the students to observe what happens to the hairs as they continue to spin, and after rotation is stopped. Have them record their observations.

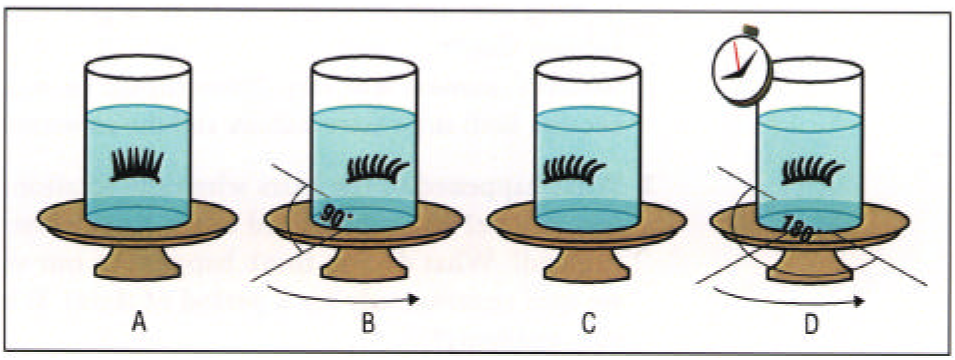


Figure 4: Diagram of a furry or wispy material or false eyelash in motion. A. At rest. B. 90^{o} motion. C. Motionless. D. 180^{o} rotation.
(Images used with permission from The Brain in Space by M. MacLeish and B. McLean)

While this experiment helps understand visually how the semicircular canals work, it is important to note that the actual process that takes place in the canals is a bit more complicated, and does not entirely rely on simple fluid motion and friction. In the inner ear, hair cell bending is proportional to endolymph displacement, not just to velocity or acceleration, as here. The reason the hair cell cilia return to upright during constant velocity rotation is because of cupula stiffness, and not just the slowing of the endolymph swirl.

Independent Activity/Homework (Part IC)

Students should evaluate the day's activities by answering the following questions,[8] adapted from *The Brain in Space: A Teacher's Guide for Neuroscience* by M. MacLeish and B. McLean.

1. How did the direction of rotation affect the direction in which the hairs bent?

   The hairs bend in the opposite direction of the rotation.

2. What happened to the hairs when the rotation was continuous for one minute? What happened to the hairs when the rotation suddenly stopped? What do you think happens to our vestibular system when we spin continuously for a period of time? What happens when we stop suddenly?

   The water and hair cells moved together which allowed the hair cells to straighten out when the motion was constant for one minute. When the hairs suddenly stopped, the water caused them to move forward. The hair cells move in the direction of the spinning. When suddenly stopped, we tend to fall forward and if we try to stand up we experience dizziness. This is due to the information the brain receives from the vestibular system (the hair cells in the semicircular canals are now moving) which triggers movements of the eyes in an attempt to compensate for the perceived motion. This "erratic" movement of the eyes makes us feel like "the world is spinning" while the rest of our senses tell the brain we are trying to stand still. This sensory conflict causes dizziness.

3. In step 7, different students took turns at a task. Were the times measured the same or different for each student? What might account for the difference in time?

   Clearly, it is hard for different people to turn the cylinder at exactly the same rate.

4. If the water in the cylinders was replaced with another substance that was more dense, such as liquid detergent, or less dense, such as air, how would the movement of the hairs change? What if the hairs were in a vacuum? What other factors might affect movement?

   If the hairs were placed in a dense liquid, the movement would be slower and not as obvious. If they were placed in a less dense substance, movement would be faster and more obvious. Assuming zero mass, if the hairs were placed in a vacuum, there would be no movement of the hairs, because there would be no frictional force, unlike the force created from water, air, etc. to

[8] See Appendix 9

make the hairs lag behind. In the real world, however, there would be a negligible movement of the hairs due to their very small mass, which is responsible for inertia.

5. Why do patients who are bed-ridden for long periods of time often experience dizziness and difficulty standing upright?

A possible explanation is that their bed-ridden vestibular systems functioned less than normally. Due to the lack of movement, when the patients stand, their vestibular system is activated and their brain has to adjust and get used again to the stronger stimuli. However, that is only a possibility, since dizziness in patients who stand up after being in bed for more than several days is usually simply due to orthostatic hypertension resulting from blood volume loss. This is generally unrelated to changes in vestibular function. It is similar to what happens to astronauts after spaceflight.

LESSON IV: The Vestibular System in the Real World

Guide for Parts IIA and IIB

Lesson Objectives:
- Students will explore processes and various instruments used in standard medical examinations.
- Students will recognize that standard medical evaluations are used as scientific tests (observations).
- Students will learn about vestibular neuritis.
- Students will explore the similarities between vestibular disorders and symptoms experienced by astronauts.

National Science Education Standards:

Earth and Space Science
- Structure of the earth's system.
- Earth in the solar system.

Science and Technology
- Abilities of technological design.
- Understanding about science and technology.

Science in Personal and Social Perspectives
- Personal health.
- Natural hazards.
- Risks and benefits.
- Natural and human-induced hazards.
- Science and technology in local, national, and global challenges.

History and Nature of Science
- Science as a human endeavor.
- Nature of science.
- History of science.
- Historical perspectives.

Benchmarks for Science Literacy – American Association for the Advancement of Science:

1A: Scientific World View
- From time to time, major shifts occur in the scientific view of how the world works. More often, however, the changes that take place in the body of scientific knowledge are small modification of prior knowledge. Change and continuity are persistent features of science.

1B: Scientific Inquiry
- Investigations are conducted for different reasons, including to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.
- Hypotheses are widely used in science for choosing what data to pay attention to and what additional data to seek, and for guiding the interpretation of data (both new and previously available).

4F: Forces of Nature
- Gravitational force is an attraction between masses. The strength of the force is proportional to the masses and weakens rapidly with increasing distance between them.

10B: Uniting the Heavens and Earth
- Newton's system was based on the concepts of mass, force, and acceleration, his three laws of motion relating them, and a physical law stating that the force of gravity between any two objects in the universe depends only upon their masses and the distance between them.
- The Newtonian model made it possible to account for such diverse phenomena as tides, the orbits of planets and moons, the motion of falling objects, and the earth's equatorial bulge.

Example of Regional Standards – Boston Public Schools Learning Standards:
- Gravitational interactions
- Velocity
- Acceleration

Materials:
- Timer
- Handouts:
  1. Appendix 3 (Experiment Worksheet)
  2. Appendix 10 (Procedures for Nystagmus Experiment)

Optional:
- Tuning fork
- Reflex hammer
- Stellar CD-ROM

Lesson Opening (Part IIA)

Students should read Part IIA of the case.
While reading the students should circle all of the unfamiliar words/terms. Make sure that the students know what each word means.

Student Guided Inquiry (Extension Part IIA)

This lesson extension allows students the opportunity to role-play the medical evaluation process.

Lesson Body
Teacher Directed Instruction (Core Part IIA)

After the students have read Part IIA, discuss what is happening to Cecilia. The students might suggest that:

- **She has gotten very sick and has gone to the hospital.**
- **She has gone to the hospital and was examined by a doctor.**
- **The various functions tested appeared to be okay, but Cecilia still could not stand and fell to the left.**

Guide whole-class discussion using the following questions:

What did Dr. Papadoupolous observe during her examination of Cecilia?
What do you know now about Cecilia's condition?
How do you know this?
Do these observations lead you to change your hypothesis about Cecilia's condition?

Students should record this information, along with any new data gathered from their reading in their Hypothesis Testing Packet.

Teacher Guided Inquiry (Core Part IIA)

Why do doctors follow standard medical evaluation protocols?

Students have explored and applied the scientific method throughout this case. Point out to the students that repeated procedures provide the doctor with information, some of which may help to rule out possibilities. This process is very similar to the scientific method, in that the doctor identifies a problem, develops a hypothesis, collects data, and then reevaluates the hypothesis. Based on these steps, the doctor moves towards isolating the cause of the medical problem.

Have the students personally reflect on their own visits to the doctor. They may find patterns in their visits and certain questions and procedures may happen frequently. Why is this so?

Student Guided Inquiry (Core Part IIA)

Students should revisit their Hypothesis Testing Packet, noting any changes in observations, hypotheses, data, or testing.

Teacher Guided Inquiry (Extension Part IIA)

This hands-on lesson helps students understand how medical instruments are used to gather vital data for healthcare providers.

Teacher Directed Instruction (Core Part IIB)

Have students read Part IIB. Discuss any unfamiliar words or concepts.

Explain to students that several things can go wrong with the vestibular system. One is known as vestibular neuritis.

Vestibular Neuritis

Vestibular neuritis, also called labyrinthitis, is generally characterized by a single, sudden attack of vertigo. Usually the patient is an adult. Neuritis is frequently preceded by a history of an upper respiratory infection (e.g., Cecilia described having had a cold). While attacks of vertigo, nausea and vomiting are abrupt and usually quite strong, hearing functions are not affected. While general labs tests are normal, a caloric test (a simple test in which a few drops of cold or hot water are inserted in the patient's hearing canal) reveals a "vestibular paresis" of the horizontal semicircular canal on one side. The nystagmus (twitching of the eye) is toward the side opposite to the lesion, while falling occurs towards the direction of the lesion. Vestibular neuritis is thought to be caused by a viral infection that creates a lesion of the vestibular nerve. This disorder is usually benign; the severe vertigo usually fades in a few days, but the same symptoms, on a smaller scale can be experienced for several weeks following the first attack, leaving the patient fatigued and upset. For example, they may be induced by a sudden movement of the head. There may be recurrences of symptoms months to years later.

Vestibular neuritis is just one of many vestibular disorders. Symptoms such as vertigo, nausea and vomiting are common to all vestibular disorders, but the causes for vestibular diseases can be quite different, and there are conditions that leave the patient with permanent loss of hearing or vestibular function. Some disorders are caused by a virus, by traumas to the head, or by medicines used to cure other diseases. There are also disorders for which researchers have not yet been able to identify a cause. If a vestibular disorder cannot be cured, the patient has to come to terms not only with the permanent damage, but also with the fact that attacks can return at any time for the rest of his or her life.

A possible treatment of vestibular neuritis is the drug meclizine, which is thought to block one type of receptor for the transmitter histamine (the H1 receptor). Another commonly used class of anti-emetic drugs is thought to block one of the types of receptors for the transmitter dopamine (the D2 receptor). Both types of drugs are speculated to block other kinds of receptors, to a lesser degree, and these secondary blocking actions may also be important. These drugs are commonly used in control of motion sickness and control of the nausea that occurs in cancer chemotherapy. These are speculations: we really don't know where and how these drugs work.

The H1 and D2 receptors occur in the reflex pathway the leads from the vestibular system to the rather complex mechanism that produces vomiting. The primary vestibular nerve fibers end in the vestibular nuclei of the brainstem (where there are H1 receptors), which send nerve fibers to the "chemoreceptor trigger zone" in the area postrema of the brainstem (where there are D2 receptors), which sends nerve fibers to the "vomiting center," a collection of nerve cells in the brainstem that organizes the act of vomiting. Consider the muscles that must act together: the jaw drops, the mouth and throat open, the tongue gets out of the way, the stomach contracts starting at the bottom and moving to the top so that its contents are expelled backward up the esophagus and out of the mouth, as other muscles brace the body.

Vestibular Disorders Are Experienced In Space

Explain to the students that disease is not the only cause for vestibular disorders. In fact, the weightless environment of space affects the vestibular system. Ask the students whether people even go where there is (almost) no gravity.

The following information will help students understand the relationship between gravity and the way the vestibular system functions.

Think back to the physical principles of the system explored in the eyelash experiment. The otolith components of the vestibular system are designed to respond to gravity. Gravity is the force of attraction between two or more bodies. The Force of gravity is directly proportional to the masses of the bodies (the bigger the masses, the larger the force), and inversely proportional to the square of the distance between the bodies (the further apart the objects, the smaller the force). The equation for the gravitational force (also known as Newton's Law of Gravitation) is:

$$\mathbf{F} = \mathbf{G}\,\frac{\mathbf{M_1 M_2}}{\mathbf{R^2}}$$

where G is the gravitational constant (fixed value), M_1 and M_2 are two masses, and R is the distance between them. The force of gravity is a vector quantity, and it is usually measured in Newtons (*N* in the SI system) or Pounds (*lbs* in the English system).

Imagine one of the two masses is large like the Earth and the other is smaller like a golf ball. The quantity R in this case represents the distance from the center of the Earth to the center of the golf ball. If we let the golf ball drop from a window, the gravitational force exerted by the much larger Earth will cause it to fall toward the center of the Earth (but the ground will soon stop it!) with an acceleration defined as the acceleration of gravity, g. Since g is also dependent on R (it is derived from the equation given above), its value slightly changes at different altitudes (R is different), but on Earth it is generally given an average value of 9.8 m/s^2. Therefore g indicates how you accelerate when you fall freely to the ground. On different planets, due to the differences in mass and radius, g has different values. Do you think the value of the force of gravity (and the acceleration of gravity) on the moon is larger or smaller than on Earth? Think about astronauts bouncing on the moon.

In a weightless environment, the otoliths[9] "float" over the hair cells, and therefore cannot provide a person with a clear sense of "up" and "down." The visual system and the saccule and utricle of the vestibular system provide conflicting information to the brain. Consequently, many astronauts experience symptoms like those experienced by Cecilia: dizziness and nausea. This is very hampering until the astronaut's brain adapts to the new condition by filtering out the conflicting vestibular information. See Figure 4 and 5 for pictures of astronauts who have adapted to weightlessness. Which astronauts are "right-side-up" and which are "upside-down?" Does it matter which way you turn the picture? When many astronauts who have adapted to weightlessness return to Earth, they experience dizziness when they try to stand and walk, until their brain re-adapts to vestibular information in the presence of Earth gravity. In their dizzy state, they have difficulty walking straight and sometimes bump into objects like walls.

In space, the semicircular canals are not significantly affected, and still tell the brain if the head turns in any direction (i.e., if there is angular acceleration). Note that while they are floating, and therefore unable to respond to gravity correctly, the otolith organs can still respond to linear acceleration in any direction (translation). Many researchers are studying the effects of space on the vestibular system and are trying to understand how the brain adapts to a new environment: see Figure 6 for an experimental apparatus designed to study the vestibular system in space. Ask students to reflect on whether they have experienced symptoms like Cecilia or the astronauts.

Think about whether you have ever been weightless. Every time you jump, e.g., on a trampoline, or when going for a slam-dunk, your body is "weightless" from the moment your feet lose contact with the ground. Although it may seem a little tricky to understand, being "weightless" while in orbit of the Earth is remarkably like free falling. In fact, technically, that is precisely what is happening: orbiting a planet is a "special case" of free fall. Any orbiting spacecraft is in fact "falling" towards the center of the Earth: the planet is exerting a force that is pulling the object towards its center, just as if you were into a free fall to the ground. However, objects in orbit do not fall back to the surface because they have enough horizontal velocity to counteract the downward pull. An object above most of the Earth's atmosphere also stays in orbit for a long time because there is less energy dissipation from air resistance (a very important factor within the Earth's atmosphere). However corrections and the use of on-board thrusters are sometimes required to re-adjust a spacecraft that, due to a loss of velocity and/or energy, may be starting to fall back into the atmosphere.

Therefore, the Space Shuttle, and everything it contains (astronauts included), is actually free falling around the Earth. This free fall is what creates weightlessness. A popular Earth-bound example about weightlessness is that of an elevator cab free-falling down the shaft. If you were in this elevator (a very unfortunate situation), everything contained in it, yourself included, would be free falling and therefore be weightless. This is *exactly* what happens in orbit: without being able to know what the outside environment around the elevator cab is, you would never be able to tell if you are in orbit or falling to the ground! Spaceflight physics can be confusing, but **the point here is that terms like "weightlessness" and "zero-gravity" are misleading when talking about orbiting objects because people tend to think that this means that gravity does not come into play, while all objects in orbit are in fact subject to gravity.** If it were not for gravity, these objects would keep on going on a straight line as soon as they left the atmosphere! "Pure weightlessness" as a result of absolute absence of gravity can only be experienced so far away from large bodies (large *R* from the gravitational force equation) that their force *F* is very small, i.e., in open space. However, being in open space and being in orbit feel exactly the same. Weightlessness is created by different factors, but the resulting effect is equal: whatever we learn about space in orbit is applicable to space travel.

Being in space and free falling on the Earth (a roller coaster ride or the "tower of terror") can also be very similar in that the pressure sensors in the feet and skin give the brain floating information, and as one falls vertically towards the ground, the otoliths tend to "float" over the hair cells. However, being weightless doesn't necessarily mean you feel that way. Visual cues are critical. You don't "feel" weightless on a trampoline, since your eyes tell you what is really happening to your body (you're falling!). On the other hand, in parabolic flight on a plane (as you will see later), on the Shuttle, or the famous falling elevator, you feel weightless, since the cabin and everything else in it falls with you (i.e., it is not moving relative to you): your eyes tell you there is no motion. This effect, added to the visual/vestibular conflict (confusing signals from the floating otolith organs about up/down, and motion of the environment around us), would make most people extremely dizzy!

Consider the opposite scenario: during take off, the astronauts are propelled in the Space Shuttle at about 3 times the acceleration of gravity (<u>macrogravity</u>). Have you ever experienced macrogravity (i.e., a centrifuge thrill ride)? In this case you weigh more than you normally do (on the Earth's surface) because a force larger than gravity is pushing on your skin and displacing your otoliths.

In order to conduct experiments in a microgravity environment (small amount of gravity) without leaving the Earth's atmosphere, NASA produces about 25 seconds of weightlessness near the earth's surface in the KC-135 airplane. The airplane achieves this by flying in a <u>parabolic trajectory</u>: while the very steep ascent and very steep descent (both at 45-degree angles) create a force greater than Earth's gravity, the central part of the parabolic route creates a virtually weightless environment inside the plane. Researchers inside the cabin have that relatively short time-window to conduct their experiments. Because of the brief duration of each microgravity session, every flight repeats a great number of parabolas. The plane usually flies over the Gulf of Mexico. Due to the constantly changing gravitational forces during these parabolas, it is very

[9] See Lesson II.

common for people inside the plane to develop very strong motion sickness: this side-effect earned the KC-135 the nickname of "vomit comet." See Figure 8 for a picture of the KC-135 during ascent and a diagram of the parabolic trajectory. Another environment used to simulate space is underwater, where astronauts are trained for extravehicular activities (EVA) and hardware servicing and repair. NASA has a Neutral Buoyancy Laboratory facility where the suited up astronauts work underwater on hardware mockups. See Figure 9 for a picture of a training session in the Neutral Buoyancy Lab.

Guide the discussion of these very different simulations:

Teacher Guided Inquiry (Core Part IIB)

- The KC-135 actually creates weightlessness, the vestibular system behaves just about as it would in space because of the absence of the proper gravity cues.

- The Neutral Buoyancy lab, however, creates the effect of "floating" by substituting water for the "emptiness" of space. Gravity is still present, as well as vestibular cues.

Because of the absence of reference points, it is possible to get disoriented underwater, and things are easier to lift because of Archimedes' principle. Archimedes' principle (also referred to as the Law of Buoyancy) states that a body immersed in a liquid is subject to an upward force equal to the weight of the volume of liquid the body displaces when it is immersed (that is why we float in fresh water, and we float still higher in the ocean). So, there is a sense of weightlessness, but the vestibular cues about gravity provided by the otolith organs are still there, because gravity is still present, unlike the KC-135 environment.

How do you think gravity changes on different planets?

Think about movies of astronauts bouncing on the moon. Is the force of gravity greater or smaller on the moon?

What about Mars? Why?

This question can be approached in two different ways: one is a more qualitative approach and the other is more quantitative, requiring the students to do some calculations. Consider the following astronomical data:

	Earth	Moon	Mars
Mass (Earth=1)	1	0.012	0.107
Radius (m)	6,400,000	1,740,000	3,395,000

Without calculating anything, recall the equation for the force of gravity introduced earlier. The force of gravity is directly proportional to the mass and inversely proportional to the square of the distance between the center of the planet and the other object (i.e., a person). This means that as the mass increases, so does the force of gravity, but as the distance *R* also increases, the force of gravity decreases rapidly. All other things being equal, the Earth has a much higher mass than the moon or Mars, which means that the force of gravity should also be larger, but it also has a larger radius, which would count as a "decreasing" factor in the equation.

Mars and the moon both have smaller masses (i.e., contribute to smaller force) and smaller radii (i.e., contribute to larger force) than the earth. Which one is going to prevail: radius or mass? Recalling images of astronauts on the moon, it is almost intuitive to say that the force of gravity there is much smaller, but what would happen on Mars? Gravity on Mars is about one third of that of the Earth. The numbers above show that the difference between the Earth's and Mars' masses are much more significant than the differences between their radii: Mars' mass is almost ten times smaller than the mass of the earth, while its radius is "only" about half of that of the earth. This great difference should lead the students to conclude that while the radius of Mars is smaller, contributing to a higher value of the force of gravity, its mass is so much smaller than that of the Earth that it will prevail over the action of the radius and result in a smaller force of gravity.

For a more quantitative approach, the students should consider calculating the values of the force of gravity *F* with the equation supplied earlier and the mass and radius values supplied above. Note that the results will be on a relative scale, since instead of providing mass values, only values relative to the Earth's mass were reported. For the equation, consider M_1 to be the planet in question (Earth, Moon, Mars) and M_2 a person on the planet surface with a mass of 60 kg (about 132 lbs.). The quantity *R* is the distance between the center of the planet and the person on the surface, therefore the radius of the planet. The value of the Gravitational Constant *G* is:

$$\mathbf{G = 6.67 \times 10^{-11}\ m^3/s^2kg}$$

Note that since we are merely comparing and not finding absolute values of the forces, G can be omitted in the calculations, as it is the same for all cases.

The results should indicate that the Earth has the highest force of gravity of the three, followed by Mars and, ultimately, the moon. The table below reports the values of the acceleration of gravity on the three planets:

	Earth	**Moon**	**Mars**
Acceleration of Gravity (m/s^2) (At the surface)	9.81	1.67	3.72

So, while we are firmly held in place by gravity on earth, we tend to bounce and lift objects very easily on the moon because gravity is only about 1/6 of that of the earth. On Mars, the conditions are a little more similar to our planet, as gravity is about a third of that of the earth, which still means that things are easier to lift, we weigh less, we can run for a longer period of time, etc.

Consider space travel to these and other planets? What challenges will the brain face in different gravities?

> **The brain needs to adapt to the altered gravities, in order to appropriately use the different signals it receives from the vestibular system. In different gravitational environments, the otoliths will behave differently (i.e., completely floating in weightlessness, somewhat "lighter" on the moon etc.), and the brain must to learn to adapt to avoid sensory conflicts that will cause motion sickness at the outset.**

Note that space affects many other systems in the body besides the vestibular system, such as the cardiovascular and musculo-skeletar systems. Scientists are currently studying these effects, as well as possible countermeasures.

Figure 5: *The Crew of the STS-90 Neurolab Space Shuttle Mission that flew in April 1998. The mission was the largest space life sciences mission to date and was dedicated to the study of the brain and the nervous system, including the vestibular system. The mission included 26 experiments ranging from vestibular research to sleep research, as well as several experiments involving animals. Who is right-side-up and who is upside-down? (Photo courtesy of NASA).*

Figure 6: *Another picture taken during the Neurolab mission. Notice that the astronauts are oriented in different directions (one is "up" on "the ceiling") without clear indications of a specific "up" or "down" directions (Photo courtesy of NASA).*

Figure 7: *A rotating chair apparatus used during the Neurolab mission for a vestibular experiment. A video camera was looking into the astronaut's eye, recording nystagmus due to the rotation (Photo courtesy of NASA).*

a.

b.

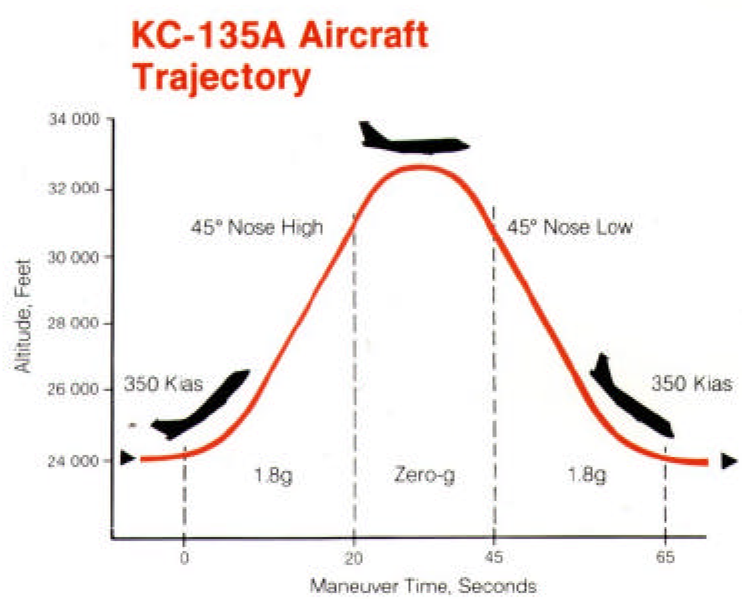


Figure 8: *a. The KC-135 during the ascent stage of a parabolic trajectory.*
b. A diagram showing the gravitational forces at the three principal stages (ascent, zero-g state and descent) of the parabolic flight (Images courtesy of NASA).

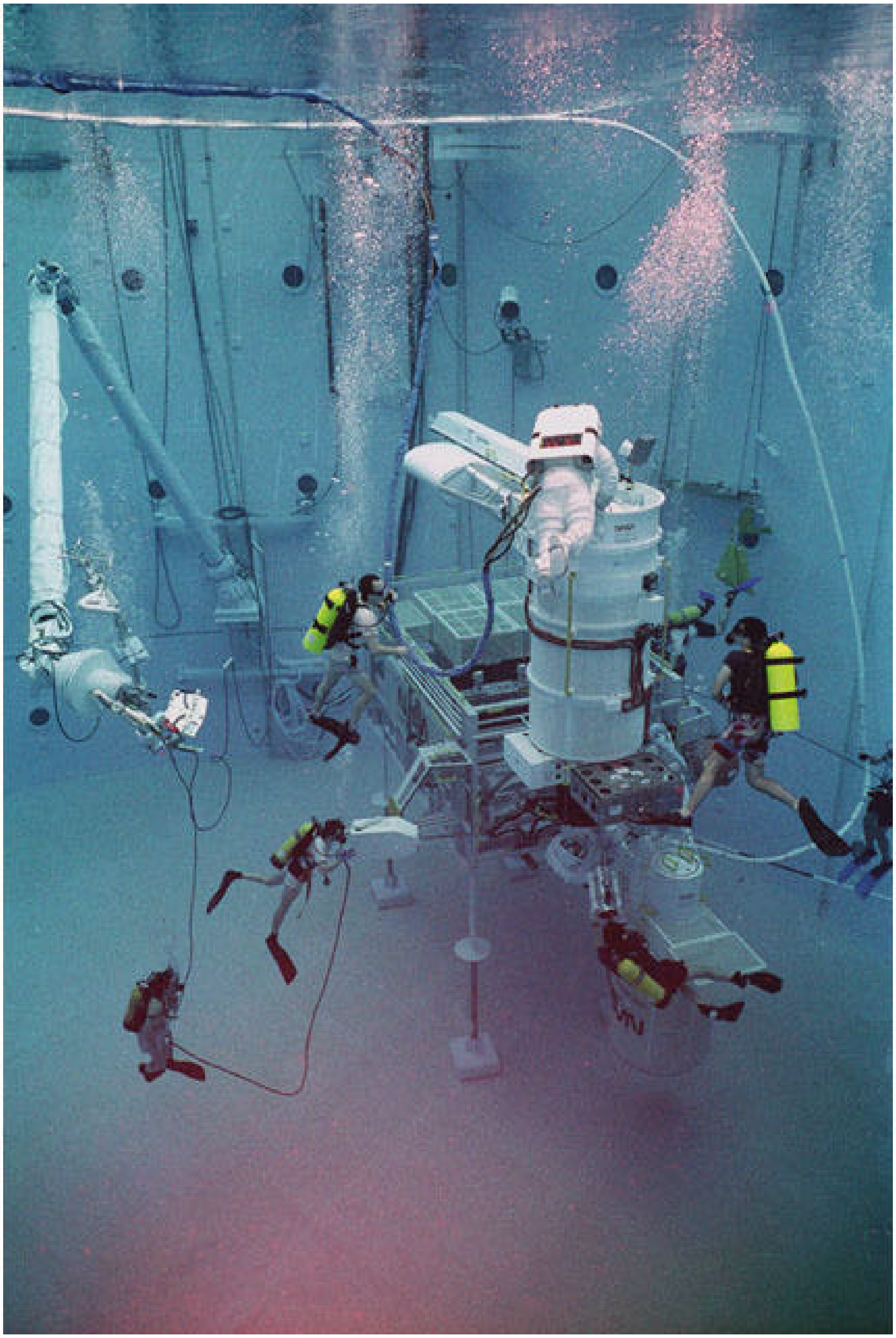


Figure 9: *A view of the NASA Neutral Buoyancy Laboratory where astronauts are trained underwater in the maintenance, servicing, repair, and installation of space structures such as the Hubble Space Telescope or the International Space Station (Photo courtesy of NASA).*

Student Guided Inquiry (Supplemental Part IIB)

Allow students to explore the Stellar CD-ROM for information about the effect of space flight on the vestibular system (Section C).

Teacher Guided Inquiry (Core Part IIB)

This demonstration will help students understand how nystagmus is produced. It is taken directly from the NeurON website.[10]

(Courtesy of The NeurON Web site http://quest.arc.nasa.gov/neuron/)

Purpose: To observe the eye's ability to help the brain detect body position and motion. Select 5 volunteers from the class. They will fill the following roles:

- Subject
- Spinner
- Timer
- Observer
- Recorder

Share this information with the students prior to the demonstration:

What is nystagmus?

Nystagmus [nis-TAG-mis] is usually defined as a rhythmic, or semi-rhythmic, involuntary oscillation of the eyes. It can occur normally or as a sign of disease. An example of normal nystagmus is optokinetic nystagmus, sometimes called railroad nystagmus. This occurs, for example, when objects are seen from the window of a moving train. First the eyes fixate on an object and then move (relatively slowly) to maintain fixation until they (rapidly) snap back to fixate on a new object. Optokinetic nystagmus, accomplished by cooperation between the visual and oculomotor systems, is an expression of one system for stabilizing the image of the real world on our retinas. The vestibular system, particularly the semicircular canal, also plays a role in image stabilization. Vestibular-induced nystagmus can be seen when a person sits in a rotating chair. This is different from optokinetic nystagmus because now the *person* is moving rather than the visual scene; it occurs even in the dark. During rotation there is a slow movement opposite to the direction of rotation and then a quick jerk back as the eyes reach the limit of movement in their orbits. (Clinical note: when physicians speak of a “left-beating nystagmus” or “nystagmus toward

[10] See “Procedures” Handout on Appendix 10.

the affected side," the direction of the nystagmus refers to the direction of the fast component – the rapid jerk.) During constant rotation in a chair, the nystagmus eventually ceases (usually after 20-30 seconds). If the rotation is suddenly stopped (making it easier to observe the person's eyes!), the nystagmus briefly resumes but in the opposite direction.

The semicircular canals transmit a continuous stream of nerve impulses to the brain even when the head is at rest. When the head rotates, the frequency of these impulses changes. For example, if the head rotates to the left, discharges from the left horizontal canal increase while those from the right horizontal canal decrease. These changes in impulse frequency inform the brain that a rotation of the head to the left, has occurred. However, suppose a disease process interrupts or decreases the impulses from the canals on one side. This would be interpreted as the head or body moving in space, while the visual system sends a conflicting signal that movement is not occurring. This conflict might be a cause of dizziness and nausea. It would also be expected to induce nystagmus because the vestibular system is signaling rotation. A similar conflict between visual and vestibular inputs can occur when a person is on a boat in rough seas (e.g., if the vestibular system reports that the head is moving, but the eyes report that there is no change in body position with respect to the boat) causing sea sickness. In space, without gravity to pull the otoliths "down," the brain gets confusing messages about body position, which can result in motion sickness.

WHAT TO DO:

(Courtesy of The NeurON Web site http://quest.arc.nasa.gov/neuron/)

1. Subject chooses a focal point at eye level at a distance of 2 meters from the subject's face.
2. Subject sits with eyes open on a chair or stool that rotates. (Alternative: If you do not have a rotating chair, subject can turn while standing in one spot, trying to keep the head level.)
   NOTE: It is important that the subject's head does not wobble.
3. The spinner (who has previously practiced turning the chair smoothly at a constant rate of one rotation per second) begins to turn the chair clockwise.
4. Without stopping the stopwatch, timer announces when one minute is up. Subject remains seated and focuses on the focal point.
5. The observer notes the direction of the nystagmus (right to left or left to right) and counts each eye motion or "twitch" until the nystagmus, has stopped.
6. Subject reports when he/she no longer feels motion. Timer stops the stopwatch and tells the recorder the full amount of time that has elapsed including the one- minute spin time.
7. Allow subject to recover before proceeding to next phase. NOTE: The same subject should be used for each of the four phases of the experiment.
8. Repeat steps 2 through 8, spinning counter-clockwise.
9. Repeat entire experiment, both clockwise and counter clockwise, this time with eyes closed for the one-minute spin. Record results.

Teacher Directed Instruction (Extension Part IIB)

This lesson extension provides an overview on the nature and function of viruses.

Independent Activity/Homework (Parts IIA and IIB)

The following activities represent the variety of topics addressed in this lesson. Feel free to choose the activities that apply to the presentation given in the class.

A. Explain which parts of the vestibular system are most affected in space and why. Use what you have learned about vestibular disorders on Earth and make connections between vestibular malfunctioning on the Earth and in space.

B. Astronauts often experience dizziness when they go to space and usually need a few hours or days to reorient themselves. However, they often experience similar symptoms when they land, and gravity affects their systems once again.

Do you think it would take longer to adapt back to gravity after a shorter or a longer space flight?

It has been observed that astronauts who have been on a longer space flight usually take longer to re-adapt to Earth's gravity and properly process their newly re-acquired vestibular functions. It has also been observed that, generally, astronauts with more flight experience due to several space missions have a shorter adaptation process both when going to space, and when coming back to Earth. Neurovestibular adaptation is a field that is being studied in great depth today, in light of upcoming longer space missions such as those that will take place on the International Space Station.

LESSON V: Recovery and Rehabilitation

Guide for Part IIC

Lesson Objective:

- Students will learn what can happen to a patient after experiencing a vestibular disorder.
- Students will be introduced to the concept of rehabilitation for certain permanent and debilitating vestibular conditions.
- Students will be exposed to the vestibular-ocular reflex and its relationship and importance to the vestibular system.

National Science Education Standards:

Life Science

- Diversity and adaptation of organisms.
- Behavior of organisms.

Science in Personal and Social Perspectives

- Personal health.
- Science and technology in society.
- Personal and community health.
- Science and technology in local, national, and global challenges.

Benchmarks for Science Literacy – American Association for the Advancement of Science:

4F: Motion

- All motion is relative to whatever frame of reference is chosen, for there is no motionless frame from which to judge all motion.

Example of Regional Standards – Boston Public Schools Learning Standards:

- Adaptation

Materials:

- Handouts:
  1. Appendix 3 (Experiment Worksheet)
  2. Appendix 11 ("Recovering from a Vestibular Disorder")
  3. Appendix 12 (Procedures for VOR Experiment)
  4. Appendix 13 (Questions about the functioning of the vestibular system)

Optional:

- Stellar CD-ROM

Lesson Opening (Part IIC)

Students should read Part IIC of the case. While reading, the students should circle all of the unfamiliar words/terms.

Lesson Body

Now that students are aware that Cecilia was suffering from a vestibular disorder, they should explore the process of rehabilitation. The following selection will assist you in facilitating a discussion around recovery and rehabilitation.

Pass out "Recovering from a Vestibular Disorder" to each student.[11] Students can read the selection independently, in small groups, or as a whole class. Use the following questions for discussion:
Explain Dr. Rauch's comparison between learning language and recovering from a vestibular disorder. Do you think this comparison is accurate? Why or why not?

Recovering from a Vestibular Disorder

The vestibular system is part of a "navigational system" that gives you information about your movements and position in space. The other "input channels" are vision and somatosensory (position sensors in muscles and joints, tactile sensors on skin, etc.). Incoming signals in these three channels (nerve impulses) go to the balance centers of the brainstem where they are compared to each other and information is passed to reflex centers, to higher brain centers for awareness and planning of voluntary actions. These higher sites then send outgoing messages to control eye movements and body movements. If the vestibular system is defective (in sensing endings, nerve fibers or synaptic endings), the patient has a sense of imbalance or dizziness.

When you were an infant or toddler, your brain had to learn to use the signals coming in from the three input channels of the navigation system, just as you had to learn to use language. During recovery from damage to the vestibular system, the brain must learn new comparisons between three different input channels. After damage, there is a "sensory conflict" in which the vestibular system sends messages that the brain interprets as motion, but the eyes and somatosensory channels disagree. It is this sensory conflict that causes nausea, fatigue, and dizziness.

Although balance information is processed in different parts of the brain than language, language learning is a good model for the recovery process that occurs after an injury or illness of the

11 See Appendix 11

balance system. Learning a new language is quicker in young people, highly motivated people, and those who practice a lot. There is also an innate language capacity that varies from person to person; some people are "good with languages" and others are not. All these factors apply to balance recovery as well: recovery is quicker in younger patients, in highly motivated patients, and in patients who move around a lot to practice. Also, there is an innate difference in balance ability in the nervous system; some of us become gymnasts and figure skaters while others do not tolerate much motion stimulation and get carsick on the subway. Recovery from an acute balance illness or injury may take anywhere from two weeks to two years. Many patients make a total recovery but some are permanently affected (like someone who moves to a different country but never becomes fluent in the new language).

For patients who are having trouble recovering, there is a type of physical therapy, vestibular rehabilitation therapy, that can often help. This therapy has two strategies. One is called accommodation. The rehabilitation therapist evaluates the patient to determine which eye, head, and body movements are most upsetting, and then gives him/her a series of exercises to practice exactly those movements. The second strategy is called sensory substitution. The therapist determines which parts of the vestibular system are providing the best or most reliable information and gives the patient a series of exercises that condition him/her to focus on the reliable vestibular information and neglect or ignore the damaged information. Every week or two the therapist evaluates the patient's progress and upgrades the exercise routine to something slightly more challenging. The benefits of rehabilitation therapy are usually achieved over two or three months.

During whole class discussion, ask students to respond to the following open-ended question: In which case would you assign accommodation or substitution therapy and why?

> **It may be possible to use accommodation to help the brain get used to certain head movements, if the patient's symptoms are not too strong, and do not require the patients to be dynamic. Substitution therapy can be assigned if the person wants to do more physical activities, yet act as normally as possible.**

After students have discussed rehabilitation from a vestibular disorder, have students consider what life might be like for a person with permanent damage to their vestibular system.

Point out to the students that of the many possible permanent damages to a person who has suffered a vestibular disorder, blurred vision is one of the most evident and debilitating after-effects. This is due to the absence of what is called the "vestibular-ocular reflex" (VOR). The VOR is a special reflex that uses inputs from the vestibular system (which tells the brain how the head is oriented and which way it is moving) to control eye movements: this way, whenever we move our head (i.e., shake it, nod, walk) the eyes also move so the image is stabilized and, therefore, not blurred or out of focus. Note that in order for the VOR to be activated, the head has to move, otherwise there are no vestibular inputs that the brain can use to control the eyes. This section only focuses on the VOR, but it should be noted that there are other reflexes related to the vestibular system.

Vision can sometimes play "tricks" on our brain and give us the illusion of moving when, in fact, we are not: this effect is called vection. Vection occurs when our brain thinks we are moving when we are in fact standing still, and it is solely based on visual inputs. A familiar example occurs when one is sitting in a plane parked at the gate while the plane next to ours is pulling out: it is possible for us to have the feeling that our plane is going forward, while the other plane is standing still! Another everyday example could be sitting in a train at the train station, watching a train on the track next to us move, and feeling that our train is moving in the opposite direction! This phenomenon usually dissipates as soon as you are able to focus on a fixed element in the environment (i.e., a tree, a pole, etc.). This tells the brain that we are not moving. For this reason, it is usually harder to get a sense of vection when sitting in a car, because usually other objects passing us (i.e., cars, people) do not completely occupy our field of view, and we can always see other elements in the environment that are not moving. These everyday examples are cases in which our sense of movement can be stimulated without the help of vestibular cues. Often this conflict between visual and vestibular cues can cause motion sickness. Imagine how often this would happen if our vestibular system was "turned off" or malfunctioning. Such a patient must rely on vision much more than normal, and phenomena like this are bound to happen more frequently than in a normal person.[12]

Student Guided Inquiry (Core Part IIC)

VOR Experiment[13]

This activity will allow students to observe how the VOR helps individuals to stabilize images when their head is in motion.

1. Hold a page with some text written on it, about 18" in front of your eyes.
2. Move your head back and forth (as if saying "no," about 2 times per second).
3. Can you read the page? Is there some blurring?
4. Now hold your head still and move the page in front of your eyes left to right (this should also happen about 2 times per second).
5. Can you read the page? Is there some blurring?
6. Record your results.
7. Discuss, compare and contrast your results with other students.
8. Students should write up their finding from the VOR experiment.

[12] There is also another factor that influences the way the brain processes motion information and that is called the "coriolis effect." In physics terms, the coriolis acceleration is a component of the acceleration that is present whenever a rotating reference frame is considered. The coriolis effect may also be responsible for motion sickness.

[13] See Appendix 12

It is important to reflect on the fact that we have two sets of vestibular organs - one set in each ear - and they are functionally redundant to a surprising degree. Patients can lose balance function completely on one side, and after a period of adaptation, have almost normal balance function, with deficits detectable sometimes only by special lab tests. Cecilia's vestibular neuritis was apparently unilateral - affecting the vestibular nerves on one side. So even if her vestibular function doesn't return on that side, the prognosis for her ultimate recovery and return to normal life are very good.

Independent Activity/Homework (Part IIC)

A. (Supplemental) Students may want to investigate the VOR in more depth. The Stellar CD-ROM, Section B, provides additional information and support in this area.

B. Students should respond to the following questions[14] adapted from *The Brain in Space: A Teacher's Guide on Neuroscience* by M. MacLeish and B. McLean. See Appendix 13 for a copy of these questions to be handed out to the class.

1. What does the vestibular-ocular reflex do?

   The vestibular-ocular reflex coordinates eye movements relative to head movement.

2. What else does the vestibular system do?

   The vestibular system helps the body to maintain balance. It helps the body to determine the difference between motion of the body and motion of things in the world.

3. Why is the vestibular system important to movement?

   It helps the body to maintain balance and to our own adjust to movements of the body and the movements of the environment (as occurs in a vehicle).

[14] See Appendix 13

4. How is motion sickness caused?

   Motion sickness can be caused by a sensory conflict between signals coming from the vestibular system and other senses (vision, somatosensory). This continuing conflict causes nausea.

5. Why do people who have problems with their vestibular systems experience dizziness?

   If the vestibular system is damaged in any way, the signals it should send to the brain about the head's position and acceleration may be missing or inaccurate. This will create a conflict with the images provided to the brain by the eyes, the joint receptors and so on. This sensory conflict can result in dizziness.

6. What happens if the vestibular system is destroyed? Explain how one would act and feel.

   A person will have problems adjusting to movement and maintaining balance. Motion sickness is common.

7. Why might a person experience motion sickness when not moving or in an IMAX theater?

   If the brain receives a great deal of visual information that could be interpreted as movement, we experience vection. If this is a strong feeling, there can be a conflict with vestibular information, which is telling the brain that we are in fact still. The sensory conflict is responsible for motion sickness.

8. Does the vestibular system adapt to microgravity? Without gravity to give us a constant downward reference, how will the roles of visual and touch cues change?

   The brain gradually learns how to interpret vestibular information in microgravity. It learns to filter out certain cues, and it relies more on visual and tactile cues, to determine our position in space. Because of the higher reliance on visual cues in space, vection seems to be more easily induced in microgravity.

"Cecilia's Story" - Lesson VI Wrap-Up

Lesson Objectives:
- Students will summarize the major topics of the case.

National Science Education Standards:
- Depending on the teacher's strategy to review the main topics of the case, any of the benchmarks mentioned in the previous lessons are applicable in this wrap-up.

Benchmarks for Science Literacy – American Association for the Advancement of Science:
- Depending on the teacher's strategy to review the main topics of the case, any of the benchmarks mentioned in the previous lessons are applicable in this wrap-up.

Example of Regional Standards – Boston Public Schools Learning Standards:
- Depending on the teacher's strategy to review the main topics of the case, any of the standards mentioned in the previous lessons are applicable in this wrap-up.

Materials:
- To be determined by the teacher

Optional:
- Stellar CD-ROM

Lesson Opening (Wrap-Up)

Have students read Part IID of the case. Ask students to reflect on the case and identify the major topics covered. Record these responses and use them to guide the next section.

Lesson Body

Teacher Directed Instruction (Core Wrap-Up)

Use the following diagram to help students understand the connections between the major topics covered in this case.

BALANCE <==> VESTIBULAR SYSTEM <= Disorders => REHAB
| |
VOR SPACE

Notice there is a double arrow between balance/vestibular system. This indicates that each of these elements can affect the other: balance can affect the vestibular system, and the vestibular system can affect balance. Note that these effects do not have to occur simultaneously.

Balance disorders involving vestibular functioning may require rehabilitation. Problems experienced by astronauts in space often resemble those experienced by patients who have vestibular disorders on Earth. The vestibular-ocular reflex is highly dependent upon proper functioning of the vestibular system. Students can also access the Stellar CD-ROM, Section D for a summary of the topics covered in the case.

Student Guided Inquiry (Extension Wrap-Up)

This extension provides several activities designed to assess what students have learned throughout the case.

Teacher Directed Instruction (Extension Wrap-Up)

This extension provides summaries of various medical and science careers related to the case.

Student Guided Inquiry (Supplemental Wrap-Up)

The Stellar CD-ROM, Section D, contains a summary of all the topics covered in the case.

“Cecilia’s Story”

Master Glossary

GLOSSARY

This section contains keywords from the case narrative (in black), as well as definitions of words included in the Teacher's Guide (in blue). Several of the definitions below were taken or adapted from Stedman's Concise Medical Dictionary and Webster's New Collegiate Dictionaries:

Acceleration: The rate of increase or decrease of velocity per unit of time.

Acceleration of Gravity: Acceleration due to the force of gravity exerted by a body (i.e., the earth) onto another body (on Earth it is generally given an average value of 9.8 m/s^2).

Archimedes' Principle: A body immersed in a liquid receives an upward buoyant force equal to the weight of the volume of the liquid which is displaced by the body.

Anti-Emetic: An emetic is an agent that induces vomiting. Therefore, an anti-emetic is an agent that prevents vomiting.

Axon: The single process of a nerve cell that under normal conditions conducts nervous impulses away from the cell body and its remaining processes.

Balance: Physical equilibrium maintained in the presence of gravity which otherwise causes the object (body) to fall: in this case, the patient's ability to stand up against the force of gravity.

Blood Clot: An abnormal mass composed of coagulated blood cells floating in the blood that can obstruct (block) the regular flow within a blood vessel.

Brain Tumor: Usually, an abnormal mass of brain cells that have divided too many times.

Brisk Right-Beating Nystagmus: A jerky rhythmical oscillation of the eyeballs. In this case (brisk right-beating), Cecilia's eyes exhibited a jerky motion toward the right. Nystagmus can also be "rotational" (the eyeballs exhibit a rotational motion around the pupil).

Caloric Test: A test in which a few drops of hot or cold water are inserted into an individual's hearing canal. The water changes the temperature of the fluid contained in the semi-circular canals of the vestibular system, inducing **nystagmus**.

Canal: A duct or channel; a tubular structure.

Congested: Concentrated in a small or narrow place.

Coriolis Effect: In physics terms, the coriolis acceleration is a component of the acceleration that is present whenever a rotating reference frame is considered.

Cranial: Of or relating to the skull or cranium. (e.g., there are 12 cranial nerves.)

CT Scan: Computer Tomography. An X-ray image of the body. The CT machine sends X-rays through successive "slices" of the body part to be analyzed. The computer can display the image of one slice or add up the images from individual slices to give a picture of the whole part.

Dendrite: One of the two types of branching protoplasmic processes of the nerve cell (the other one being an axon).

Deep Tendon Reflexes: An involuntary contraction of a muscle when (e.g., the "knee jerk") a tendon is tapped. It is initiated when the muscle stretch receptor nerve fibers in the muscle are stimulated by tapping the tendon; these sensory nerve fibers make excitatory synapses on nerve cells in the brain or spinal cord that cause the muscle to contract, to resist the sudden stretch produced by the tap on the tendon.

Dizzy/Dizziness: Imprecise term commonly used by patients in an attempt to describe various symptoms such as faintness, vertigo, disequilibrium or unsteadiness.

Electrocardiogram: A record of the electrical activity that accompanies the successive contractions of the heart.

Gravity: The force of attraction between two or more bodies, dependent on their masses and distance. The equation that relates gravity, mass and distance is given on page 34.

Heart Problem: A problem with the function of the cardiac (heart) muscle.

Horizontal Semicircular Canal: The semicircular canal oriented in the horizontal plane with of the head.

Humidify: To add moisture (into the air). From Latin *humiditas*, dampness.

Joint Position: A Joint is the contact, usually more or less movable, between two or more bones. The sense of joint position is served by sensory receptors in the joints that tell the brain or spinal cord what the present position of a joint is and which way the joint is moving (if it is moving).

Labyrinth: Usually, the complex of the vestibular system located in the inner ear, so called because of the intricate structure of its passageways.

Macrogravity: Larger than Earth's gravity.

Meclizine: An anti-emetic agent used to treat nausea and vertigo. See Lesson IV for more information about meclizine.

Nausea: A feeling of being sick to the stomach; an inclination to vomit.

Neurons: The functional unit of the nervous system consisting of the nerve cell body with its dendrites and axon.

Neurotransmitter: A substance that transmits nerve impulses across the synapse.

Neutral Buoyancy Laboratory: An underwater NASA facility, designed to simulate a microgravity environment for the purpose of training astronauts in the servicing, installation and repair of space structures.

Nystagmus: See **Brisk Right-Beating Nystagmus**.

Otoliths: (i.e., Otolith organs). The elements within the vestibular system responsible for the ability to detect linear acceleration (up/down, forward/backward) by lagging behind when the head accelerates; they also respond to gravity and provide information about up and down even when we are not moving.

Parabolic Trajectory: The curve that a body describes in space. If parabolic, the trajectory is in the shape of a parabola.

Range of Motion: Joint movement (active, passive, or a combination of both) carried out to assess, preserve, or increase the arc of joint range of motion. The extent to which joints can move.

Receptor: A structural protein molecule on the cell surface or within the cytoplasm that binds to a specific factor, such as a hormone, an antigen, or neurotransmitter.

Reflex: A reflex is a more or less rapid and automatic response to a stimulus: the brain or spinal cord causes certain muscles to contract, without the person thinking about, or planning, the movement. Example: the eyelid blinks when an object approaches the eye unexpectedly; the pupil of the eye constricts when light is shone into the eye (pupillary eye reflex).

Reflex Hammer: A small rubber hammer used to test tendon reflexes.

Rehab: To restore or bring to a condition of health or useful and constructive activity.

Sense of Touch: Sense is the faculty of perceiving a stimulus. Sense of touch is awareness of a slight contact with the skin or a mucous membrane. Touch is one of the five "classical" senses, there are many "senses" associated with changes inside and on the surface of the body.

Sinus: A cavity or hollow space in bone or other tissue (in Cecilia's case, we are talking about sinuses in the skull behind the nose).

Somatosensory System: Position sensors (receptors) in muscles and joints, tactile and pressure sensors in skin, etc. that tell the brain and spinal cord about body position and contact with the surrounding environment.

Speed: The magnitude (i.e., the simple "value," or "number") of velocity, without any information about direction.

Spinning: The sensation that everything around a person, or the person him/herself, is rotating.

Suppressant: An agent (such as a drug) that tends to suppress or reduce in intensity rather than eliminate something (such as appetite).

Synapse: The functional membrane-to-membrane contact of the nerve cell with another nerve cell, an effector (muscle, gland) cell, or a sensory receptor cell.

Symptom: Any morbid (morbid as referring to disease; unhealthy) phenomenon or departure from the normal in structure, function or sensation, experienced by the patient.

Tone (muscle): Degree of muscle tension or resistance during rest or in response to stretching.

Tuning Fork: Metal instrument roughly resembling a two-pronged fork, the vibrations of the prongs of which, when struck, give a musical tone of restricted bandwidth; used to test the hearing and vibratory sensation.

Unsteady: Not fixed in position; unstable (i.e., unable to keep balanced).

Vection: The illusion that the body is moving in a circle (circular vection) or in a line (linear vection) when, in fact external visual cues are moving relative to the body.

Velocity: The measure of distance traveled by an object per unit of time. A vector quantity having magnitude and direction.

Vertiginous: Characterized by or suffering from vertigo or dizziness.

Vertigo: A disordered state in which the individual or his surroundings seem to whirl dizzily.

Vestibular Neuritis: "Neuritis" is an inflammatory or degenerative lesion of a nerve marked especially by pain, sensory disturbances, and impaired or lost reflexes. Therefore, vestibular neuritis is a disorder caused by the inflammation of the nerve connected to the vestibular system.

Vestibular-Ocular Reflex (VOR): A special kind of reflex that coordinates inputs from the vestibular system to eye movements, and helps to stabilize the visual image on the retina during head movements.

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Related Web Sites

The following is a list of web sites related to associations, activities, and research efforts on the vestibular system.

NASA WEB SITES

The NASA Web Site
http://www.nasa.gov

NeurON: Neurolab Online.
http://www.quest.arc.nasa.gov/neuron

Quest Team: NASA K-12 Internet Initiative.
http://www.quest.arc.nasa.gov/

Space Neuroscience Page (Physiology Background)
http://www.hq.nasa.gov/office/olmsa/lifesci/neural.htm

OTHER SITES

American Association for the Advancement of Science - Benchmarks for Science Literacy
http://project2061.aaas.org/tools/benchol/bolframe.html

Baylor College of Medicine Center for Balance Disorders
http://www.bcm.tmc.edu/cfbd

Hearing and Vestibular Internet Links
http://www.bme.jhu.edu/labs/chb/links.html

Massachusetts Eye and Ear Infirmary
http://www.meei.harvard.edu

Massachusetts Eye and Ear Infirmary Jenks Vestibular Laboratory
http://www.jvl.meei.harvard.edu

Massachusetts General Hospital Biomotion Laboratory
http://www.mgh.harvard.edu/depts/biomotion/index.htm

Massachusetts Institute of Technology, Man-Vehicle Laboratory
http://web.mit.edu/aeroastro/www/labs/MVL/NEW/MVL/home.html

Multimedia Lecture: "Clinical Approach to Nystagmus, Imbalance and Dizziness" (Queen's University at Kingston, Canada)
http://eolas.ca/oculomtr/oculomot.htm

Multimedia Vestibular Sites
http://www.adworks.com/dizzy/multimed.html

National Academy Press – National Science Education Standards
http://www.nap.edu

National Council of Teachers of Mathematics
http://standards-e.nctm.org

NSBRI Neurovestibular Adaptation Integrated Research Team
http://web.mit.edu/aeroastro/www/labs/MVL/NEW/Neurovestibular/Pages/

NSBRI Online Version of the Educational Text: "Human Physiology In Space"
http://nsbri.tamu.edu/HumanPhysSpace/index.html

The Vestibular Disorders Association (VEDA)
http://www.vestibular.org

Vestibular Disorders Hotsheet: Coping with Dizziness (Resource for Patients)
http://www.adworks.com/dizzy/vestib.html

Vestibular Patients Stories & Support Groups
http://www.adworks.com/dizzy/patient.html

Vestibular System: Frequently Asked Questions (FAQ)
http://www.bme.jhu.edu/labs/chb/faq/faq.html

“Cecilia’s Story”

Appendices

Student Guided Inquiry (Part IIA)

Choose several students to act out the emergency scene. This will allow students the opportunity to role-play the medical evaluation process. This might help students to understand why medical professionals use standard testing procedures to gather data in order to form hypotheses about a patient's condition.

This activity also employs multiple learning strategies, thus engaging students who might be reluctant to participate in traditional classroom activities.

Teacher Guided Inquiry (Part IIA)

How do medical instruments help medical practitioners collect and test data?

Discuss the instruments used in Cecilia's examination. Explain to students the purpose of the instruments and the way they help the doctor or nurse gather data. The teacher should demonstrate the correct way to use the tuning fork and/or the reflex hammer.

Student Guided Inquiry (Part IIA)

Allow students the opportunity to use the reflex hammer and tuning fork. Monitor students to ensure proper and safe use.

Teacher Directed Instruction (Part IIB)

Some students might recognize that viruses are often involved in disabling a person's vestibular system. For these classrooms, a discussion about viruses might be appropriate. The section below provides an overview on the nature and function of viruses.

Viruses were initially identified, about one hundred years ago, as agents that transmitted diseases from one person or animal to another but appeared not to be bacteria. These novel agents were so small they passed through special filters that retained even the smallest bacteria. Bacteria can be seen in the light microscope; viruses cannot. Viruses can be seen, however, in great detail, in the electron microscope. We now know that a virus is a tiny package of genetic material surrounded by a protein coat. In many types of virus the genetic material is, as expected, DNA. However, there are also viruses in which the genetic material is RNA (the AIDS virus, HIV, is an example). A virus is not a cell. It is not free-living. It can only reproduce by entering a living cell – an animal, plant or bacterial cell. It can be thought of as a miniature chromosome that is able to survive outside of cells. But it is also able to re-enter cells and, once inside, to subvert the cell into making many copies of itself. The process of making so many virus particles may kill the cell. The cell membrane then ruptures or becomes leaky allowing the newly reproduced viruses to escape and infect other cells. A virus has been referred to as: "…a piece of bad news wrapped in protein." It is essentially a package of information on how to make more of itself. The protein coat helps to protect the enclosed piece of DNA or RNA when the virus is outside of a cell and it can be important for getting the nucleic acid into a new host cell. Not all viruses escape by killing their host cells. Some bud off from the cell taking a piece of the cell membrane with them. In such cases they have a cell-derived membranous envelope, containing protein and lipid, in addition to the virus-specific protein coat.

One of the many surprising discoveries about viruses was that the nucleic acid of the miniature chromosome could be either double-stranded or single-stranded. The Watson-Crick model of the double helix, consisting of two intertwined strands of complementary DNA, was thought to be universal, the only form in which the DNA could remain stable; the double helix provides a means for repairing damage to individual bases caused, for example, by radiation or mutagenic chemicals. It also provides a neat means of replication each strand directs the synthesis of its complementary strand to make new double helices. But, in fact, viral nucleic acid can be either single or double-stranded; it can be in the form of a linear string or of a small circle. Mutation is not a problem for viruses. It is less likely to occur in such a short strand of nucleic acid and, even if it does, so many viruses are produced that a few faulty ones do not matter. Replication from a single strand begins by making its complement.

The discovery that some viruses contain RNA instead of DNA was also surprising at the time, because RNA was not thought of as primary genetic material. It was known only as a product of transcription from DNA – an intermediate in the chain of events that allow the DNA of the genes to direct the synthesis of specific proteins. There are several types of RNA viruses with different strategies for replication and for directing the synthesis of the proteins they encode. Most RNA viruses have only single strands of RNA. In some of these (such as flu virus) the RNA is "anti-sense" (negative strand) and cannot be translated directly into protein. First, a complementary "sense" (positive) strand of RNA must be synthesized by a special virus-encoded RNA polymerase. In such viruses this viral polymerase is pre-packaged in the viral particle; without the polymerase the anti-sense RNA strand is useless. In other RNA viruses the single-strand is positive. This strand immediately directs synthesis of enzymes needed for virus replication and is used as a template for making more RNA.

The replication of DNA viruses is more conventional. The viral DNA directs both replication of more DNA and transcription of messenger RNA for protein synthesis. (NOTE: This might provide an opportunity to teach or review some basic molecular biology – the structure of genes; how DNA replicates; how it directs the synthesis of RNA; how mRNA directs the synthesis of protein by way tRNAs and ribosomes).

The nucleic acid of a virus may code for only a few genes or as many as 200. Papovaviruses, small DNA viruses, may have only 5,000 base pairs while the Herpes virus, a large RNA virus, has 150,000 base pairs. For the most part the viral genes code for the proteins necessary for replicating their own nucleic acids, for making their protein coats and for assembling new virus particles. However, viruses lack the enzymes for metabolizing nutrients, producing high-energy phosphates (like ATP), or synthesizing carbohydrates or lipids; they also lack ribosomes and the other machinery needed to assemble their own proteins. Viruses can only reproduce inside of cells that carry out these functions – they are, of necessity, parasites. One could ask students to define life. Is a tree alive? Why do we say that cells in our bodies are alive but that viruses are not? How does a living cell differ from a dead cell?

Not all viral infections lead to cell death, with lysis of the cell membrane. As mentioned above some viruses bud off from a cell by enclosing themselves in an envelope formed from a bit of the cell's membrane. In addition, and this was another surprising discovery, part of the DNA (one or a few genes) of certain DNA viruses occasionally become permanently incorporated into the host-cell genome. In this condition, the virus-derived DNA is replicated only during cell division, without the production of viral particles, and is present in all the cell's progeny. Remarkably, certain RNA viruses (retroviruses) can do a related trick. First, however, they must transcribe their RNA into DNA using a special enzyme called reverse transcriptase. First, a hybrid RNA/DNA double strand is made and from this a DNA double strand. In this case the total DNA double strand becomes incorporated into the host cell genome from where it transcribes multiple copies of its RNA, both for replication and for protein synthesis.

The presence of the virus-derived DNA in the host genome may have important consequences. The inserted viral DNA may code for proteins that alter the cell's ability to control its own growth. The cell, having lost these normal constraints, may then divide repeatedly – it has been transformed into a tumor cell. That certain viruses (like Rous sarcoma virus and polyoma virus) can induce tumors in animals is well established. Only a few human tumors (like Burkitt's lympoma) appear to be caused by viruses. Fortunately, Cecilia Rossi does not need to worry about her viral infection ever leading to cancer.

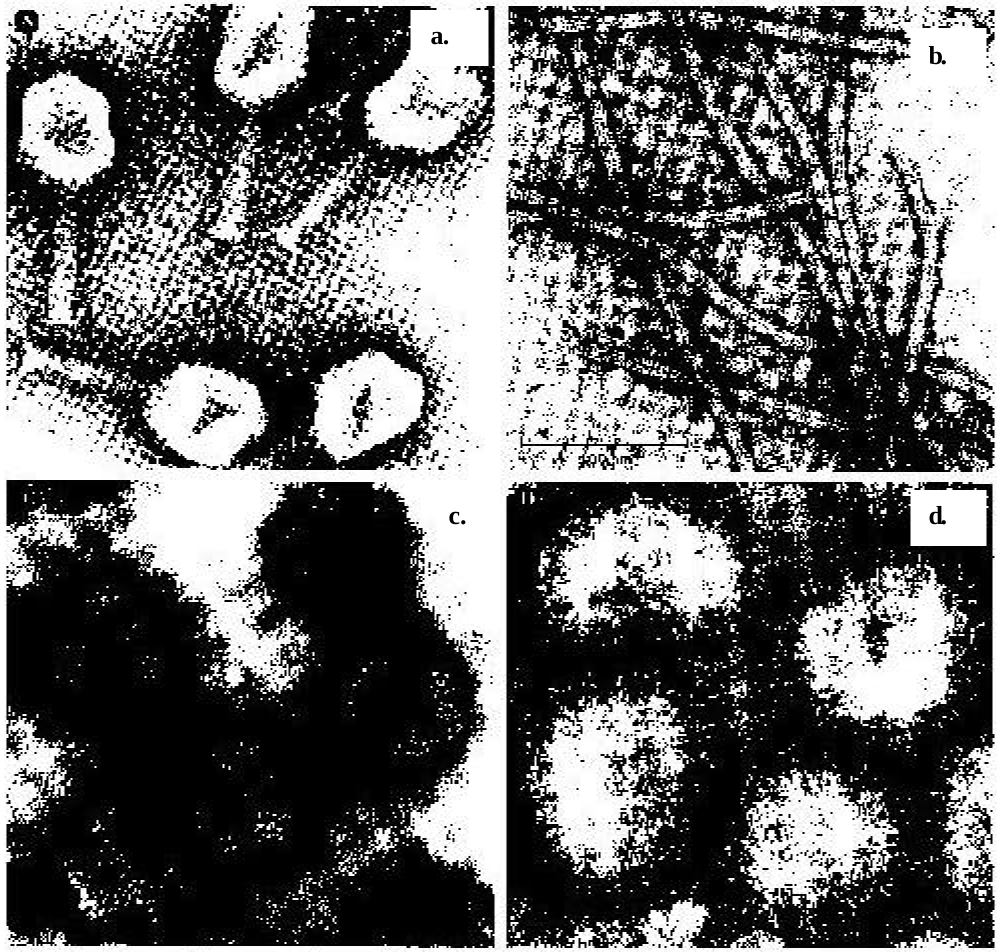

Figure 10: *Electron micrographs (all the same magnification: see scale indicated in b.) of the negatively stained virus particles.*

a. Bacteriophage T4, a large DNA-containing virus that infects the E. coli bacterium. The DNA is stored in the bacteriophage head and injected into the bacterium through the cylindrical tail (courtesy of James Paulson.)

b. Potato virus X, a filamentous plant virus that contains an RNA genome (courtesy of Graham Hills.)

c. Adenovirus, a DNA-containing virus that can infect human cells. The protein capsid forms the outer surface of the virus (courtesy of Mei Lie Wong).

d. Influenza virus, a large DNA-containing animal virus whose protein capsid further enclosed in a membranous envelope (Courtesy of R.C. Williams and H.W. Fisher). Image and caption used with permission from Molecular Biology of the Cell, by B. Alberts et. al.

Student Guided Inquiry (Wrap-Up)

Go through the portfolio and design a final project that involves the major concepts explored. Projects should be approved by the instructor. Examples include the following:

- Build a mock vestibular system
- Design an experiment to test the vestibular system
- Design a space experiment to test the vestibular system
- Report on space vestibular research and lessons learned so far
- Interview researchers from your local institutions and beyond
- Research and write a paper on a specific vestibular disorder.

Teacher Directed Instruction (Wrap-Up)

Students were exposed to various careers in medicine and science in this case. Summaries of these careers are provided below.

Physician/Researcher in the vestibular field works in a hospital setting, such as the Massachusetts Eye and Ear Infirmary. The physician/researcher examines patients and decides the best course of action, and also researches the workings of the system.

Researcher in a clinical setting is someone with a degree in a technical or scientific field who works in a clinical setting and collaborates with doctors in analyzing the vestibular system. He or she also does research on new ways to cure diseases by developing new technologies, such as prostheses, and new testing equipment.

There are also many researchers outside of hospitals who discover new information about the vestibular system. Most of them work in academic institutions. They also develop new technologies for dealing with many aspects of the vestibular system. Researchers work in disciplines such as physiology, engineering (electrical, aerospace, biomedical), biology and more. For example, aerospace biomedical engineers study things like:

- The effect of space on humans
- The issues to be considered in a long-duration space flight
- The effect of weightlessness (microgravity) or artificial gravity on the body

Most researchers of this kind have a doctorate or a master's degree. There are many graduate students in these fields as well, working to obtain a master's or Ph.D. degree.

Name ___________________________ Date ____________

The Scientific Method

Used with permission from Mary's Mystery

The following is a review of the steps of the **Scientific Method**:

1. State a question about the problem you are dealing with or the phenomena that you have observed.
2. Based upon what you already know formulate a hypothesis [make a guess] to answer the question.
3. Gather data to test your hypothesis.
4. Evaluate the data to determine whether the data fit the hypothesis.
5. Based on your evaluation of the data you can:
   a. Conclude that your hypothesis is a plausible explanation for your observations for now,
   b. Revise your hypothesis in a way that accounts for the data, or
   c. Reject the original hypothesis and devise another.
6. When there is new information, original hypotheses are reevaluated.

Name ____________________________ Date ____________

Hypothesis Testing Packet

Date Lesson	The Problem	Your Hypothesis/es	Your Observations	Hypothesis/es Testing

Name ______________________ Date ___________

Experiment Worksheet

For any experiment, you will follow the steps of the scientific method.

1. What is the problem you are investigating?

____

____

2. What is your hypothesis about the problem?

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3. Record your observations. These might include written descriptions or illustrations.

____

____

____

4. What tests, if any, did you perform? What were the outcomes of these tests?

____

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5. Was your hypothesis supported? Please elaborate.

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Name _____________________ Date ___________

Procedures for the Balance Demonstration

1. Lay the pillow on the floor. The volunteer should place the blindfold over his/her eyes. Instruct the volunteer to stand on the pillow in bare feet with both arms extended. Have another student write down the observations of the class on the chalkboard.

2. Instruct the volunteer to stand on one foot. [Teacher is standing next to volunteer, to prevent student from falling.] Write down observations.

Name ___________________________ Date ____________________

Questions on Balance

1. What systems in the body make you steady and able to stand up and walk?

2. What things (movements, activities) make you unsteady? Think about what happens when your foot goes numb, or you have an ear infection, or you are going up or down the stairs in the dark.

3. Try to think of other situations or activities where you may be unsteady.

4. Do all these systems need to communicate somehow? Where and how are they connected?

Name ______________________ Date ____________________

Finding Data on the Vestibular System

Used with permission from *Human Physiology in Space* by B. Lujan and R. White, illustrated by H. Bartner.

How do we remain standing despite the perpetual pull of gravity? Why can you whirl around suddenly without falling down? The vestibular organs (Figure 1), also called the vestibular apparatus, in the inner ear help maintain equilibrium by sending the brain information about the motion and position of the head. The vestibular organs consist of three membranous semi-circular canals (SCCs), and two large sacs, the utricle and saccule. All the vestibular organs share a common type of receptor cell, the hair cell. Let's examine the structure and function of the vestibular organs a little more closely.

The three semicircular canals (SSCs) within the vestibular organ of each ear contain fluid and hair receptor cells encased inside a fragile membrane called the cupula (Figure 2). The cupula is located in a widened area of each canal called the ampulla. When you move your head, the fluid in the ampulla lags behind, pushing the cupula a very tiny bit which causes the hairs to also bend a very tiny bit. The bending hairs stimulate the hair cells, which in turn trigger sensory impulses in the vestibular nerve going to the brain to "report" the movement. Hair cells are amazingly sensitive. For example, a cupula movement of even a thousandth of an inch is detected by the brain as a big stimulus.

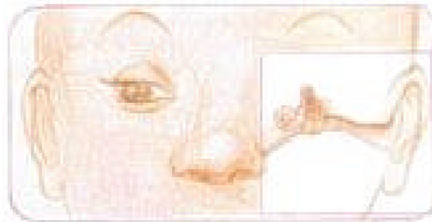
The three canals are positioned roughly at right angles to one another in the three planes of space. Thus, the canals react separately and in combination to detect different types of swiveling head movement. They detect when we nod in an up and down motion (pitch), when we tilt our head to the side towards our shoulder (roll), and when we shake our head "no" in a side to side motion (yaw). The semicircular canals are responsible for detecting any kind of rotational motion in the head.

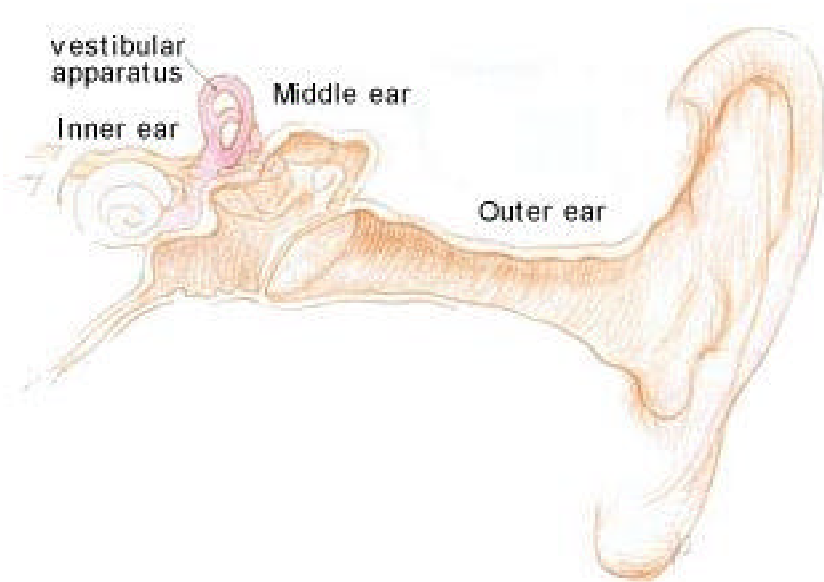
Two other vestibular organs are located in membranous sacs called the utricle and the saccule. On the inside walls of both the utricle and the saccule is a bed (a macula) of several thousand hair cells covered by small flat piles of calcium carbonate crystals which look like sand, imbedded in a gel-like substance (Figure 2b). The crystals are called otoliths, a word which literally means "ear stones." In fact, the utricle and the saccule are often called the otolith organs.

When a person's head is in the normal erect position, the hair cells in the utricle lie approximately in a horizontal plane. When the head is tilted to one side, the stones want to slide "downhill." This moves the gel just enough to bend the sensory hairs. The bending hairs stimulate the hair cells, which in turn send a signal to the brain about the amount of head tilt. The stones also move if the person is accelerated forward and back, or side to side. Similarly, the hair cells in the saccule are oriented in somewhat of a vertical position when the head is erect. When a person tilts their head, or is accelerated up and down (as in an elevator), or moved forward and back, the otoliths move and a signal is sent to the brain. The signals from the otoliths in the saccule and the utricle complement each other and give us an integrated signal about our movement. The otolith organs are primarily responsible for detecting any degree of linear motion of the head.

Name ______________________ Date ____________________

Finding Data on the Vestibular System





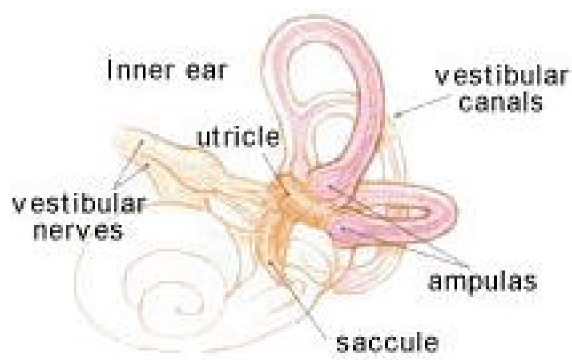


Figure 1: *The vestibular organs are located in the inner ear portion of the ear canal. The three semicircular canals detect rotational head movement and the otolith organs (located in the utricle and saccule) detect linear head movement (Images used with permission from Human Physiology in Space by B. Lujan and R White, illustrated by H. Bartner).*

Name ______________________ Date ____________________

Finding Data on the Vestibular System

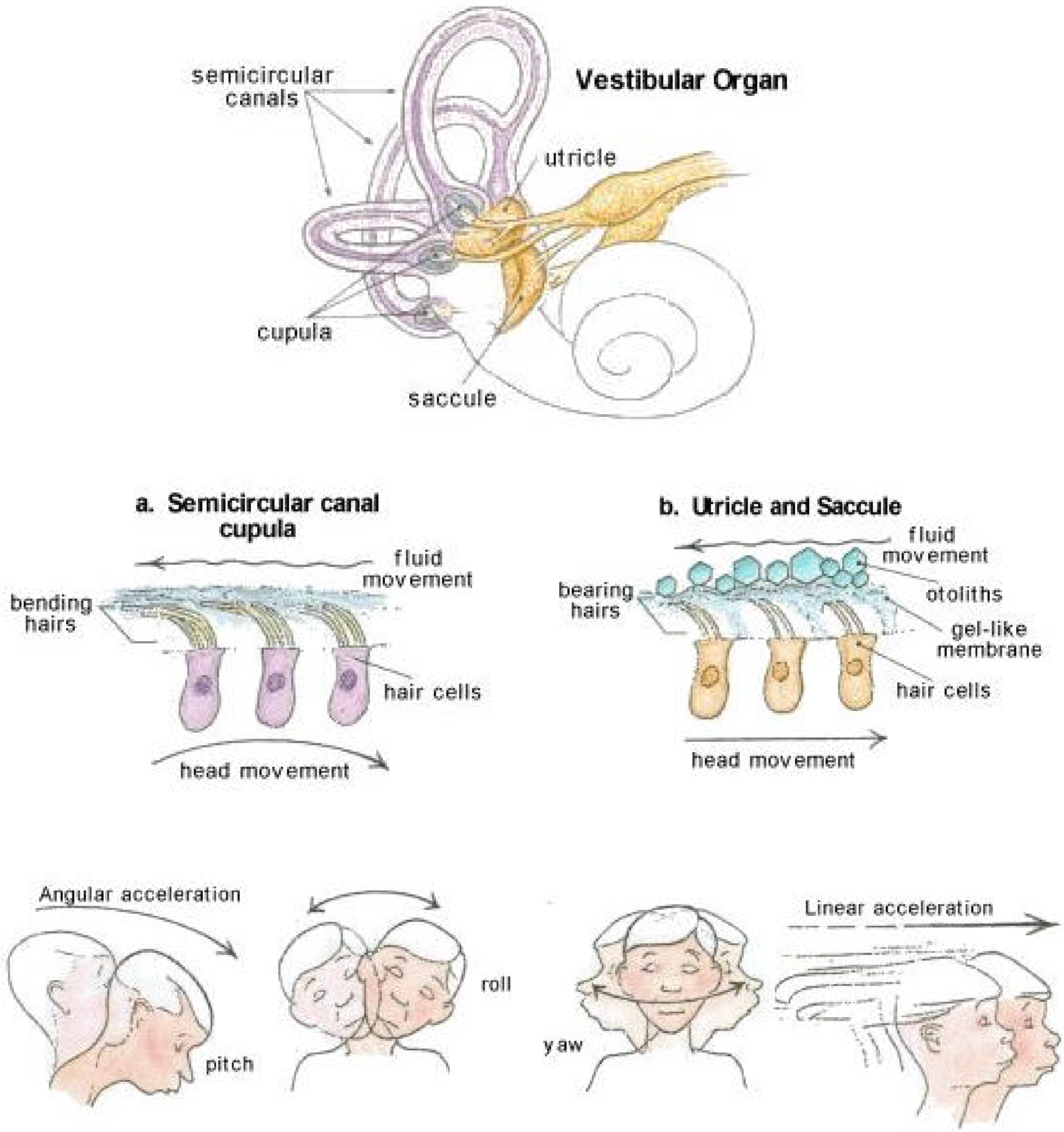


Figure 2: *a. The fluid in the semicircular canals bends the receptor hairs of the cupula in response to rotational head movement.*
b. The otoliths are embedded in a gel-like substance and, in response to linear head movements, the otoliths move and bend the receptor hairs (Images used with permission from Human Physiology in Space by B. Lujan and R. White, illustrated by H. Bartner).

Name ______________________ Date ____________________

Finding Data on the Vestibular System

Answer the Following Questions:

1. What is the main difference between the semicircular canals and the otolith organs?

2. Provide and explain several examples of activities (i.e., sports, jobs etc.) in which the vestibular system is especially stimulated. Indicate whether the brain is processing information coming from the semicircular canals or the otolith organs.

Name ________________________ Date __________________

Procedures for the Mock Vestibular Experiment

Adapted from *The Brain in Space: A Teacher's Guide with Activities for Neuroscience* by M. MacLeish and B. McLean.

1. At least one day before actually performing the activity, glue (or have the students glue) the false eyelashes or strands of other fuzzy material to the inside of the beakers, jars or glass cylinders. Attach to the side of the cylinder (not the bottom).
2. Organize students into pairs or groups of 3-4, depending on the amount of materials that are available.
3. Have one student from each group fill the cylinder with water. Let the water settle until it is motionless.
4. Direct the students to rotate the cylinder quickly 90 degrees to the right (maintaining the vertical position of the cylinder) and observe what happens to the hairs on the eyelashes (Figure 1 B).
5. Have the students rotate the cylinder 90 degrees in the other direction and record observations.
6. After the motion stops, have students quickly rotate the cylinder 180 degrees to the right, this time using a watch to measure the amount of time required for the hairs to return to a straight position. Have students record the time (Figure 1 D).

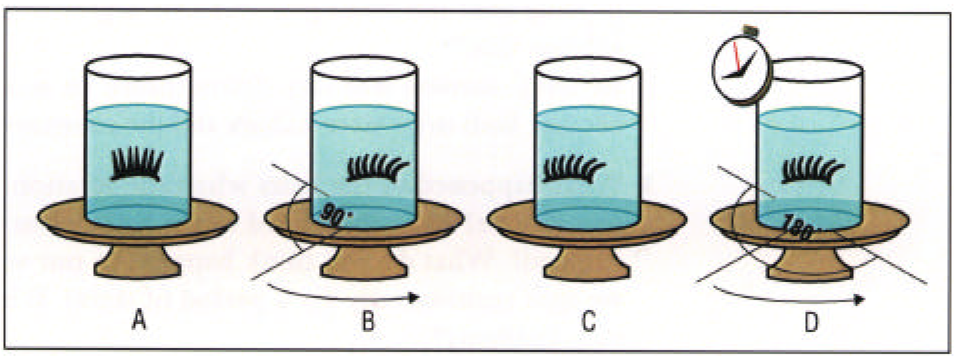


Figure 1. Diagram of a furry or wispy material or false eyelash in motion. A. At rest. B. 90^o motion. C. Motionless. D. 180^o rotation.

7. Direct the students to repeat this procedure, with each student taking a turn at rotating the cylinder, observing the watch, and recording the time [all the students should try to rotate the cylinder at approximately the same rate]. Have them record the name of the person who rotated the cylinder and the person who observed the watch beside the measured time.
8. Have the students calculate the average time required for the hairs to come to rest after rotating the cylinder, and to record their calculations.
9. Have students quickly rotate the cylinder 90 degrees to the right and then immediately rotate 180 degrees to the left, measuring the time required for the hairs to stop moving. Have them record their observations.
10. Have students present their data from steps 7,8, and 9 in tabular format.

Name ________________________ Date ___________

Table for Mock Vestibular System Experiment

90° observation	180° time	90°/180° time	One min rotation observations	Person rotating	Person w/ stopwatch

Name ______________________________ Date ____________________

Questions over the Mock Vestibular System Experiment

Used with permission from, *The Brain in Space: A Teacher's Guide with Activities for Neurosciences* by M. MacLeish and B. McLean

1. How did the direction of rotation affect the direction in which the hairs bent?

2. What happened to the hairs when the rotation was continuous for one minute? What happened to the hairs when the rotation suddenly stopped? What do you think happens to our vestibular system when we spin continuously for a period of time? What happens when we stop suddenly?

3. In step 7, different students took turns at a task. Were the times measured the same or different for each student? What might account for the difference in time?

4. If the water in the cylinders was replaced with another substance that was more dense, such as liquid detergent, or less dense, such as air, how would the movement of the hairs change? What if the hairs were in a vacuum? What other factors might affect movement?

5. Why do patients who are bed-ridden for long periods of time often experience dizziness and difficulty standing upright?

Name ______________________________ Date ________________________

Procedures for Nystagmus Demonstration

Taken from the NeurON web site at http://quest.arc.nasa.gov/neuron/

1. Subject chooses a focal point at eye level at a distance of 2 meters from the subject's face.
2. Subject sits with eyes open on a chair or stool that rotates. (Alternative: If you don't have a rotating chair, subject can turn while standing in one spot, trying to keep the head level.) NOTE: It's important that the subject's head does not wobble.
3. The spinner (who has previously practiced turning the chair smoothly at a constant rate of one rotation per second) begins to turn the chair clockwise.
4. Without stopping the stopwatch, timer announces when one minute is up. Subject remains seated and focuses on the focal point.
5. The observer notes the direction of the nystagmus (right to left or left to right) and counts each eye motion or "twitch" until the nystagmus, has stopped.
6. Subject reports when he/she no longer feels motion. Timer stops the stopwatch and tells the recorder the full amount of time that has elapsed including the one- minute spin time.
7. Allow subject to recover before proceeding to next phase. NOTE: The same subject should be used for each of the four phases of the experiment.
8. Repeat steps 2 through 8, spinning counter-clockwise.
9. Repeat entire experiment, both clockwise and counter clockwise, this time with eyes closed for the one-minute spin.
10. Record results.

Recovering from a Vestibular Disorder

By S. Rauch, Massachusetts Eye and Ear Infirmary

The vestibular system is your "navigational system." It gives you constant information about your movements and position in space. There are three "input channels": inner ear, vision, and somatosensory (body sensations such as position sensors in muscles and joints, tactile sensations on skin, etc.). Incoming signals on these three channels send nerve messages to the balance centers of the brainstem where they are compared to each other and information is passed to higher brain centers for awareness voluntary actions, and to coordinate centers. These sites then send outgoing messages to control eye movements and body movements. If the vestibular system breaks down anywhere, input channels, central processing, or output channels, the patient has a sense of imbalance or dizziness.

Just like learning language, when you were an infant and toddler, your brain was learning to understand the signals coming in on the three input channels of the vestibular system. Recovery from damage to the system, for example the inner ear, is sending a different message than it used to, the brain must learn new comparisons between the different inputs. Until that is accomplished, there is a "sensory conflict" in which the damaged inner ears send a message that the brain interprets as motion but the eyes and somatosensory channels disagree. It is the sensory conflict that causes the nausea, fatigue, and other symptoms of dizziness.

Although balance information is processed in a different part of the brain than language, language learning is a good model for the recovery process that occurs after an injury or illness of the balance system.

Learning a new language is quicker in young people, highly motivated people, and those who practice a lot. There is also an innate language capacity that varies from person to person; some people are "good with languages" and others are not. All these factors apply to balance recovery as well: recovery is quicker in younger patients, in highly motivated patients, and in patients who move around a lot to practice. Also, there is an innate difference in balance ability in the nervous system; some of us become gymnasts and figure skaters while others do not tolerate much motion stimulation and get carsick on the subway. Recovery from an acute balance illness or injury typically takes anywhere from two weeks to two years. Many patients make a total recovery but some are permanently affected (just like someone who moves to a different country but never becomes fluent in the new language).

For patients who are having trouble recovering, there is a type of physical therapy, vestibular rehabilitation therapy, that can often help. This therapy has two strategies. One is called accommodation. The rehabilitation therapist evaluates the patient to determine which eye, head, and body movements are most provocative, and then gives him/her a series of exercises to practice exactly those movements. The second strategy is called sensory substitution. The therapist determines which parts of the vestibular system are providing the best or most reliable information and gives the patient a series of exercises that condition him/her to focus on the reliable vestibular information and neglect or ignore the damaged information. Every week or two the therapist evaluates the patient's progress and upgrades the exercise routine to something slightly more challenging. The benefits of the rehabilitation therapy are usually achieved over the course of two or three months.

Name ____________________________ Date _________________________

Procedures for the VOR Demonstration

Used with permission from *The Brain in Space: A Teacher's Guide with Activities for Neurosciences* by M. MacLeish and B. McLean.

1. Hold a page with some text written on it, about 18" in front of your eyes.
2. Move your head back and forth (as if saying "no," about 2 times per second) but keep the page steady.
3. Can you read the page? Is there some blurring?
4. Now hold your head still and move the page in front of your eyes left to right (about 2 times per second).
5. Can you read the page? Is there some blurring?
6. Record your results below.
7. Discuss, compare and contrast your results with other students.

TRIAL 1: Steady page, moving head

TRIAL 2: Steady head, moving page

Name ______________________________Date _______________________________

Questions on Vestibular-Ocular Reflex

Adapted from *The Brain in Space: A Teacher's Guide for the Neurosciences* by M. MacLeish and B. McLean.

1. What does the vestibular-ocular reflex do?

2. What else does the vestibular system do?

3. Why is the vestibular system important to movement?

4. How is motion sickness caused?

5. Why do people who have problems with their vestibular systems experience dizziness?

6. What happens if the vestibular system is destroyed? Explain how one would act and feel.

7. Why might a person experience motion sickness when not moving or in an IMAX theater?

8. Does the vestibular system adapt to microgravity? Without gravity to give us a constant downward reference, how will the roles of visual and touch cues change?